Manuscript Details

Manuscript number	PROOCE_2018_54_R2
Title	Coral forests and Derelict fishing gears in submarine canyon systems of the Ligurian Sea

Abstract

Biodiversity of coral forests and occurrence of Derelict Fishing Gears (DFGs) have been assessed in canyon systems of the western Ligurian Sea (Dramont, Monaco, Bordighera, Arma di Taggia and Bergeggi) exposed to different anthropic pressures. Arborescent cnidarians were elected as representative species due to their role as structuring organisms and their vulnerability to DFGs damage; hence, their occurrence, density and distribution were correlated to the presence of DFGs. The canyon systems were mapped using a Multibeam Echo Sounder and visually surveyed by means of a Remotely Operated Vehicle between 20 and 445 m depth. With the exception of the Bergeggi canyon system all sites host rich assemblages of structuring anthozoans, accounting for more than 2000 colonies belonging to 11 species, predominantly Corallium rubrum, Dendrophyllia cornigera, Eunicella cavolinii, E. verrucosa, and Paramuricea clavata. The coral forests appear vulnerable with the larger structuring gorgonians being the most susceptible to mechanical injuries. DFGs, represent 85% of the total marine litter is the most serious threat to resident sessile communities, most noticeably in the eastern canyons. The fishing footprints is strongly influenced by vicinity to ports, size and fishing effort of local fleets, and by socio-economical differences in the fishing activity . Our study further confirms the role of submarine canyons as site of high coral biodiversity and vulnerability to the mechanical damages by fishing-related littering, calling for adequate management measures to reduce fishery pressure and concomitant DFG discharge.

Submission Files Included in this PDF

File Name [File Type]

Giusti_et_response_to_reviewers.docx [Response to Reviewers]

Highlights.docx [Highlights]

Giusti_et_al_071218.docx [Manuscript File]

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Ref: PROOCE_2018_54_R1
Title: Derelict fishing gear and megabenthic cnidarian distribution in submarine canyons of the Ligurian Sea and adjacent shelves
Journal: Progress in Oceanography

Dear Dr. GIUSTI,

Thank you for submitting your manuscript to Progress in Oceanography. Guest Editor Danovaro has completed the review of your manuscript and a summary is appended below. He recommends reconsideration of your paper following major revision. I invite you to resubmit your manuscript after addressing all reviewer comments.

When resubmitting your manuscript, please carefully consider all issues mentioned in the reviewers' comments, outline every change made point by point, and provide suitable rebuttals for any comments not addressed.

To submit your revised manuscript:

- Log into EVISE® at:
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I look forward to receiving your revised manuscript as soon as possible.

Kind regards,

Dr Mantua
Co Editor-in-Chief
Progress in Oceanography

Comments from the editors and reviewers:
-Editor Danovaro

Dear Dr Giusti,

As you can see in the reviewers' report, Rev#1 is positive and suggests minor revision while Rev#2 is still critic on the content of your paper.

Although the present version has been improved according to most of the previous Rev#2's comments, the request of statistical analyses to support data has been completely neglected.

I would like to offer you the possibility to respond to the specific comment on data elaboration and other suggestions provided by the ref#2 in this second report.

If you are not in the position to respond to all rev#2'comments, I regret to inform you that your contribution cannot be considered for publication in this special issue.

-Reviewer 1

Dear Editor,

Please find attached my comments on Giusti et al. In this current version authors have addressed some of my suggestions. After carefool consideration I believe this manuscript still requires lots of work and it cannot be published in its current status. My biggest concern is that authors have failed to provide any statistical evidence that reinforce their assumptions. Authors indicate that they did not have enough time to do required statistical analysis. I consider that this is not a valid argument. Some of the suggested statistical analyses were very simple and could have been done with the available data (linear regressions evaluating cnidarian and DFG densities).

The Introduction and the Materials and Methods have been improved. As I previously mentioned, in the Results section I think that authors must provide statistical analyses regarding the relationship between DFGs and cnidarian density. Moreover, authors are looking at the relationship of DFGs and megabenthic cnidarians I think it is necessary to give information on the status of these populations' necrosis and epibiosis (number of colonies, necrotic or epiphyted surface %, dimensions of affected colonies, which is the epiphyte species). This information can easily be extracted from the video transects. Once more, I do not think it is a valid argument to say that authors have ran out of time. In the previous version of the manuscript authors did not show the number of entangled colonies (Fig. 8). I assume they had to review the videos to provide this information. In this sense, I believe authors could have easily provided the number of epiphyted or necrotic colonies. To do so only 3 canyons needed to be revised, since authors mentioned that they already have the number of epiphyted colonies for Arma di Taggia canyon (Authors original quote*: We were not able provide the necrotic colonies and the epibiosis presence because we didn't clearly identified them, except for the Arma di Taggia canyon and buecause, due to the large number of changes made with the help of the reviewer, we ran out of time*).

Most of the Discussion section is mainly a summary of the previously mentioned results. Author's indicate that *E. verrucosa* faces the highest risk of entanglement what are the bases for this? This contradicts the results in Fig. 8. Less than 10 colonies out of 267 (Table 2) have been entangled, this represent ~4% of all observed colonies. Other species such as *D. cornigera* (approx. 120 entangled colonies out of 175, ~68% of observed colonies), *C. rubrum* (approx.130 entangled colonies out of 287, ~45% of observed colonies), or *P. clavata* (appox.100 colonies out of 417, ~24% of observed colonies) present much larger entangling values. Authors need to dig deeper on their results, compare them with previous data on the Mediterranean and other areas of the world. For instance, why do you think *D. cornigera*is so heavily impacted? Could it be that *C. rubrum* colonies were affected since they tend to occur on overhanging rocks where fishing gear can easily get stuck? *P. clavata* is a species that can reach very large dimensions (e.g. Linares *et al*. 2018), was there any size pattern regarding entangled colonies? Which type of fishing gear tends to entangle the most? In case there is a trend is it the same in all canyons? Authors should add a few conclusions summarizing their most relevant findings.

Regarding the Reference authors need to correct all mistakes an add newly added references.

Authors have a very interesting data set with great potential make the best of it.

Considering that this manuscript was submitted in a special issue of Progress in Oceanography I leave on the hands of the Editor to decide if it should go to major changes or be rejected.

- The paper was greatly modified according to the reviewer's suggestions.
  The ROV dataset has been viewed again and the data analysis redone; the statistical analysis has been added as well as the analysis of the entangled, epibiotic and necrotic cnidarians species. Compared to the previous version, this one has been significantly modified in the hope of having responded adequately to all the reviewers' suggestions.
  The title has been modified to : "Coral forests and Derelict fishing gears in submarine canyon systems of the Ligurian Sea" to better focalize the subject of our manuscript.
  As for the answers below, we tried to answer as best as possible, but the work has changed a lot compared to the previous one: for example, the numbers of the lines no longer correspond to those of the previous version and several sentences have been removed and / or modified, as well as some bibliographical references.

Authors have not addressed the following suggestions or mistakes from the previous review:

Regarding my previous comment: *Depth range are given into four different forms* "*-47 and -93 m, 242 –423 meters, 60-116 meters, 64m and 287m*". *Use only one form I suggest: 242 – 423 meters depth*.

- The form suggested was used

Please, sea lines 282–290, lines 337–344 of the current version.

- Modified as suggested

Please, correct line 372, 376, 389, 391 of the current version, species names are not properly written.

- Species names corrected

Quoting authors response: Corrected. The name of the species was also ganged throughout the text from E. cavolinii to E. cavolini , as reported by the world Register of Marine Species

E. cavolinii should be maintained as this gorgonian species was named after Filippo Cavolini, and consequently double final "i" is needed following the international code of zoological nomenclature

- Corrected

Line 370-371: *In particular, DFG was found along all the depths at which E. verrucosa is present.*

The bathymetric distribution of DFGs in Arma di Taggia canyon cover the entire bathymetric range overlapping with all species found in this canyon why do you focus on *E. verrucosa*?

- The reviewer is right and the phrase was removed

Please see my previous comment on *S. dubia*.

You have not corrected Table 2 and Figure 4, lines 295: change *Swiftia dubia*to *Swiftia* sp.

- *Swiftia dubia* changed to *Swiftia* sp.

Regarding density values, authors have mentioned that they have used 1 m^{-2}(Authors quote*: Density was calculated as colonies per 1 m^{-2}*). If this is correct how can you obtain such low values in 1 m^{-2}? Based on my experience such low densities are found with surface units larger than 1 m^2. Please, clarify if you have calculated density considering the hall surface of the transect or surfaces larger than 1 m^{-2}.

- Density of cnidarians was expressed as number of colonies per square meter of hardground.

  Data were checked again and we obtained such low densities values.

Minor comments:

Lines 74-81: This study is based on canyons on the Ligurian Sea. Why do you focus on the canyons on the Adriatic Sea? If authors wanted to give an example of Mediterranean submarine canyons hosting CWC and sponge assemblages there are many examples all over the western Basin: North Ionian Sea (Saviani et al., 2010), Sardinia (Taviani et al., 2015); Southern Thyrrenian (Pierdomenico et al., 2016); Corsica (Fourt et al., 2017), Gulf of Lion (Gori et al., 2013) Catalan Margin (Lastras et al., 2016); Balearic Islands (Grinyó et al., 2018; Santín et al., 2018).

Authors have given a much-detailed vision of CWC assemblages in submarine canyons of the NW Mediterranean improving this section. However, if Authors consider that the Adriatic Sea is part of the Eastern Basin shouldn't they consider the North Ionian Sea as part of the Eastern Basin?

- The reviewer is right and the North Ionian Sea was moved to the phrase concerning the Eastern Basin.

Line 87:

Remove extra space.

- Removed

Line 94:

"Lost fishing gear, (Derelict Fishing Gear = DFG)…" please change as follows *"Lost fishing gears, referred from now one as Derelict Fishing Gears (DFG)…"*

- Changed

Line 99:

Correct (Cánovas- Molina *et al*. 2016) to (Cánovas-Molina *et al.,*2016).

- Corrected

Line 101

Small fleets or small boats?

- Phrase modified in the text

Line 167

Correct "0ºto" to "0º to"

- Corrected

Line "0º-52º": in all previous cases you've used "to". Change 0º to 52º.

- Changed

Line 174:

There is an extra space: "with moderately".

- Extra space removed

Line 176:

Please change Km to km.

- Km was changed to km

Table 1:

"Dive lenght" to "Dive lenght" correct lenght to length

- corrected

Line 185:

Remove extra space between Bordighera and ,.

- Extra space removed

Line 192:

Remove extra space "…vessels. The three…"

- Extra space removed

Line 243, 301 and 330:

Correct: "m-^{2}" to "m^{-2}"

- Corrected

Line 255:

I suggest adding megabenthic in front of cnidarins:

"In this study, megabenthic cnidarian species were chosen…"

- Phrase modified in the text

Table 288:

Correct 117 -310 to 117–310.

- Corrected

Line 387: Change "twenty two" to 22. In line 34 authors numerical values "22 megabenthic species" please be consistent throughout the manuscript.

- Changed "twenty two" to 22

Line 406: *"E. verrucosa*, as other large anthozoans (e.g. other gorgonians and antipatharians), isa long-lived species, able to form dense three-dimensional habitats (the so called "coral gardens" or "animal forests")"

Provide reference for coral gardens and the animal forest and please look beyond *E. verrucosa*. You have shown in Figure 8 that other species are, actually, more susceptible to entanglement than *E. verrucosa*.

- References for coral gardens and the animal forest were added and new considerations about the entanglement of the species were also added

Line 410: "As a consequence, there is a higher probability of losing fishing gear and thus increasing the risk of being caught in the nets."

Why is there a higher probability of losing fishing gear? Is it due to the three-dimensional structure of the organisms forming the animal forests?

- Phrase modified in the text

Line 412: "We can speculate that this large amount of lost fishing nets at this site is due to the fact that it is close to the coast, in front of the Bordighera port and near San Remo port, which makes this canyon more accessible to fishing vessels."

How about the fishing fleet is it larger than in other canyons? You need to discuss this. Do you think recreational fishing may also play a role in the degradation of this canyons ecosystems? Could it be that recreational fishing boats also visited this area more often due to its proximity to shore?

- Phrase modified in the text

Line 421:

Please correct: "that coveri"

- Corrected

References:

The following references are missing in the Reference list:

Saviani *et al*., 2010

Pierdomenico *et al*., 2016

Fourt *et al*., 2017

Gori *et al*., 2013

Lastras *et al*., 2016

Grinyó *et al*., 2018

Santín *et al*., 2018

- References were modified according to the changes made in the manuscript

Extra spaces on lines 445, 478, 486, 501, 583, 587, 739.

- Extra spaces removed

Line 519: Sarda change to Sardà

- Sarda changed to Sardà

Line 529: Italics?

- Corrected

Line 578: García not Carcìa

- Reference removed

Line 605: Nazare to Nazaré

- Reference removed

Line 606: you are missing)

- Added

Line 610, 621, 653, 715: you are missing a space

- Added

-Reviewer 2

The Authors checked the ms according to the referee' suggestion. In my opinion can be accepterd. In the file attached I have marked some errors in the bibliography.

- The bibliography was checked and the errors corrected.

Highlights

- Derelict Fishing Gears (DFGs) cause severe impact on megabenthic species.
- High biodiversity areas are the primary target for artisanal fisheries.
- Derelict Fishing Gears (DFGs) are present up to a depth of 300 meters.
- None of the five canyons investigated were free from DFGs.

Coral forests and Derelict fishing gears in submarine canyon systems of the Ligurian Sea

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Abstract

Biodiversity of coral forests and occurrence of Derelict Fishing Gears (DFGs) have been assessed in canyon systems of the western Ligurian Sea (Dramont, Monaco, Bordighera, Arma di Taggia and Bergeggi) exposed to different anthropic pressures. Arborescent cnidarians were elected as representative species due to their role as structuring organisms and their vulnerability to DFGs damage; hence, their occurrence, density and distribution were correlated to the presence of DFGs. The canyon systems were mapped using a Multibeam Echo Sounder and visually surveyed by means of a Remotely Operated Vehicle between 20 and 445 m depth. With the exception of the Bergeggi

31 canyon system all sites host rich assemblages of structuring anthozoans, accounting for more than

32 2000 colonies belonging to 11 species, predominantly *Corallium rubrum*, *Dendrophyllia cornigera*,

33 *Eunicella cavolinii*, *E. verrucosa*, and *Paramuricea clavata*.

34 The coral forests appear vulnerable with the larger structuring gorgonians being the most susceptible

35 to mechanical injuries. DFGs, represent 85% of the total marine litter is the most serious threat to

36 resident sessile communities, most noticeably in the eastern canyons. The fishing footprints is

37 strongly influenced by vicinity to ports, size and fishing effort of local fleets, and by socio-

38 economical differences in the fishing activity

39 Our study further confirms the role of submarine canyons as site of high coral biodiversity and

40 vulnerability to the mechanical damages by fishing-related littering, calling for adequate management

41 measures to reduce fishery pressure and concomitant DFG discharge.

42

43 **Keywords:** structuring anthozoans; marine litter; Derelict Fishing Gears, fishing impact; Ligurian

44 Sea; canyons .

45

46 **Introduction**

47 Submarine canyons are major geomorphic features of continental margins characterised by steep and

48 complex topography (e.g. Lastras *et al.*, 2007; Harris and Whiteway, 2011; Amblas *et al.*, 2017).

49 They are formed at the junction of the continental shelf with the continental slope. Schematically,

50 they are a V-shaped valley, with steep walls (e.g. Shepard, 1972). A submarine canyon consists of an

51 upper part, the "canyon head", that deeply incises the continental shelf extending down to the

52 continental slope and ending at the base of the continental slope, where it forms a "canyon mouth"

53 (Canals *et al.*, 2009; Würtz, 2012). Canyons are characterised by a variety of topographic situations

54 and bedforms (Rowe *et al.*, 1982; Vetter, 1994; Trincardi *et al.*, 2007; McClain and Barry, 2010;

55 Migeon *et al.*, 2012; De Leo *et al.*, 2014; Fabri *et al.*, 2014; Lo Iacono *et al.*, 2015; Quattrini *et al.*,

56 2015; Robert *et al.*, 2015).They influence current patterns (Shepard *et al.*, 1979; Canals *et al.*, 2006;

Xu, 2011), and are a major pathway for the particle-transport from the continental shelf to the deep-sea (Nittrouer and Wright, 1994; Amaro *et al*., 2016; Fildani, 2017), thus playing a fundamental role in shelf-deep ocean exchanges (Würtz, 2012).

From a biological perspective, they play a key role in providing habitat, nursery and refuge for spawning pelagic and benthic species, some of which of commercial interest (Sardà *et al*., 1994; Yoklavich *et al*., 2000; Tyler *et al*., 2009; De Leo *et al*., 2010; Hoff, 2010; Vetter *et al*., 2010; Company *et al*., 2012, Farrugio, 2012; Morris *et al*., 2013; Fernandez-Arcaya *et al*., 2017). Canyons often house Vulnerable Marine Ecosystems (VMEs) usually dominated by gorgonians, antipatharians, scleractinians, and sponges (Schlacher *et al*., 2007; Huvenne *et al*., 2011; Davies *et al*., 2014; Morris *et al*., 2013; Brooke and Ross 2014, Miller *et al*., 2015; Trotter *et al*., 2018), having the ability to form three-dimensional habitats (coral forests, coral gardens, or animal forests: Rossi *et al*., 2017). For instance, the Mediterranean canyons provide habitat to Cold-Water Coral (CWC) as documented in the western basin for the Catalan Margin (Orejas *et al*., 2009; Lastras *et al*., 2016), Balearic Islands (Grinyó *et al*., 2018; Santín *et al*., 2018), Gulf of Lion (Gori *et al*., 2013; Fabri *et al*., 2014, 2017), Ligurian canyons (Fanelli *et al*., 2017), Corsica (Fourt *et al*., 2017), South Sardinia (Taviani *et al*., 2017), Gulf of Naples (Taviani *et al*., in press), and southern Tyrrhenian Sea (Pierdomenico *et al*., 2016). In the central basin, most information is available for the southern Adriatic Sea, i.e. the Bari Canyon (Freiwald *et al*., 2009; Bo *et al*., 2012; Sanfilippo *et al*., 2013; Angeletti *et al*., 2014; D'Onghia *et al*., 2015, 2016; Taviani *et al*., 2011, 2016), the Tricase Canyon (Prampolini *et al*., *in press*) and canyons and incisions in the eastern side of Montenegrin and Albanian margins (Angeletti *et al*., 2014, 2015, *in press*; Taviani *et al*., 2016, *this issue*).

Submarine canyon systems resent climate change that can modify the intensity of the currents and seriously affect the structure and functioning of the benthic communities, for example, by impinging on the nutrient supply to the deep ocean ecosystems (Solomon, 2007; Levin and Le Bris, 2015). However, the main source of impact is due to human activities, such as dumping (Hughes *et al*., 2015; Ramirez-Llodra *et al*., 2015), oil and gas extraction (Harris *et al*., 2007), litter (Mordecai *et al*.,

2011; Ramirez-Llodra *et al.*, 2013; Bergmann *et al.*, 2015; Tubau *et al.*, 2015; Cau *et al.*, 2017), chemical pollutants (Palanques *et al.*, 2008; Koenig *et al.*, 2013; Pham *et al.*, 2014), and fishing activities (Palanques *et al.*, 2001; Oberle *et al.*, 2018).

Fishing exerts considerable pressure on submarine canyons by altering their morphology (Puig *et al.*, 2015; Daly *et al.*, 2018) directly impacting the benthic assemblages thriving here. The negative effects related to fishing activities are due to the removal of conspicuous habitat-forming species (gorgonians, black corals, scleractinians, sponges and bryozoans) and also to the accidental loss of demersal gears (Company *et al.*, 2003; Mortensen *et al.*, 2005; Martín *et al.*, 2008; Orejas *et al.*, 2009; Buhl-Mortensen *et al.*, 2015; Cau *et al.*, 2017; Gori *et al.*, 2017; Taviani *et al.*, 2017).

Lost fishing gears (Derelict Fishing Gears: DFGs, hereafter) can affect negatively the seafloor integrity by suffocating benthic organisms and inducing epibiont overgrowth, or by mechanical removing mostly of erect species (Bavestrello *et al.*, 1997; Bo *et al.*, 2014). The loss of three-dimensionality, in turn, may lead towards an over-simplification of the community structure (Ponti *et al.*, 2014). Once on the seabottom, DFGs like nets or traps, may continue to exert negative effects for long by trapping fish and other organisms, a problem known as ghost fishing (Fernandez-Arcaya *et al.*, 2017). Several studies have highlighted the impact of DFGs on deep benthic communities or have used indicators of impact regarding structuring species as parameters of ecological indexes evaluating the health status of these communities (e.g. Bo *et al.*, 2014, 2015; Cánovas-Molina *et al.*, 2016; Oberle *et al.*, 2018).

The problem of fishing impact is usually related to demersal artisanal fisheries operating on the continental shelf (0 - 200 m) or on the upper bathyal zone (200 - 400 m) (Forcada, 2009), and it can be amplified by recreational fishermen insisting on the same grounds (Bo *et al.*, 2014). Canyon biota are negatively impacted by bottom trawling, mainly operated along the mouth of the canyon, because of the heavy mechanical action of the trawl net enhanced by metal footropes, accompanied by deleterious sediment resuspension (Martín *et al.*, 2014; Payo-Payo *et al.*, 2015; Paradis *et al.*, 2017).

Fishing in the Mediterranean Sea is a significant activity, especially intense in the Ligurian Sea

109 (Cattaneo Vietti *et al.*, 2010); thus far, only few studies have been, however, devoted to evaluate the

110 environmental status of the deep benthic communities (Cánovas-Molina *et al.*, 2016).

111 This paper describes the megabenthic biodiversity, with main focus on the anthozoan component, and

112 the occurrence of lost fishing gears and lines (DFGs) in five canyons located in the western Ligurian

113 Sea (north-western Mediterranean Sea). Presence, density and distribution of cnidarian megabenthic

114 species as well as DFGs, were analysed and related to two physical descriptors of seafloor

115 morphology, depth and slope.

116

Materials and methods

Study area

119 The five investigated canyon systems are, from West to East: Dramont (France), Monaco

120 (Principality of Monaco), Bordighera, Arma di Taggia, and Bergeggi (Italy) (Fig. 1). The study sites

121 were mapped using a Multibeam Echo Sounder (MBES) and explored with a Remotely Operated

122 Vehicle (ROV) from 20 to 445 m. Except Bergeggi, all canyons, were investigated during a scientific

123 campaign organised in the frame of the RAMOGE (Saint-RApahel, MOnaco and GEnoa) agreement.

124 The main objective of RAMOGE is to coordinate the activities of France, Italy and Monaco for

125 protection of the marine environment, through the establishment of multidisciplinary collaboration

126 between local and regional administrations, scientific institutions and users of the sea in order to

127 carry out joint actions. During the 2014 *ad hoc* workshop on the Mediterranean Sea organized within

128 the framework of the Convention on Biological Diversity (CBD) in Malaga (Spain), two Ecologically

129 or Biologically Significant Marine Areas (EBSAs) were identified in the North-western

130 Mediterranean Sea: one for pelagic and one for benthic ecosystems. Through cross-border

131 cooperation between RAMOGE countries for the implementation of CBD criteria, 35 focus areas

132 were identified in the Ligurian Sea (Italy), 6 in Monaco and 25 in the Provence-Alpes-Côte d'Azur

133 Region (France). Most of the identified areas are represented by submarine canyon heads and outer

134 continental shelf rocky outcrops. In 2015, RAMOGE organized its first deep-sea exploration

135 campaign at a depth range of 50 - 400 m aimed to obtain an overall picture of the habitats, occurrence

136 of protected and commercial species, and human pressures. Six ecological focal areas were identified

137 for the campaign (Daniel *et al.*, 2017), four of which are the canyon systems examined by this study.

138 A fifth site (Bergeggi) was investigated during the CNR oceanographic cruise BIOLIG, designed to

139 explore mega- and macrobenthic communities, and meiofauna of the Ligurian Sea canyons.

140
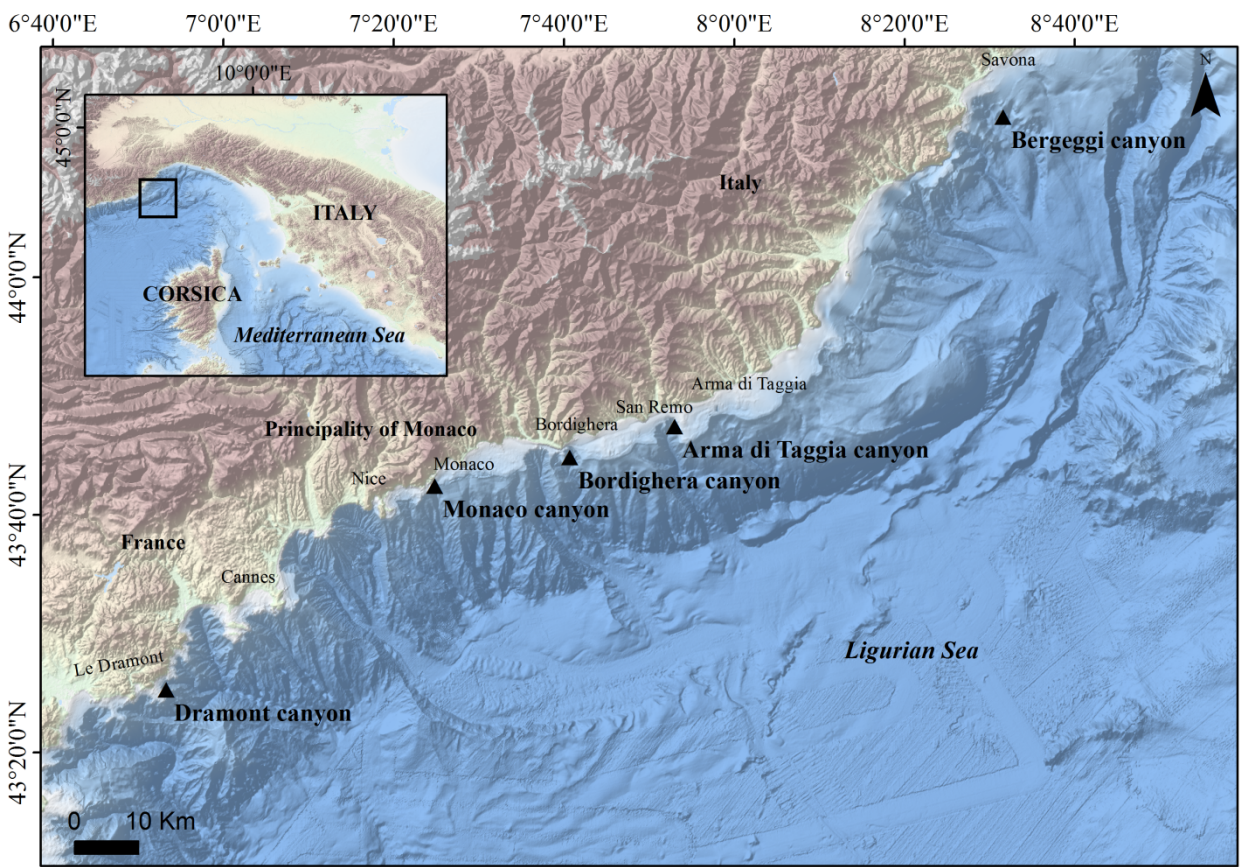
Fig. 1. Location of the five investigated canyons and nearby shelf regions.

143

144 The canyon systems under scrutiny are exposed to various human stressors, above all fishing

145 activities. Bergeggi is located at a distance of about 4 km from the port of Savona. According to the

146 fleet register data (http://ec.europa.eu/fisheries/fleet/index.cfm), Savona hosts 64 artisanal fishing

147 vessels (less than 12 m overall length). Arma di Taggia and Bordighera, are located at a distance of 6

148 km and 8 km, respectively, from the port of San Remo that hosts, according to the fleet register data,

149 about 30 artisanal fishing vessels. These three canyons are important fishing areas for local, small-

150 scale fishery fleets. The Monaco canyon, belonging to the Principality of Monaco, could be

151 considered as a reference site for fishing activities pressure because there is only one artisanal fishing

152 boat operating in the area (L. Tunesi, unpublished).

153

154 *Data acquisition and analysis*

155 The RAMOGE research campaign was conducted on board the R/V *Astrea* from 16 to 23 August

156 2015. During the survey, high resolution bathymetric data were collected using an MBES Kongsberg

157 EM 2040, operating at a frequency of 300 kHz and nine ROV dives were carried out, five in the

158 canyon heads and seven on the adjacent continental shelves (Table 1). The BIOLIG oceanographic

159 cruise took place on board the R/V *Minerva Uno* from 9 to 12 May 2013. High-resolution

160 bathymetric data of the Bergeggi Canyon were collected using an MBES Reason SeaBat 8160,

161 operating at a frequency of 50 kHz. The canyon was explored through three ROV dives, two in the

162 canyon's head and one on the nearby continental shelf (Table 1).

163 High-resolution bathymetric data were collected using the Seafloor Information System (SIS)

164 software and were analysed with the HIPS and SIPS (CARIS) software. The morphometric

165 parameters were extrapolated with the open source SAGA GIS software (Conrad *et al.*, 2015),

166 georeferenced to the World Geodetic System 1984 ellipsoid and converted to metres within Zone

167 32N of the Universal Transverse Mercator projection.

168 Preliminary georeferenced maps were generated on-board first from non-filtered MBES data in order

169 to identify the presence of hard bottoms suitable to be explored by ROV. Twelve ROV dives were

170 then performed between 20 - 445 m to assess megabenthic communities and anthropic impact (Table

171 1). A "Pollux III" ROV was equipped with a high-resolution video camera and a reflex (DSLR)

172 Canon camera with two strobes; real-time position was provided by an underwater acoustic

173 positioning system (Linquest – Tracklink 1500 MA), connected with a Geographic Information

174 System (GIS) (Blue Marble geographics, Global Mapper v17; a depth sensor, a compass and two

175 laser beams placed 10 cm apart for scale complete ROV equipment. The ROV navigated at an

176 average speed of 0.3 m s^{-1}, approximately 1.5 m above the substrate. The field of view of the ROV

177 was estimated to be approximately two metres wide (defined on the distance of the two parallel laser

178 pointers) when moving at that distance from the bottom (Bo *et al*., 2009).

179 Georeferenced videos were recorded continuously and images were extrapolated from the video

180 tracks for a total of 642 frames by means of the free Internet software DVDVideoSoft, every 10 s,

181 (Table 1). For every image the following parameters were considered: i) megabenthic diversity; ii)

182 number of cnidarian colonies; iii) number and typology of litter items. Density of cnidarians

183 (expressed as number of colonies per square meter) was obtained for each site and for each

184 topographic area (shelf and canyon head). Impacted colonies (entangled or epibionted) were also

185 annotated and compared in terms of percentage of frames over the entire site dataset.

186 Precise location, depth and number of cnidarian colonies and litter items were also mapped in

187 ArcGIS 10.1 (ESRI) to check and avoid for image overlapping.

188 Marine litter was classified according to the categories reported in the "Guidance on monitoring of

189 Marine Litter in European Seas" (GMML) (Galgani *et al*., 2015). The DFGs belonging to categories

190 A. 6, A. 7 and A. 9 were used to calculate the density of the various litter categories (expressed as

191 number of items per hectare).

192 Morphobathymetric data were used to extrapolate two physical descriptors of seafloor morphology,

193 depth and slope. Due to the fact that data were collected using two different MBES models, these

194 descriptors were gridded differently in the corresponding raster files. MBES data collected within the

195 framework of the RAMOGE campaign were gridded in raster files with 1x1 m cell size, while MBES

196 data collected within the framework of the BIOLIG campaign were gridded in raster files with 10x10

197 m cell size. These are the highest possible resolution MBES cell sizes that can be retrieved from the

198 systems used, operating at the depths reported above, without losing information (Giusti *et al*., 2017).

199 Depth and slope are considered to be among the main factors influencing coral distribution on hard

200 bottoms (e.g. Davies and Guinotte, 2011; Giusti *et al*., 2014 , 2017; Angeletti *et al*., *in press*). Slope

describes the rate of change in elevation, with low values associated with flat bottom and a high probability of sediment deposition sites, and higher values indicating potential hard bottoms (rocky or lithified sediments). The output slope raster was calculated in degrees from 0° (flat) to 90° (vertical).

In this study, arborescent anthozoans were chosen due to their paramount role as structuring organisms and their vulnerability to DFGs (Bo *et al.*, 2014). For this reason, their occurrence was related to the two terrain attributes described above (depth and slope).

Furthermore, with the aim of better understand the correlation between the co-occurrence of structuring cnidarians and DFGs, partial correlation matrices were calculated. In order to do that the ROV data were organized in a table that reports the depth, the distance from the coast, the distance from the nearest port, the presence or absence of cnidarians and DFGs and, in case of presence, the number of specimens/items found. The linear correlation between presence or absence of cnidarians and DFGs did not show any statistically significant result. However, simple linear correlations between the presence of the species and that of DFGs could lead to misleading results due to other variables that could influence both the habitat of the species and the presence of DFGs, such as depth, distance from the coast and from the nearest port (Ferrigno *et al.,* 2017; Consoli *et al.*, 2018).

To control the effect of other variables, partial correlations were used to calculate the relationships between species, DFGs, depth, distance from the coast and from the nearest port. Partial correlations allow to calculate the linear correlations between two variables removing the effects of the other variables, that can be numerically associated to the two variables of interest, thus leading to confound results (Anderson *et al*., 1958). The partial correlations were calculated in the R environment (R Core Team, 2018) using the "ppcor package" (Kim, 2015) and the relative matrices were drawn using the "corrplot package" (Wei *et al*., 2017).

227   *Sites description*

228   The canyon systems here considered present different topographic characteristics. (1) Dramont (Fig.

229   2A) is W-E oriented and is located at a distance of 1.5 km from the coast, with the canyon's actual

230   incision starting at ca. 145 m. The slope in the W-E direction ranges from 6° to 34°. (2) Monaco (Fig.

231   2B) is oriented in a NW-SE direction; it is at a distance of 1.6 km from the coast, starting at a depth

232   of 102 m; the slope in the NW-SE direction ranges from 6° to 31°. (3) Bordighera has two heads

233   (Fig. 2C), both oriented in a N-S direction, located at a distance of about 0.5 km from the coast,

234   beginning at a depth of 80 m; both heads have a slope range from 0° to 85°. (4) Arma di Taggia is

235   formed by two heads (Fig. 2D). One is oriented in a N-S direction, the other mainly W-E. Both heads

236   are at a distance of about 2 km from the coast, beginning at a depth of 100 m. The N-S oriented slope

237   ranges from 7° to 46°. The slope of the other head ranges from 7° to 34° (5) Bergeggi canyon (Fig.

238   2E) is NW-SE oriented and located at about 4.6 km from the coast. The slope ranges from 0° to 55°.

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43°24'0"N

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le Dramont

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43°44'30"N
43°43'30"N
43°42'30"N
43°41'30"N

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la Turbie
Beausoleil
Monte-Carlo
Monaco
Cap-d'Ail

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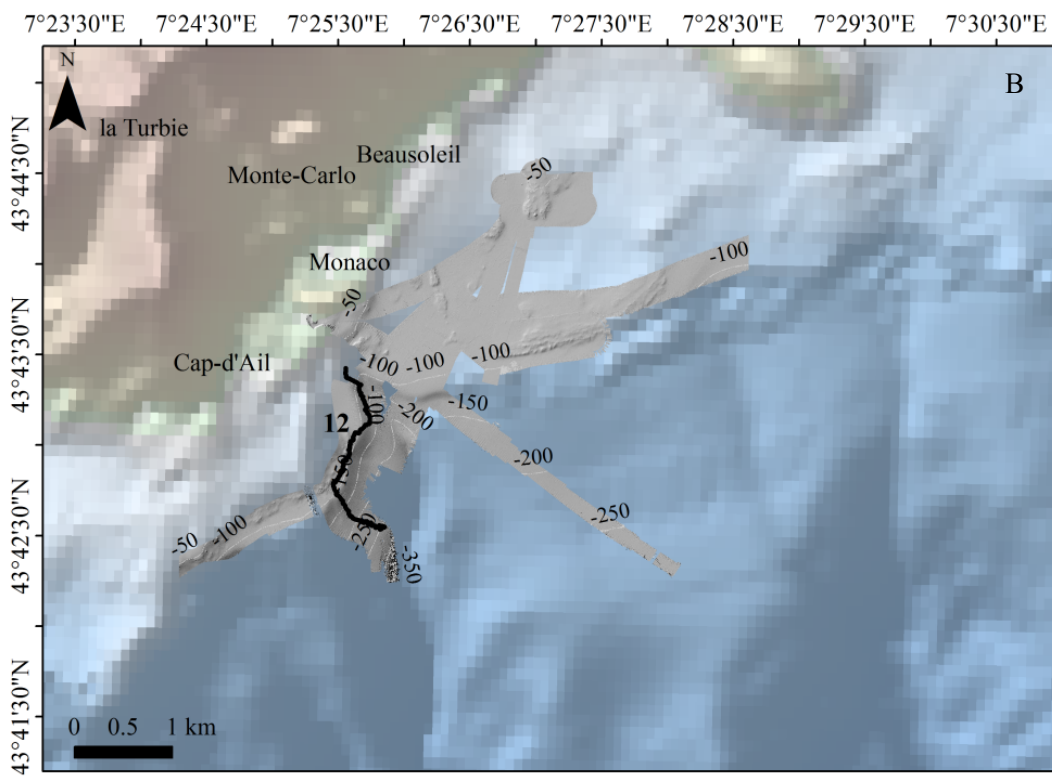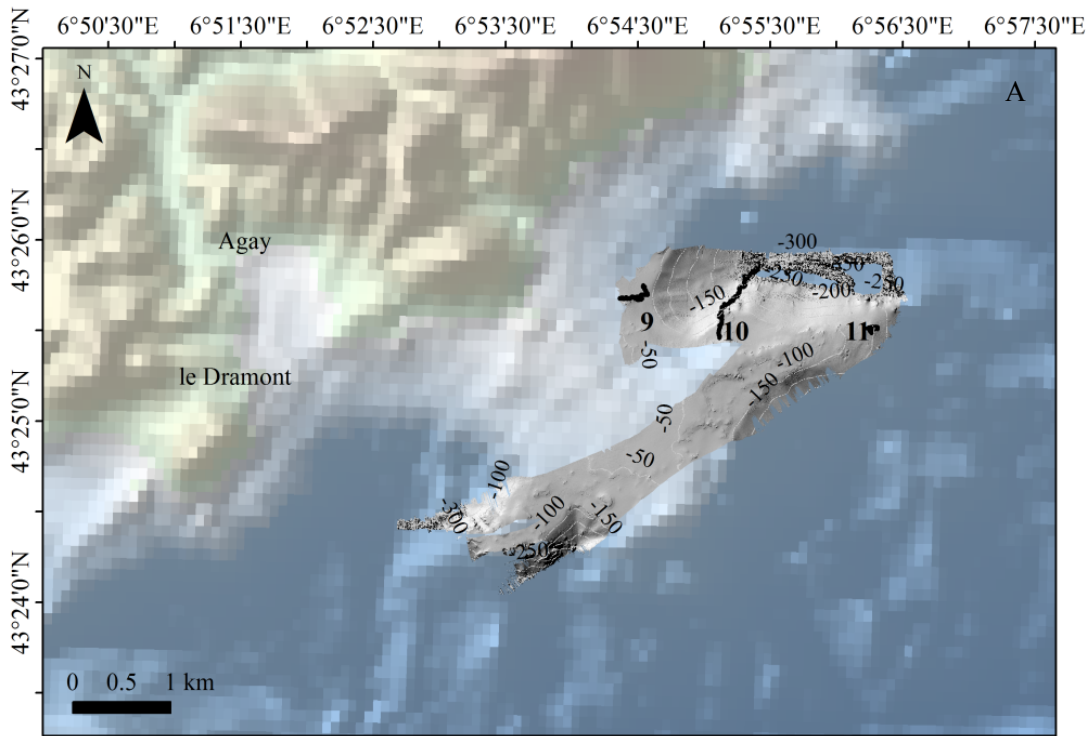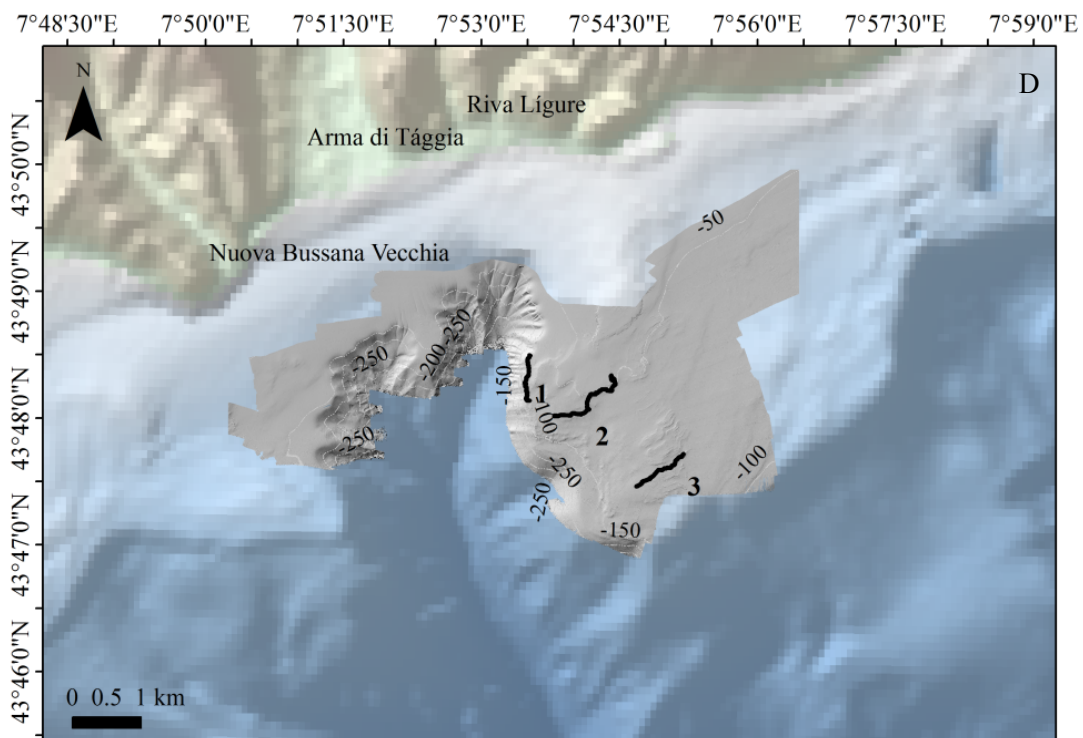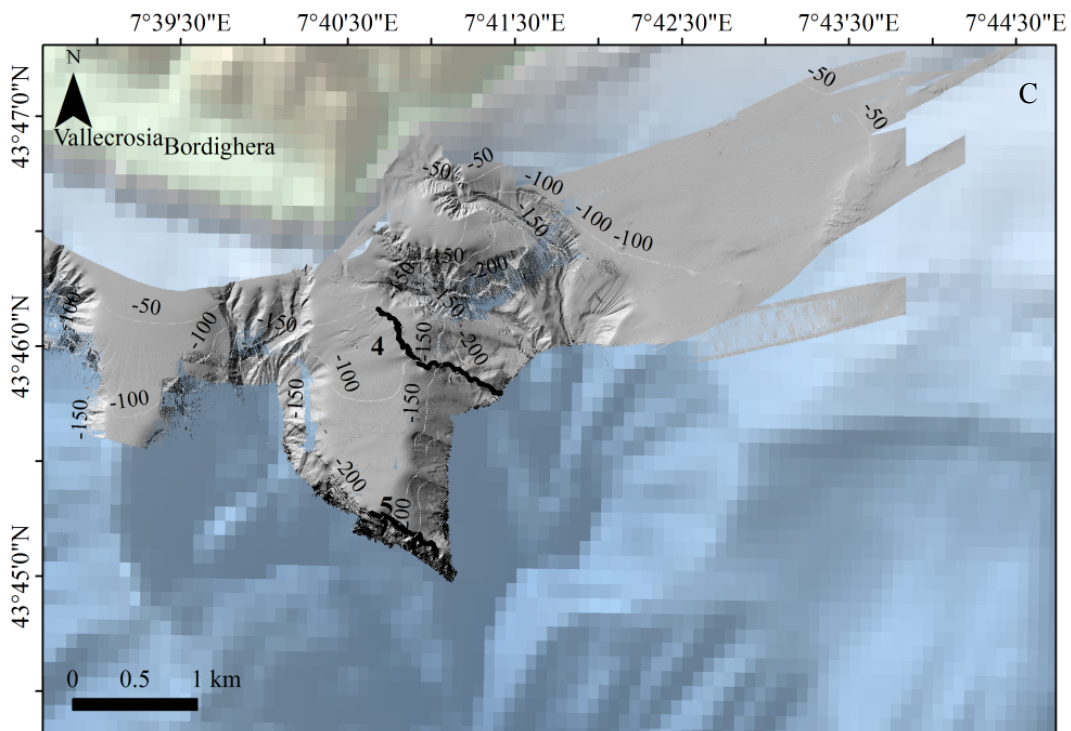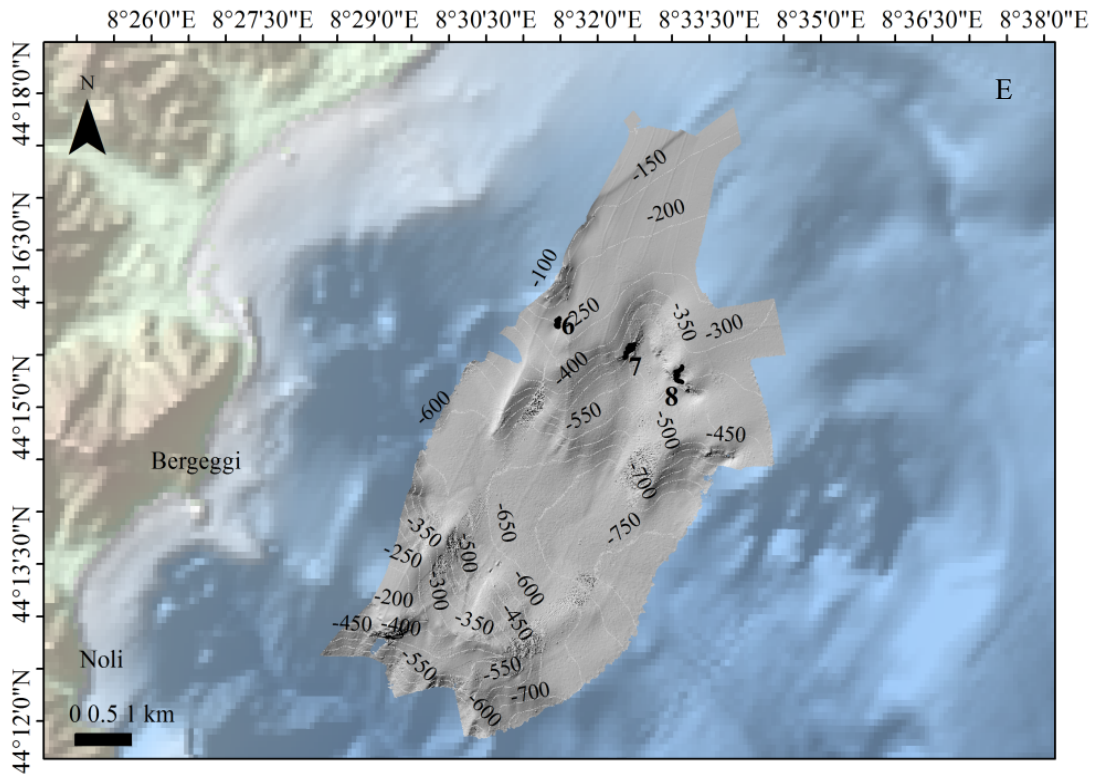
Fig. 2. Morphobathymethric maps with the position of the ROV dives (black lines); (A) Dramont, (B) Monaco, (C) Bordighera, (D) Arma di Taggia, (E) Bergeg

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260 **Table 1.** Metadata of ROV dives (the ROV dives executed in the canyon heads are marked with an*).

Canyon	ROV dive	Dive start position (decimal degrees)		Dive end position (decimal degrees)		Dive duration (h:mm)	N° of frames per site	Dive depth-range (m)	Dive length (m)	Hard bottom length (m)	Dive area (m²)	Hard bottom surface (m²)
		latitude	longitude	latitude	longitude							
Dramont	9	43.433	6.925	43.433	6.925	2:09	99	20-342	2,476	2,476	3,071	3,071
	10*	43.429	6.907	43.430	6.910	1:08		20-90	811	354	1,269	554
	11	43.427	6.939	43.427	6.939	0:36		20-165	530	530	731	731
Monaco	12	43.710	7.432	43.710	7.432	2:45	38	40-251	4,360	412	5,621	531
Bordighera	4*	43.770	7.678	43.764	7.691	2:50	246	20-300	2,282	830	3,575	1,300
	5*	43.755	7.678	43.752	7.685	1:36		22-263	1,427	1,427	2,192	2,192
Arma di Taggia	1	43.792	7.912	43.796	7.921	0:46	179	25-61	959	615	1,709	1,096
	2	43.801	7.897	43.801	7.898	1:53		25-66	1,726	494	2,920	836
	3	43.809	7.893	43.805	7.892	0:58		25-95	956	956	1,483	1,483
Bergeggi	6	44.264	8.523	44.265	8.525	1:37	80	230-240	890	134	1,349	203
	7*	44.260	8.541	44.260	8.541	2:35		383-405	1,640	224	2,271	310
	8*	44.257	8.553	44.255	8.553	2:18		352-445	1,247	184	1,647	243

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Results

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Structuring cnidarians: diversity, abundance, distribution and vulnerability

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265 The ROV dives surveyed the sea bottom over a distance of 19,304 linear m (8,636 m are hard

266 substrates) covering an area of 27,838 m² (12,550 m² are hard substrates) (Table 1).

267 Considering the shelves and the canyons heads altogether, a total of 140 species have been recorded

268 (Table 2). The most diverse community was found in the Italian canyons of Bordighera and Arma di

269 Taggia, where 73 and 72 species were found, respectively, followed by Dramont canyon hosting 64

270 species, Monaco canyon hosting 30 species, and, lastly, Bergeggi canyon with only 12 species.

271 Among benthic invertebrates, cnidarians are the most common taxonomic group, with a consistent

272 presence in all investigated sites (from 15% to 70%) followed by sponges (from 15% to 24%) (Fig.

273 3). Another highly diversified taxon is that of fish, ranging from 12% in Bergeggi canyon to 40% in

274 the Monaco canyon.

Table 2. Species recorded in the five investigated canyon systems.

Species observed in the five canyons		Dramont	Monaco	Bordighera	Arma di Taggia	Bergeggi
Kingdom: Plantae						
Phylum	**Species**					
Chlorophyta	*Palmophyllum crassum*	x				
Rhodophyta	*Peyssonnelia* sp.	x				
Kingdom: Animalia						
Phylum	**Species**					
Porifera	*Aaptos aaptos*	x		x		
	Agelas oroides				x	
	Aplysina cavernicola	x		x	x	
	Axinella damicornis	x	x	x		
	Axinella polypoides		x	x	x	
	Axinella sp.	x	x	x	x	
	Axinella verrucosa	x		x		
	Chondrosia reniformis				x	
	Cladocroce fibrosa	x				
	Clathrina clathrus				x	
	Dysidea sp.				x	
	Haliclona magna			x		
	Haliclona poecillastroides	x	x	x	x	
	Hemimycale sp.				x	
	Hexadella pruvoti	x		x	x	
	Hexadella racovitzai	x		x	x	
	Spongia lamella		x		x	
	Spongia officinalis			x		
	Pleraplysilla spinifera				x	
	Poecillastra compressa	x				
	Oscarella sp.				x	
	Petrosia ficiformis				x	
	Sarcotragus foetidus				x	
	Tethya sp.	x				
Cnidaria	*Alcyonium acaule*	x		x	x	
	Alcyonium coralloides	x		x	x	
	Alcyonium palmatum	x	x			
	Antipathella subpinnata	x		x	x	
	Antipathes dichotoma	x				x
	Caryophyllia sp.				x	
	Cerianthus membranaceus			x	x	x
	Corallium rubrum	x		x	x	
	Dendrophyllia cornigera	x		x	x	x
	Eunicella cavolinii	x		x	x	
	Eunicella singularis				x	

Phylum	Species					
	Eunicella verrucosa	x	x	x	x	
	Funiculina quadrangularis	x		x		x
	Leiopathes glaberrima					x
	Leptogorgia sarmentosa	x	x	x	x	
	Paramuricea clavata	x	x	x	x	
	Parantipathes larix					x
	Parazoanthus axinellae				x	
	Pennatula phosphorea			x		
	Pennatula rubra		x	x		
	Solmissus sp.					x
	Switfia sp.			x		
	Villogorgia bebrycoides					x
Mollusca	*Eledone cirrhosa*	x				
	Loligo sp.				x	
	Neopycnodonte cochlear		x	x		
	Octopus salutii			x		
	Octopus vulgaris			x		
	Pteria hirundo			x	x	
	Peltodoris atromaculata	x			x	
Anellida	*Bonellia viridis*	x	x	x	x	
	Filograna/Salmacina complex				x	
	Myxicola sp.	x				
	Myxicola infundibulum				x	
	Protula sp.				x	
	Sabella sp.	x				
	Sabella spallanzanii				x	
	Serpula vermicularis		x			
Artrhopoda	*Latreillia elegans*	x				
	Macropipus tuberculatus			x		
	Munida sp.	x	x	x		x
	Pagurus prideaux	x		x		
	Palinurus elephas	x	x	x	x	
	Plesionika gigliolii			x		
	Plesionika sp.					x
Brachiopoda	*Gryphus vitreus*	x		x		
Bryozoa	*Myriapora truncata*	x				
	Reteporella sp.	x		x		
	Turbicellepora avicularis				x	
	Smittina cervicornis				x	
	Myriapora truncata				x	
	Pentapora fascialis				x	
	Reteporella grimaldii				x	
	Schizomavella mamillata				x	

Phylum	Species					
Echinodermata	*Amphiura* sp.				x	
	Anseropoda placenta			x		
	Astrospartus mediterraneus	x		x	x	
	Centrostephanus longispinus	x		x	x	
	Echinaster sepositus			x	x	
	Echinus melo			x	x	
	Hacelia attenuata	x		x	x	
	Holothuria forskali	x	x	x	x	
	Holothuria poli				x	
	Holothuria sp.	x	x	x	x	
	Leptometra phalangium			x		
	Marthasterias glacialis			x		
	Parastichopus regalis	x	x	x		
	Peltaster placenta	x			x	
	Spatangus purpureus				x	
Chordata	*Acantholabrus palloni*	x		x		
	Anthias anthias	x	x	x	x	
	Argentina sphyraena			x		
	Aulopus filamentosus	x		x		
	Benthocometes robustus	x				x
	Capros aper	x	x	x		
	Chlorophthalmus agassizi	x				
	Ciona intestinalis				x	
	Ciona sp.				x	
	Clavelina sp.				x	
	Coelorinchus caelorinchus	x				
	Conger conger			x	x	
	Coris julis				x	
	Diplodus vulgaris				x	
	Gadiculus argenteus		x	x		
	Halocynthia papillosa	x	x	x	x	
	Helicolenus dactylopterus	x		x		
	Lappanella fasciata			x		
	Lepidorhombus boscii	x		x		
	Lepidorhombus whiffiagonis			x		
	Lesueurigobius friesii			x		
	Lophius piscatorius			x		
	Macroramphosus scolopax	x	x	x		
	Mullus barbatus			x		
	Mullus surmuletus		x			
	Muraena helena	x		x	x	
	Pagellus acarne	x				
	Pagellus bogaraveo	x		x		

	Phycis blennoides					x
	Phycis phycis	x	x	x	x	
	Scorpaena elongata		x			
	Scorpaena porcus				x	
	Scorpaena scrofa		x		x	
	Scorpaena sp.	x	x	x	x	
	Scyliorhinus canicula	x				
	Seriola dumerili	x		x		
	Serranus cabrilla	x	x	x	x	
	Serranus hepatus	x	x			
	Spicara maena			x		
	Spicara smaris				x	
	Symphodus mediterraneus				x	
	Scyliorhinus sp.				x	
	Trachurus sp.			x		
	Zeus faber			x		
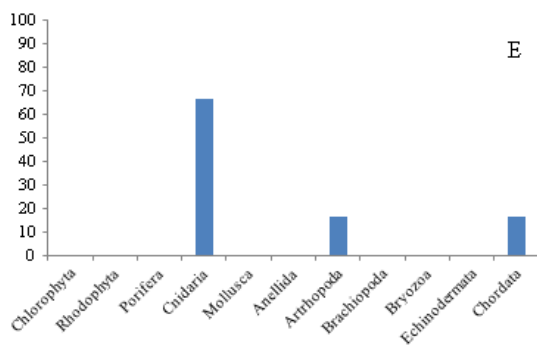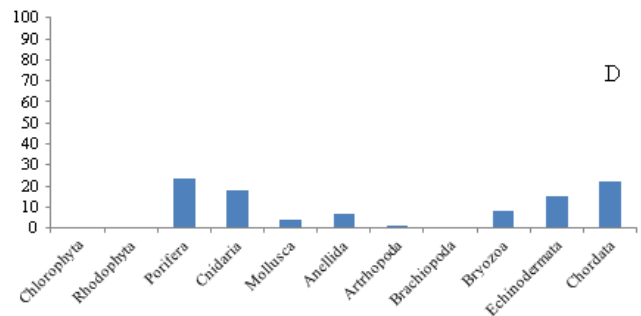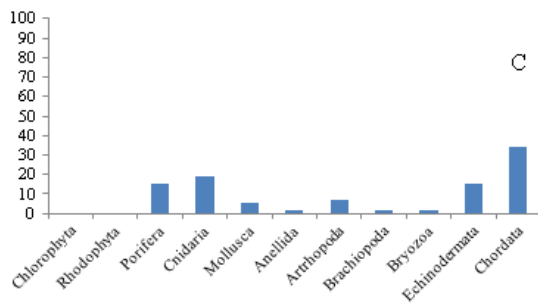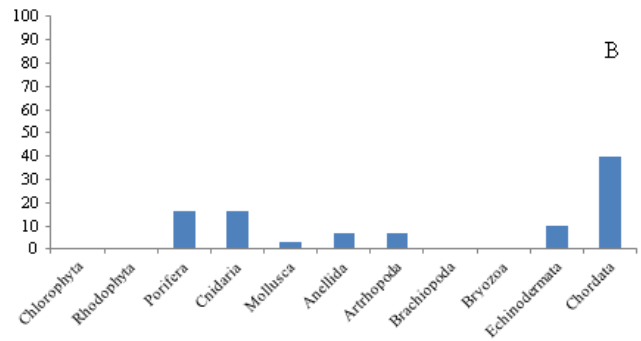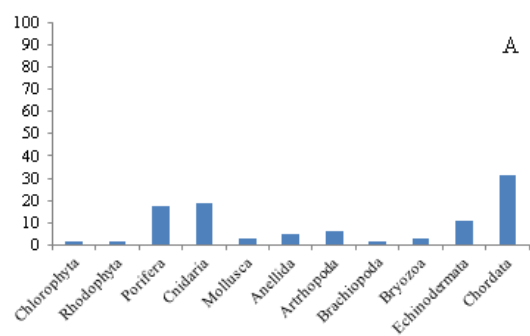
Fig. 3. Percentage taxa composition of the investigated communities: (A) Dramont, (B) Monaco, (C) Bordighera, (D) Arma di Taggia and (E) Bergeggi.

Cnidarians accounted for 22 species, 11 of which can be ascribed to structuring arborescent taxa settling hardgrounds (2080 colonies) (Table 3). Four such arborescent species (three gorgonians and one scleractinian) represented > 97% of the total records, with *Eunicella cavolinii* being the most representative (42%) (Table 3). Three species, *E. verrucosa*, *Leptogorgia sarmentosa* and *Paramuricea clavata*, occur in all canyon sytems, except Bergeggi, while *Dendrophyllia cornigera* was not detected in Monaco (Table 3).

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291 **Table 3.** Cnidarian diversity and abundance in Ligurian canyon systems; the five most representative

292 species are noted in bold, while the asterisk refer to the structuring taxa.

Cnidarian species	Colonies total number	Dramont	Monaco	Bordighera	Arma di Taggia	Bergeggi
Alcyonium acaule	3	1		1	1	
Alcyonium coralloides	13	1		1	11	
Alcyonium palmatum	12	1	10	1		
Antipathella subpinnata*	39	6		26	7	
Antipathes dichotoma*	6	1				5
Caryophyllia sp.	3				3	
Cerianthus membranaceus	5			2	3	
Corallium rubrum*	287	142		49	96	
Dendrophyllia cornigera*	173	6		157	1	9
Eunicella cavolinii*	881	244		331	306	
Eunicella singularis*	1				1	
Eunicella verrucosa*	267	31	64	148	24	
Funiculina quadrangularis	67	5		61		1
Leiopathes glaberrima*	2					2
Leptogorgia sarmentosa*	6	2	1	1	2	
Paramuricea clavata*	417	74	4	301	38	
Parantipathes larix*	1					1
Parazoanthus axinellae	292				292	
Pennatula phosphorea	9			9		
Pennatula rubra	3		2	1		
Swiftia sp.	2			2		
Villogorgia bebrycoides	1					1
TOTAL	**2,490**	**514**	**81**	**1,091**	**785**	**19**

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294 Some differences appear in the composition of the structuring cnidarians observed at canyon heads

295 and continental shelf (Fig. 4). Both situations share eight conspicuous, arborescent species;

296 *Antipathes dichotoma* and *Antipathella subpinnata* were only observed in the canyon heads, whereas,

297 *E. singularis*, *Leiopathes glaberrima,* and *Parantipathes larix* were detected only on the continental

298 shelves (Fig. 4).
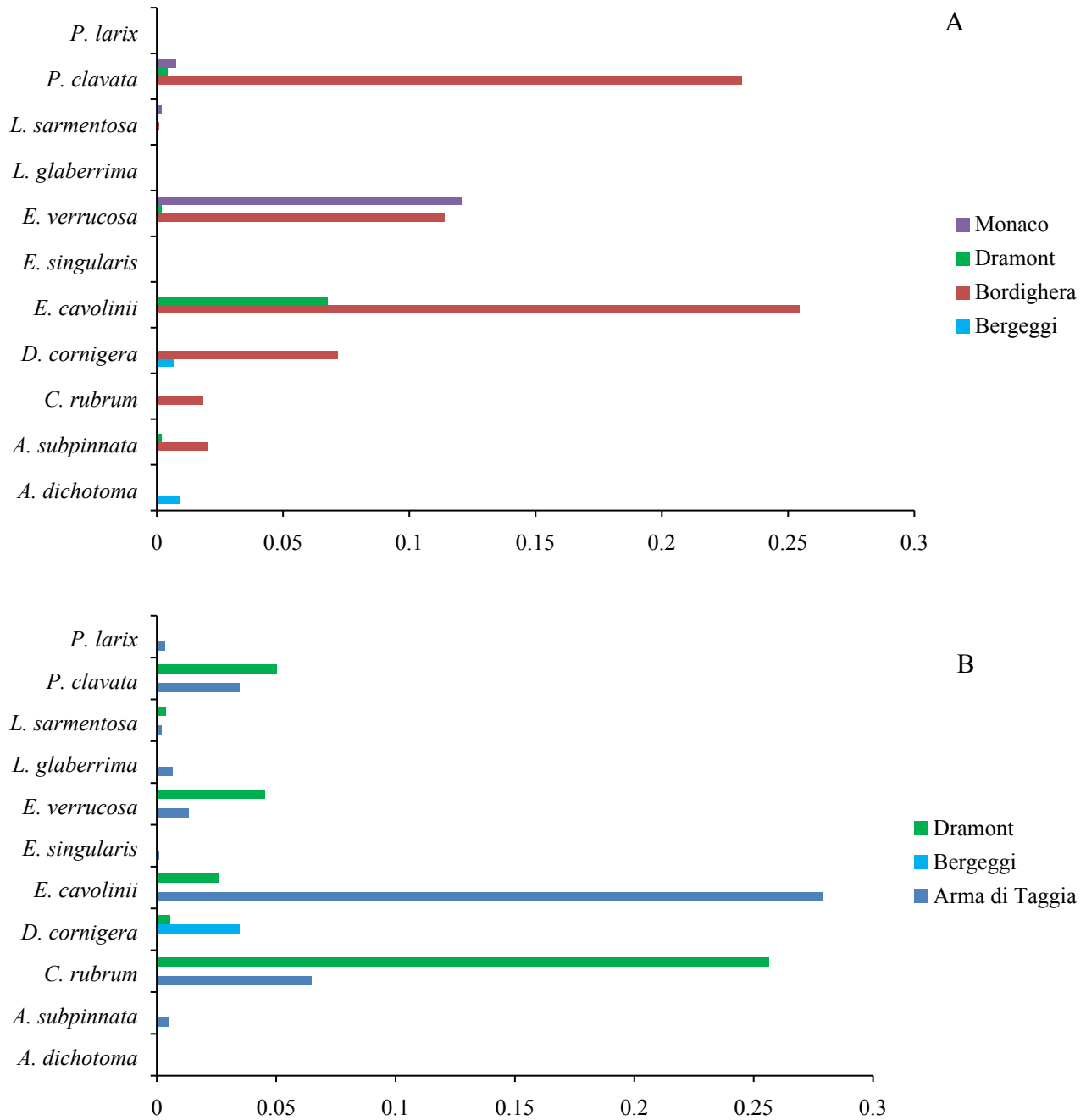
Fig. 4. Density (n° colonies m^{-2}) of the structuring species in the canyon heads (A) and on the continental shelves (B).

The occurrence of coral forests relate differently to the abiotic variables in the five study sites. At Arma di Taggia, structuring colonies were found between 47 – 93 metres depth on substrates with a slope range of 6° - 50°. At Bergeggi, structuring species were observed between 229 – 394 metres depth, with slopes of 29° - 41°. At Bordighera, structuring species were observed between 117 - 310

metres depth along slopes ranges of 22° - 47°. Structuring cnidarians in Dramont were identified between 64 – 287 metres depth on substrates with an inclination range of 6° - 62°. Finally, at Monaco the structuring species were found between 84 - 128 metres depth over slopes of about 14°. On average, our data show that 95% of the structuring cnidarian colonies in canyons' heads mainly settled in correspondence of slope range values of 6 °- 61 °, whereas, on the continental shelf, 97.6% of the colonies occurred on sites with slope range values of 7° - 49°.

Various parameters have been gathered concerning the vulnerability of the most common structuring species in the five areas. Monaco and Bordighera canyon systems showed the highest percentage of impacted frames (58% and 47%, respectively), followed by Arma di Taggia (26%), Dramont and Bergeggi (20% and 12%). Despite this, Monaco showed no frames with entangled colonies; a relatively low percentage was observed in all other canyons with the exception of Bordighera (17%). A total of 553 impacted colonies were counted, divided into 72% of entangled specimens, 21% of epibiotic and 31% of necrotic ones. When considering the single species, the ones mostly interested by these phenomena are *P. clavata*, *E. cavolinii*, *E. verrucosa*, *D. cornigera*, and *C. rubrum*, with site-specific differences. In Arma di Taggia shelf, 67% of red coral colonies are entangled, while *P. clavata* and *E. verrucosa* showed the highest percentage of overgrown and necrotic colonies (Fig. 5A-C). Significant necrosis signs were observed only in this site. *P. clavata* colonies are usually colonized by the serpulid *Filograna* spp., whose presence and degree of coverage (about 11%), however, is considered normal. *E. verrucosa* colonies are commonly colonized (about 10% of the surface) by the parasitic soft coral *Alcyonium coralloides* and sometimes by hydroids. In the Bordighera Canyon, *E. cavolinii* is the species most affected by the epibiosis phenomena (Fig. 5B): colonies are usually covered by the *A. coralloides* or hydroids for nearly 40% of their surface. *D. cornigera*, instead, is observed to be the most frequently entangled in lines (Fig. 5A). In the Bergeggi Canyon, few species are affected by epibiosis and necrosis phenomena, as well as entanglements (Fig. 5A-C).
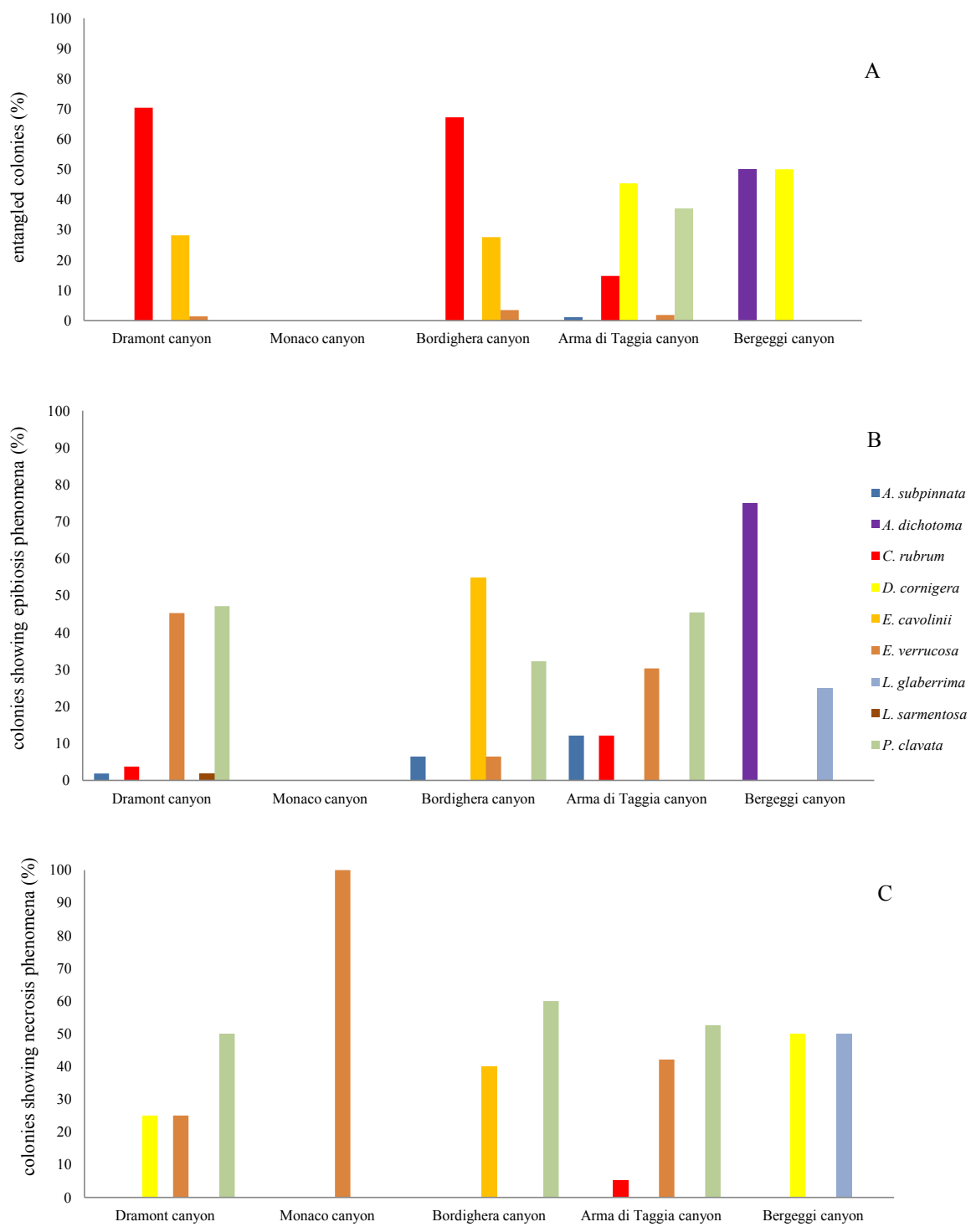
Fig. 5. Percentage of colonies showing entanglement (A), epibiosis (B) and necrosis (C) .

At Dramont *P. clavata* and *E. verrucosa* displayed the largest percentage of overgrown colonies (Fig. 5B), almost all of them being colonized by *A. coralloides* or hydroids covering the gorgonians

surfaces for over 40%. High percentages of entangled colonies concerned *E. cavolinii* and *C. rubrum* (Fig. 5C). Finally, the Monaco canyon system hosted the least compromised coral forests (Fig. 5A-B).

Regarding necrosis, the largest number of necrotic colonies were found in the Arma di Taggia site where *P. clavata* was the species most affected by the phenomenon (Fig. 5C). A single colony of *E. verrucosa* entirely necrotic was observed in Monaco (Fig. 5C).

Marine litter: typologies and distribution

The presence of marine litter was widely registered along the paths of the twelve ROV dives carried out in the canyons (Table 4; Fig. 6).
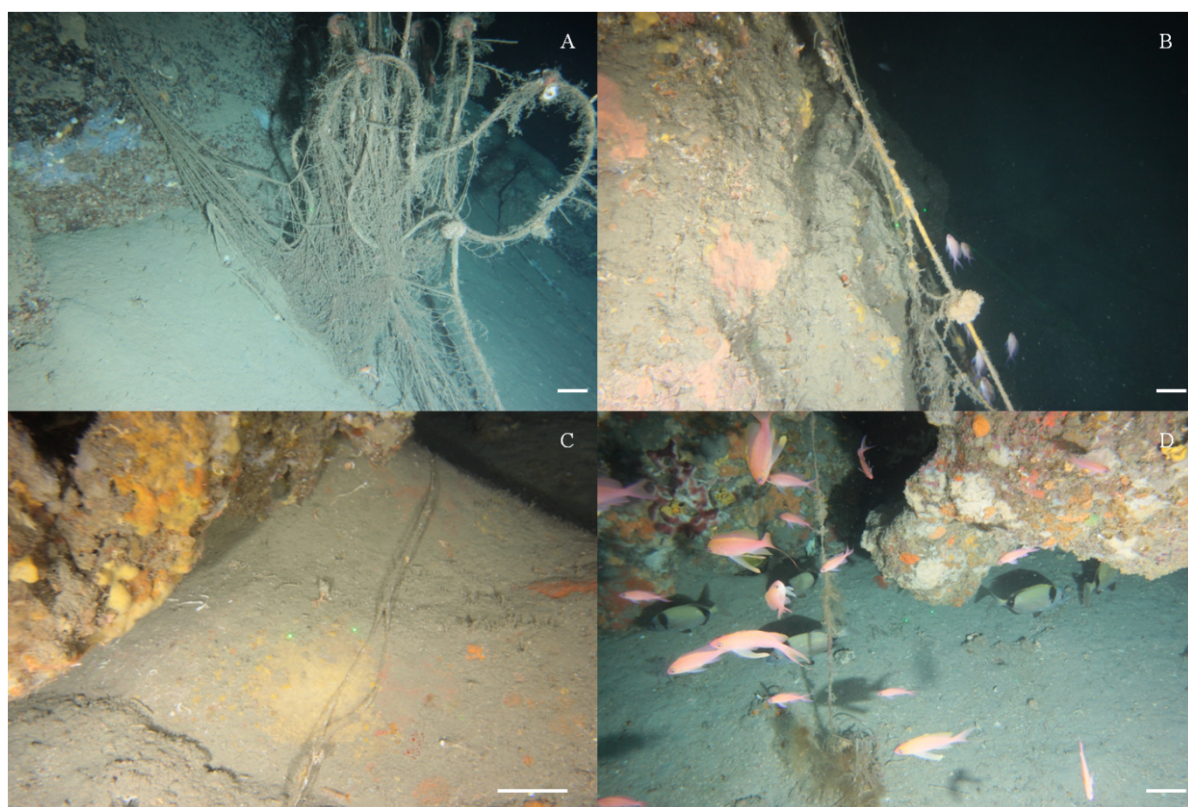
Fig. 6. Examples of Derelict Fishing Gears: (A) lost trammel net in the Bordighera Canyon; (B) lost trammel net in the Arma di Taggia site; (C-D) lost fishing lines in the Arma di Taggia site. Scale bar= 10 cm.

A total of 146 items were found in the study areas, accounting for 85% of DFGs (divided into fishing nets (57%), lines (12%) and ropes (16%)). The remaining 15% is related to general urban litter, mainly plastic (12%), followed by glass and metals.

None of the five canyons investigated were free of DFGs, however, some differences were reported among sites in terms of litter density per hectare: the site with the highest density of litter was Bergeggi, followed by Monaco and Bordighera (Fig. 7). DFGs are well represented in the sites of Bergeggi and Bordighera, while urban litter is more abundant in Monaco.

Marine litter also was related to the considered environmental variables. In the Dramont Canyon, litter was found between 68 - 227 m depth, with slope range from 23° to 44°. In the Monaco Canyon, litter was found between 95 - 127 m with a slope values of about 13°. In the Bordighera Canyon, litter was observed between 62 - 300 m with slope range from 15° to 34°. In Arma di Taggia site, litter was found between 47 - 93 m over slope range from 9° to 21°, while in the Bergeggi Canyon, litter was observed between 229 - 434 m with slope range from14° to 44°.

Table 4. Number of marine litter items observed along the ROV dive tracks. Codes from Galgani *et al*. (2015) of the categories are reported in brackets.

Canyon System	ROV dive	Fishing nets (A.6)	Fishing lines (A.7)	Fishing ropes (A.9)	Metals (C)	Glass (D)	Other (I)
Dramont	9	4				2	
	10	4					
	11	3					
Monaco	12	4				1	7
Bordighera	4	28			1		2
	5	38					1
Arma di Taggia	1		5				3
	2		4				2
	3	2	8	3			
Bergeggi	6	1		7	1		1
	7			6			
	8			7			1
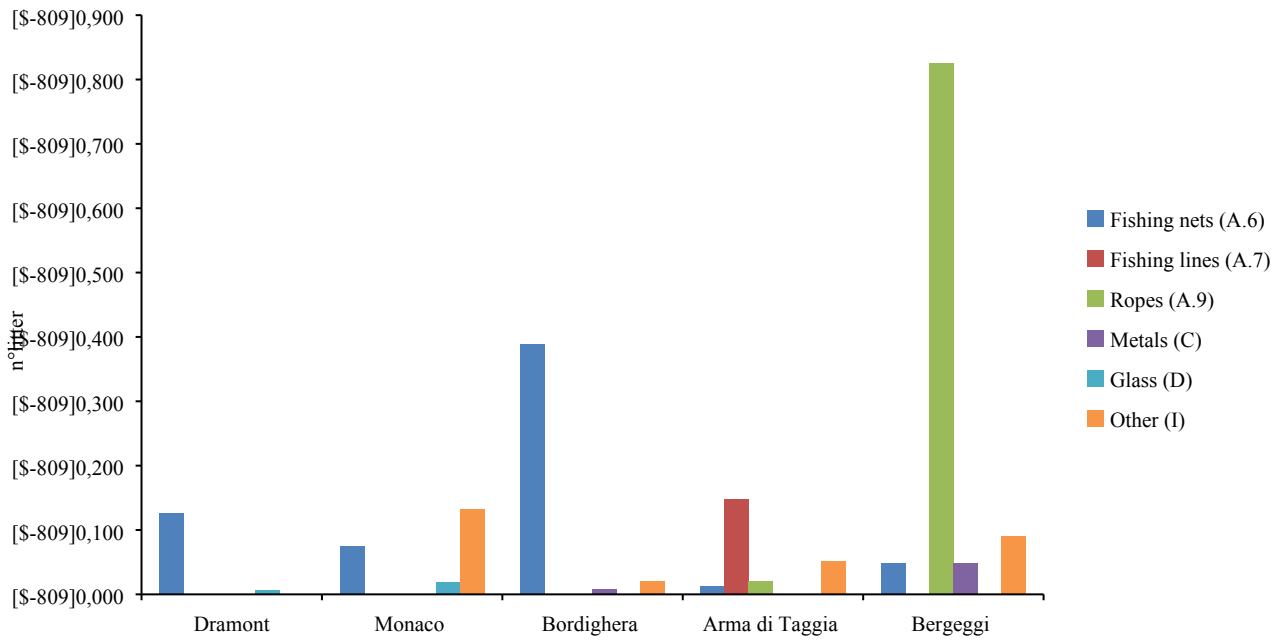
Fig. 7. Density of marine litter items (n° litter items ha^{-1}) observed along the path of the ROV dives.

A representation of the partial correlations between DFGs, occurrence of structuring cnidarians, depth, distance from the coast and from the nearest port is shown in Fig. 8 for the whole dataset, and in Fig. 9A-E for each canyon. In both, positive correlations are displayed in blue, and negative correlations in red colours. The correlation values that are not statistically significant (p-value > 0.05) are not displayed.

Focusing on DFGs, the matrix showing the partial correlations calculated on the whole ROV dataset (Fig. 8) highlights that:

- the presence of fishing nets is negatively partially correlated with that of *D. cornigera* (r = - 0.25), *E. verrucosa* (r = - 0.23), *A. subpinnata* (r = - 0.20), *A. dicothoma* (r = - 0.15), *E. cavolinii* (r = - 0.14), *L. sarmentosa* (r = - 0.12) and *L. glaberrima* (r = - 0.12). Moreover, the fishing nets are positively correlated with depth (r = 0.42) and negatively correlate with the distance from the nearest port (r = - 0.25), the distance from the coast (r = - 014) and the presence of ropes (r = - 0.23);

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- 387 the presence of fishing lines is not significantly correlated with the presence of any species, it is correlated negatively with depth (r = - 0.14) and positively with the distance from the coast (r = 0.20);

- 390 the presence of ropes is negatively correlated with that of *A. dicothoma* (r = - 0.29), *L. glaberrima* (r = - 0.29), *D. cornigera* (r = - 0.24) and *P. larix* (r = - 0.21). In addition, the presence of ropes is positively correlated with depth (r = 0.52) and the distance from the coast (r = 0.20), and it is negatively correlated with the presence of fishing nets (r = - 0.23).
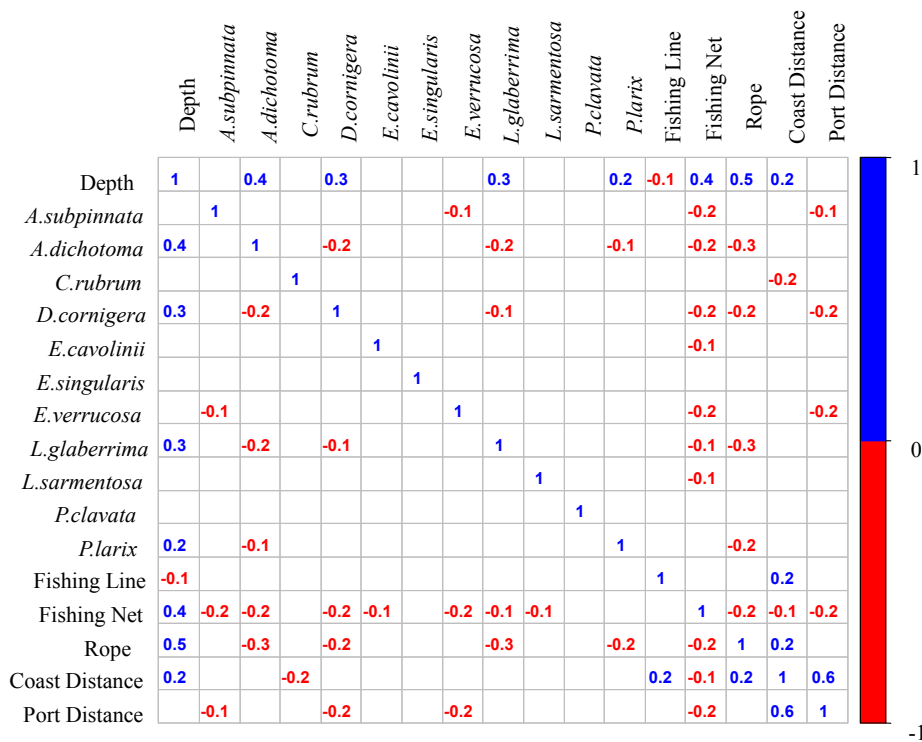
Fig. 8. Partial correlations matrix calculated on the whole dataset.

Regarding the partial correlations of DFGs calculated for each canyon system, the matrices of Fig. 9 point out that:

- in the Dramont Canyon (Fig. 9A) the presence of fishing nets is negatively correlated with that of *A. dicothoma* (r = - 0.54) and *D. cornigera* (r = - 0.41), and is positively partially correlated with depth (r = 0.60);

- in the Monaco Canyon (Fig. 9B) there are no statistically significant correlations.

- in the Bordighera Canyon (Fig. 9C) the presence of fishing nets is negatively correlated with that of *D. cornigera* (r = - 0.33), *E. verrucosa* (r = - 0.25) and *A. subpinnata* (r = - 0.23);

- in the Arma di Taggia site (Fig. 9D) the presence of fishing nets is negatively correlated with that of *C. rubrum* (r = - 0.24). The presence of fishing lines is negatively correlated with that of *E. verrucosa* (r = - 0.32) and *E. cavolinii* (r = - 0.29), with depth (r = - 0.30) and presence of ropes (r = - 0.25). The latter is also negatively correlated both with the presence of *C. rubrum* (r = - 0.25) and of fishing lines (r = - 0.25).

- in the Bergeggi Canyon (Fig. 9E) the presence of fishing nets is negatively correlated with the presence of *D. cornigera* (r = - 0.41) and the presence of ropes (r = - 0.46); the presence of ropes is negatively correlated with the presence of *D. cornigera* (r = - 0.66), *L. glaberrima* (r = - 0.66), *A. dicothoma* (r = - 0.65), *P. larix* (r = - 0.55) and with the presence of fishing nets (r = - 0.46).

A

	Depth	A.subpinnata	A.dichotoma	C.rubrum	D.cornigera	E.cavolinii	E.verrucosa	L.sarmentosa	P.clavata	Fishing Net	Coast Distance	Port Distance
Depth	1		0.7		0.4					0.6		
A.subpinnata		1										
A.dichotoma	0.7		1		-0.4					-0.5	-0.3	
C.rubrum				1							-0.3	
D.cornigera	0.4		-0.4		1					-0.4	-0.3	0.4
E.cavolinii						1						
E.verrucosa							1					
L.sarmentosa								1				
P.clavata									1			
Fishing Net	0.6		-0.5		-0.4					1		
Coast Distance			-0.3	-0.3	-0.3						1	1
Port Distance					0.4						1	1

B

	Depth	E.verrucosa	L.sarmentosa	P.clavata	Fishing Net	Coast Distance	Port Distance
Depth	1					-1	1
E.verrucosa		1					
L.sarmentosa			1				
P.clavata				1			
Fishing Net					1		
Coast Distance	-1					1	1
Port Distance	1					1	1

C

	Depth	A.subpinnata	C.rubrum	D.cornigera	E.cavolinii	E.verrucosa	L.sarmentosa	P.clavata	Fishing Net	Coast Distance	Port Distance
Depth	1									0.8	-0.7
A.subpinnata		1							-0.2		
C.rubrum			1								
D.cornigera				1					-0.3		
E.cavolinii					1						
E.verrucosa						1			-0.2	-0.2	0.2
L.sarmentosa							1				
P.clavata								1		0.2	-0.2
Fishing Net		-0.2		-0.3		-0.2			1		
Coast Distance	0.8					-0.2		0.2		1	1
Port Distance	-0.7			0.2				-0.2		1	1

D

	Depth	A.subpinnata	C.rubrum	D.cornigera	E.cavolinii	E.singularis	E.verrucosa	L.sarmentosa	P.clavata	Fishing Line	Fishing Net	Rope	Coast Distance	Port Distance
Depth	1		0.3		-0.2					-0.3			-0.3	
A.subpinnata		1	-0.3											
C.rubrum	0.3	-0.3	1				-0.3				-0.2	-0.3		
D.cornigera				1										
E.cavolinii	-0.2				1		-0.3	-0.3		-0.3				
E.singularis						1								
E.verrucosa			-0.3		-0.3		1	-0.3	-0.3					
L.sarmentosa					-0.3			1						
P.clavata							-0.3		1					
Fishing Line	-0.3				-0.3		-0.3			1		-0.2		
Fishing Net			-0.2								1			
Rope			-0.3							-0.2		1		
Coast Distance	-0.3												1	1
Port Distance													1	1

E

	Depth	A.dichotoma	D.cornigera	L.glaberrima	P.larix	Fishing Net	Rope	Coast Distance	Port Distance
Depth	1							0.9	-0.9
A.dichotoma		1	-0.5	-0.5	-0.4		-0.6		
D.cornigera		-0.5	1	-0.5	-0.4	-0.4	-0.7		
L.glaberrima		-0.5	-0.5	1	-0.4		-0.7		
P.larix		-0.4	-0.4	-0.4	1		-0.5		
Fishing Net			-0.4			1	-0.5		
Rope		-0.6	-0.7	-0.7	-0.5	-0.5	1		
Coast Distance	0.9							1	1
Port Distance	-0.9							1	1

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0

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Fig. 9. Partial correlations matrices calculated for each sites. (A) Dramont, (B) Monaco, (C) Bordighera, (D) Arma di Taggia and (E) Bergeggi.

Regarding the five most representative species (Table 3), the partial correlations underline that:

- *C. rubrum* occurrence is mostly hampered by fishing nets and ropes in Arma di Taggia site (Fig. 9D) and does not show any statistically significant correlation in the aggregate data (Fig. 8) and in Bordighera (Fig. 9C) and Dramont canyons (Fig. 9A);

- *D. cornigera* presence is mostly affected by fishing nets and ropes in the aggregate data (Fig. 8) and in Bergeggi Canyon (Fig. 9E) and by fishing nets both in Bordighera (Fig. 9C) and Dramont canyons (Fig. 9A). It does not show any statistically significant correlation in the sites of Arma di Taggia (Fig. 9D) and Monaco (Fig. 9B);

- *E. cavolinii* is mostly affected by fishing nets in the aggregate data (Fig. 8), by fishing lines in the Arma di Taggia site (Fig. 9D), and does not show statistically significant correlation both in Bordighera (Fig. 9C) and Dramont canyons (Fig. 9A);

- The presence of *E. verrucosa* presence is negatively correlated with that of fishing nets in the aggregate data (Fig. 8) and in Bordighera Canyon (Fig. 9C), with that of fishing lines in the Arma di Taggia site (Fig. 9D), and does not show statistically significant correlation in the canyons of Dramont (Fig. 9A) and Monaco (Fig. 9B).

- *P. clavata* presence does not show statistically significant correlations in the aggregate data matrix (Fig. 8) and in none of the matrices of the canyons where it was observed (Fig. 9A, B, C and D).

Discussion

A better understanding of the biological and ecological role as well as of threats and vulnerability of deep-sea environments such as canyons, is crucial for their sustainable governance. Only a limited number of the over 500 canyons recorded for the Mediterranean Sea (Würtz, 2012) has been investigated for their resident biota. With respect to the Western Mediterranean, the Spanish and French canyons are among the best known with respect to sessile macro- and megabenthos (Orejas *et al.*, 2009; Gori *et al.,* 2013; Fabri *et al.*, 2014), while lesser is known for Ligurian canyons (Tunesi *et al.*, 2001; Fanelli *et al.*, 2017). The Ligurian region comprehends 24 major canyons, out of 19 are along the Italian coasts, one in Monaco and four along the French coastline (Würtz, 2012; Fabri *et al.*, 2014). In this context, this study represents the first description of the deep assemblages of five Ligurian canyons' head and adjacent shelf areas.

Of the five investigated topographic features, all except one (Bergeggi), showed rich megabenthic communities mainly dominated by arborescent anthozoan forests, recognized as highly valuable and complex Mediterranean ecosystems both along the continental shelf and in deeper areas (Bo *et al.*, 2015; Gori *et al.*, 2017; Chimienti *et al.*, *in press*). This situation is related to a higher occurrence of

hardgrounds in those canyons with a shallower canyon head; hard sloping substrates are considered preferential habitats for coral forests formed by dense aggregations of gorgonians and black corals (Gori *et al.*, 2017). Additionally, it has to be noted that the deeper depth range investigated in Bergeggi was mainly outside the bathymetric distribution interval of the main recorded species, *E. cavolinii*, *E. verrucosa* and *P. clavata*.

A great effort was dedicated in investigating the structure, habitat preference and environmental status of the coral forests. The assemblages are multi-specific, mainly composed of gorgonians and only occasionally by antipatharians. Species show distinct habitat preferences: on average, in the canyon heads forests are found on moderately sloped sites, whereas, on the continental shelf they thrive on flatter surfaces. Slope and depth are among the abiotic drivers well recognized as environmental constraints of benthic settling that control the distribution of large filter-feeders (e.g.: Mortensen and Buhl-Mortensen, 2004; Davies and Guinotte, 2011; Angeletti *et al.*, *in press*, Lo Iacono *et al.*, *in press*): the mean slope values found are probably a compromise in relation to the local current movements, allowing specimens to prevent sedimentation and ensure a correct exposure to the water flow for the food supply. Moreover, slope can be considered an important factor in providing protection from bottom trawling, because this kind of fishing cannot be carry out on sloping sea bottoms (Fabri *et al.*, 2014). Canyons, as privileged environments for deep hydrodynamic circulation, are generally considered good fishing grounds (Revenga Martinez de Pazos, 2012). This assumption is based on the fishing footprints available for canyon ecosystems, but can be derived also on the base of the well-recognized role of animal forests in supplying food and protection attracting a rich associated fauna, including fish of commercial interest, thus enhancing the fishing exploitment of these areas (Cerrano *et al.*, 2010; D'Onghia *et al.*, 2012; Bo *et al.*, 2014; Galgani *et al.*, 2018). The occurrence of steep flanks and rocky outcrops in canyon areas (Fourt *et al.*, 2013) enhances the settling of coral forests that, indirectly, enhance fishing effort. Because of their steep profiles, canyons are generally protected from bottom trawling, but, on the other hand, are highly

485 exploited by artisanal and recreational fishermen, especially in the Ligurian context in which the

486 canyons' heads are relatively close to the coastline, hence accessible.

487 This study confirms the vulnerability of such ecosystems to fishing activities as demonstrated by the

488 high frequency of occurrence of DFGs in all investigated canyons and a high rate of entanglements

489 especially for large arborescent species (*P. clavata*) and fragile, calcareous ones (*D. cornigera* and *C.*

490 *rubrum*). As previously observed, the size of the colonies as well as the complexity of their canopies

491 or the fragility of their skeletons, greatly affect the catchability of conspicuous, structuring species,

492 hence their vulnerability (Sampaio *et al.*, 2012; Bo *et al.*, 2014; Mytilineou *et al.*, 2014; Cau *et al.*,

493 2017). The fragility of these species and the risk for their habitats due to the fishing activities

494 pressure, clearly emerged from the many negative indexes of the partial correlations calculated

495 between the presence of the species and that of the DFGs (Figs. 8 and 9A-E). This result points out

496 that the presence of all the species, with the exception of *P. clavata* and *E. singularis*, is negatively

497 affected by that of one or more types of DFGs. Considering the aggregate data (Fig. 8), the fishing

498 nets, that are the most numerous DFGs, seem to have the greatest impact. However, in the Bergeggi

499 Canyon and Arma di Taggia shelf, the DFGs that are more representative, and that have the major

500 number of negatively correlation with the occurrence of the species, are ropes and fishing lines,

501 respectively. Every canyon has a predominant DFGs typology, but whatever it is, its presence is

502 negatively correlated with that of one or more species, with the exception of Monaco where no

503 meaningful correlations were found. In the case of *P. clavata*, one of the most entangled species, the

504 partial correlation matrices are not statistically significant regarding the co-occurrence of specimens

505 *vs* DFGs. Considering that 1) in the studied areas specimens are surely affected by the presence of

506 DFGs (percentage of entangled specimens); 2) respect to the overall population, the colonies highly

507 damaged (presence of necrosis and/or epibiosis) are a small number; 3) no evidence of broken

508 colonies were found; and 4) the presence of the *P.clavata* is not correlated with the presence of

509 DFGs, we can speculate that *P. clavata* could have a certain degree of resilience respect to the fishing

activities, probably due to its flexible skeleton. DFGs, also, were found in sites moderately sloped which indicate the presence of rocky bottoms where the nets remain entangled.

The contribution of generic urban trash to the observed litter is minimal, whilst the majority is attributable to DFGs, especially nets and lines. Our results agree well with published results regarding the continental platform and slopes in the Mediterranean Sea (Fabri *et al.*, 2014; Bo *et al.*, 2014; Angiolillo *et al.*, 2015; Cau *et al.*, 2017). The Bordighera canyon system appears to be the most affected in respect to the abundance of litter and its impact on cnidarian colonies, followed by Arma di Taggia and Dramont. The Monaco canyon system is the less impacted by fishing litter, likely because of a reduced fishing effort there operated by the small local fleet, what guarantees the protection of its coral forests. Still, major differences are reported between Italian and French sites, probably ascribable to different socio-economic and cultural approaches to fishing activities, as well as to the body of the local fleets, besides local physiographic differences in the various canyon systems that may influence the actual exposure to fishing malpractices for their benthic ecosystems. A similar difference was highlighted by Fabri *et al.* (2014) when comparing the abundance of litter and typology of material between the Gulf of Lion's canyons and those in the French Ligurian Sea.

Conclusions

We have identified the occurrence of vulnerable coral forests in canyon systems and adjacent shelves of the Ligurian Sea. Although these canyon systems share a number of arborescent cnidarian species in common, they also display local differences in their compositions. Many such environments appear impacted at various degree by fishing, especially with respect to the local abundance of derelict fishing gears. We urge to implement specific abatement measures aimed at containing malpractices in the use of small-scale professional fishing gears in submarine canyons as well as promoting the identification of "Ecologically or Biologically Significant Marine Areas (EBSAs)" to protect and include in basin-scale protection networks.

Acknowledgements

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