



# Does the Bari Canyon (Central Mediterranean) influence the fish distribution and abundance?

Letizia Sion<sup>a,\*</sup>, Crescenza Calculi<sup>b</sup>, Francesca Capezzuto<sup>a</sup>, Roberto Carlucci<sup>a</sup>, Angela Carluccio<sup>a</sup>, Laura Cornacchia<sup>a</sup>, Porzia Maiorano<sup>a</sup>, Alessio Pollice<sup>b</sup>, Pasquale Ricci<sup>a</sup>, Angelo Tursi<sup>a</sup>, Gianfranco D'Onghia<sup>a</sup>

<sup>a</sup> Department of Biology, University of Bari Aldo Moro, LRU CoNISMa, Bari, Italy

<sup>b</sup> Department of Economics and Finance, University of Bari Aldo Moro, Bari, Italy

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## ABSTRACT

The objective of this study was to evaluate whether the Bari Canyon influences the distribution and abundance of fish fauna in the southern Adriatic Sea. Data were collected in the Bari Canyon and in an adjacent area on the continental slope during an experimental longline survey carried out in June 2015. A total of 19 fish species were collected (16 inside and 13 outside the canyon). Differences between the sites were evaluated by means of a set of univariate and multivariate methods (analysis of variance, permutational multivariate analysis of variance, non-metric multidimensional scaling). The abundance and biomass of the whole catch were significantly greater inside than outside the canyon. The most abundant species were the shark *Galeus melastomus* and the teleost fishes *Conger conger*, *Helicolenus dactylopterus*, *Merluccius merluccius*, *Pagellus bogaraveo* and *Phycis blennoides*. All these species were found to be more abundant in the canyon than in the adjacent area. However, a significantly greater abundance inside the canyon than outside was detected for *C. conger*, while *P. blennoides* showed both significantly greater abundance and biomass in the canyon than outside. *P. bogaraveo* was exclusively caught inside the canyon. *C. conger* and *P. blennoides* exhibited significant differences in their sizes between the canyon and the adjacent area: a greater number of both smaller and larger individuals were found in the canyon than on the open slope. Mature females and males were mostly observed in the canyon in all the most abundant species, with the exception of *P. blennoides* due to its autumn-winter spawning. The present study corroborates the role of the Bari Canyon as a refuge area and an Essential Fish Habitat for fish species exploited in the neighbouring fishing grounds, highlighting the need for conservation measures.

## 1. Introduction

Submarine canyons are geomorphic features along the continental margins (Fernandez-Arcaya et al., 2017). They act as conduits often connecting coastal or shelf waters to the deep sea through the transport of water masses, sediment, organic matter and materials of different nature and origin (Canals et al., 2006; Trincardi et al., 2007; Turchetto et al., 2007; Ramirez-Llodra et al., 2013; Pham et al., 2014). The downwelling currents which increase the availability of nutrients and trophic resources associated with the complex physical setting make canyons favourable habitats for filter and suspension feeders such as sponges and cold-water corals (CWC) (e.g. Orejas et al., 2009; Vetter et al., 2010; Huvenne et al., 2011; Miller et al., 2012; Angeletti et al., 2014; D'Onghia et al., 2015a), enhancing the abundance and diversity of benthic and benthopelagic fauna (e.g. De Leo et al., 2010; Ramirez-

Llodra et al., 2010a, 2010b; Farrugio, 2012). Canyons can act as feeding, spawning and recruitment areas for this type of fauna (e.g. Sardà et al., 1994, 2009; Brodeur, 2001; Etnoyer and Warrenchuck, 2007; Baker et al., 2012; Farrugio, 2012; Fabri et al., 2014; Fernandez-Arcaya et al., 2017) and can have ecological implications for populations during episodic events such as sunken drift macrophytes and sediment flushing (Okey, 1997, 2003) as well as dense water cascading (Company et al., 2008). The accumulation of phytodetritus, organic matter and trophic resources favours the occurrence of deposit feeders, scavengers and predators of different taxonomic groups (Vetter and Dayton, 1998, 1999; King et al., 2008; Ramirez-Llodra et al., 2010a; D'Onghia et al., 2015a, 2015b). It has also been shown that certain pelagic species are retained within the canyon, resulting in increased abundance and diversity (Gili et al., 1999; Albaina and Irigoien, 2007; Robison et al., 2010). The upwelling generated by the local water mass

\* Corresponding author.

E-mail address: [letizia.sion@uniba.it](mailto:letizia.sion@uniba.it) (L. Sion).

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dynamics enhances local primary productivity, influencing the food chain up to mammals and birds (e.g. Danovaro et al., 2010; Vella and Vella, 2012; Würtz, 2012). All these aspects, in addition to the high habitat heterogeneity, mean canyons have higher diversity and biomass than the adjacent slope outside the canyons (Rowe et al., 1982; Sardà et al., 1994; Gage et al., 1995; Vetter and Dayton, 1999; Ramirez-Llodra et al., 2010a, 2010b; Company et al., 2012; Farrugio, 2012; De Leo et al., 2014; Fernandez-Arcaya et al., 2017). However, some studies have shown no significant differences in biomass and abundance of benthic fauna between the continental slope outside the canyons and canyon habitats (Houston and Haedrich, 1984; Ramirez-Llodra et al., 2010b; Smith and Lindholm, 2016) or even lower biomass and abundance in the canyon (Maurer et al., 1994) and greater abundance only for some taxonomic groups, such as sea urchins (Vetter and Dayton, 1999). In the Catalan Sea (western Mediterranean), Tecchio et al. (2013) revealed higher diversity, but not biomass, inside the canyon than on the adjacent open slope, and a significantly different assemblage composition between the two habitats. Fish species compositions in the Baltimore and Norfolk canyons (U.S.) were not substantially different from the surrounding slopes (Ross et al., 2015). Quattrini et al. (2015), exploring the canyon-incised continental margin of the north-eastern United States, found that depth and broad-scale habitat significantly influenced demersal fish and decapod crustacean assemblages. In particular, species composition and/or diversity differed between soft-sedimented open-slope, cold-seep and canyon sites.

The Mediterranean Sea is a semi-enclosed basin characterized by more than 500 submarine canyons widespread along the continental margin (Harris and Whiteway, 2011). One of these Mediterranean canyons characterized by the presence of CWC, episodic cascading processes and habitat heterogeneity is off the city of Bari in the southern Adriatic Sea (Central Mediterranean) (Canals et al., 2009; Freiwald et al., 2009; Taviani et al., 2016). The role of this canyon in the sediment transport and water cascading processes has been documented (Ridente et al., 2007; Rubino et al., 2010; Trincardi et al., 2007; Turchetto et al., 2007; Verdicchio et al., 2007). Contributions to the knowledge on the distribution and abundance of benthic sessile species in the Bari Canyon (hereafter BC) have been reported in the last decade (Freiwald et al., 2009; Bo et al., 2012; Sanfilippo et al., 2013; Angeletti et al., 2014; D'Onghia et al., 2015a; Taviani et al., 2016). Quantitative data on composition and abundance of the fish fauna are reported in D'Onghia et al. (2015a, 2015b, 2016). The BC is well recognized at international level for its biodiversity and ecological role in the Mediterranean basin. A proposal for protection of the Mediterranean, called MedNet, envisages various geomorphological features, such as seamounts, escarpments, mud volcanoes, also including submarine canyons (Oceana, 2011). The BC is among the “jewels of the Mediterranean”, satisfying both EBSA (Ecologically and Biologically Significant Marine Area) (Marin and Aguilar, 2012) and VME (Vulnerable Marine Ecosystem) criteria (FAO, 2009).

The aim of this study is to compare the composition and abundance of fishes between the BC and an adjacent area on the outer continental slope of the southern Adriatic Sea, in order to reveal whether this canyon can influence the distribution of the fish fauna in the study area.

## 2. Materials and methods

### 2.1. Study area

The BC is a complex morphological structure that cuts through the SW Adriatic shelf in a west–east direction. It is 10 km wide, 30 km long and ranges between 200 and about 1000 m in depth. The BC consists of two main branches separated by a mounded relief, a slope-confined trough between 500 and 700 m in depth (Ridente et al., 2007; Trincardi et al., 2007). The BC plays an important role in dense-water cascading and particulate transport processes (Ridente et al., 2007; Trincardi et al., 2007; Turchetto et al., 2007; Verdicchio et al., 2007; Tesi et al.,

2008; Rubino et al., 2010) in relation to the complex hydrography of the Apulian margin (e.g. Manca et al., 2002; Civitarese et al., 2005; Budillon et al., 2010). By cascading and flowing across the slope, the dense waters have an impact on the sea floor and increase the complexity of the margin morphology, generating near-bottom currents that erode and deposit large amounts of fine-grained sediment. These features drive suspended organic matter providing a crucial source for the biological activity on the slope (Taviani et al., 2005; Verdicchio and Trincardi, 2006; Trincardi et al., 2007; Turchetto et al., 2007; Taviani et al., 2016). The BC hosts a diverse community of cnidarians, sponges, serpulids, bryozoans and fishes (Freiwald et al., 2009; Bo et al., 2012; Sanfilippo et al., 2013; Angeletti et al., 2014; D'Onghia et al., 2015a, 2015b, 2016). In particular, the BC is one of the six provinces characterized by the two main framework-forming CWC species, *Madrepora oculata* and *Lophelia pertusa*, so far identified in the Mediterranean Sea (Taviani et al., 2017).

In the southern Adriatic Sea, around the BC, there are several fisheries operating with different fishing techniques and with more than 1000 fishing vessels (Mannini and Sabatella, 2015). The small-scale fisheries have the greatest number of vessels overall, whereas the trawlers account for the greatest gross tonnage, engine power and fishing effort (Lembo and Donnalioia, 2007; Spedicato et al., 2017). The most abundant demersal resources along the southern Adriatic Sea are the hake (*Merluccius merluccius*) between the shelf and upper slope and the red mullet (*Mullus barbatus*) in coastal waters, but also the crustaceans such as the Norway lobster (*Nephrops norvegicus*), deep water rose shrimp (*Parapenaeus longirostris*) and cephalopods including the horned octopus (*Eledone cirrhosa*) and the broadtail shortfin squid (*Illex coindetii*) (Spedicato et al., 2017). The impact of fishing in the BC is almost exclusively due to longline, with occasional fishing operations with a variable number of vessels operating according to the season. Fishermen sometimes deploy longlines to catch large individuals of valuable species, but they often lose or damage their fishing gear. Trawling cannot be carried out within this canyon due to its steep walls and very complex topography.

### 2.2. Survey methodology

Experimental longline surveys were carried in the BC and in an adjacent area (thereafter AA) on the continental slope (Fig. 1) during June 2015. A commercial fishing vessel was hired. It had the following characteristics: LFT 18.0 m, GRT 9.98 t; engine power 124 kW. The fishing vessel was equipped with a monofilament longline (Table 1), the selectivity of which mostly depends on the size of the hooks. The size and type of hook and bait are important gear parameters affecting the species selectivity of longlines. The type of hooks employed were J-hook 7 and J-hook 10. This latter was used with the aim of catching the blackspot seabream *Pagellus bogaraveo* which seems to be a fish species associated with the presence of corals (D'Onghia et al., 2010, 2011, 2012, 2015b).

During the survey twenty longline hauls, ten for each habitat (BC and AA), were carried out; the depth ranges were 314–608 m in the BC and 296–600 m in the AA (Table 2). Each day, 3 longlines were employed (2 with number 7 J-hooks and 1 with number 10 J-hooks); the soak time lasted about 4 h on average and the fishing effort was 1500 hooks/day.

Total length (TL) (mm), weight (g) and sex were recorded for each specimen collected.

### 2.3. Data analysis

The catch per unit effort (CPUE) in number (N) and biomass (kg) were calculated as relative indices of abundance and biomass respectively (CPUE = catch in N/1000 hooks and kg/1000 hooks on the longline). With the aim of investigating differences between the sampling stations in terms of the CPUE, the average CPUE value was

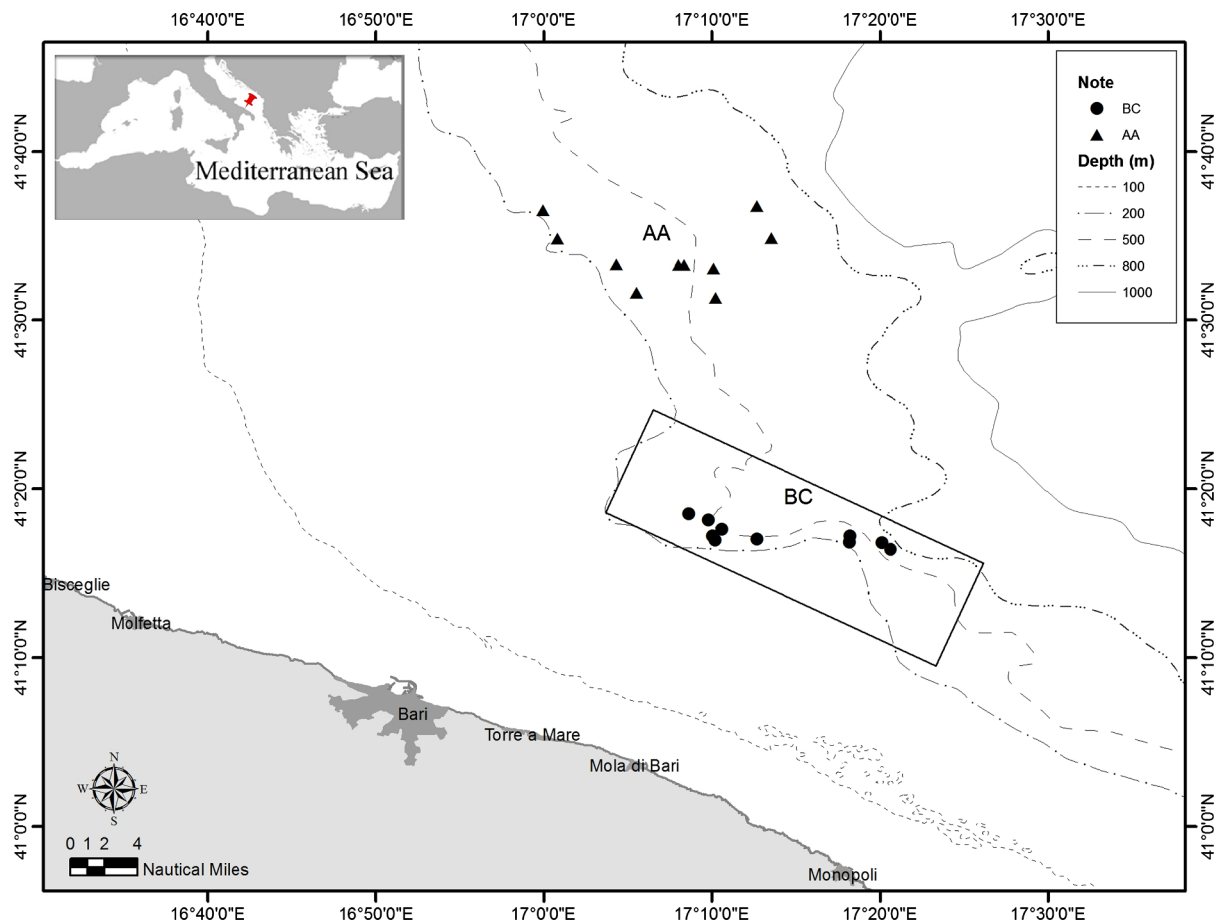


Fig. 1. Map of the study area with indication of the sampling stations in the Bari Canyon (BC) and in the Adjacent Area (AA).

Table 1

Technical characteristics of the bottom longline used in the Bari Canyon and in the Adjacent Area.

Type of gear	Longline_monofilament
Length deployed (m)	~3000
Mean soak time (hours)	4.18 ± 0.23
Bait	Fresh <i>Sardina pilchardus</i>
Hook type	J-hook
Hook size	7/0 and 10/0
Number of hooks	500/line
Diameter of mainline (mm)	6
Material of mainline	Synthetic fibre
Material of snoods	Nylon
Snood distance (m)	5
Length of snoods (m)	2.5
Floats/weights	Floats are attached to a big cement weight (about 5 kg) by means of a rope at the beginning and end of the main line

calculated as follows:  $\Sigma CPUE_i/n$ ; where  $CPUE_i$  is the catch per unit effort at each station and  $n$  is the number of stations in the survey. Box-plots of the CPUE in abundance and biomass of all fish species captured were obtained. Box-plots of CPUEs and the length-frequency distributions were obtained for the most abundant fish species. Sex and maturity stages of the gonads were recorded for a representative subsample of individuals according to Stehmann's (2002) and Nikolsky's (1963) macroscopic scales for Chondrichthyes and Osteichthyes, respectively. The features of the gonads in terms of size, shape, thickness and colour were used to classify three main maturity stages: immature,

Table 2

Sampling stations, with average depth (m) and geographic coordinates, carried out in the Bari Canyon (BC) and in the Adjacent Area (AA) during June 2015.

Station	Habitat	Average depth (m)	START		END	
			Lat. (N)	Lon. (E)	Lat. (N)	Lon. (E)
1	BC	492	41°18.556	17°08.654	41°18.534	17°08.871
2	BC	376	41°16.850	17°18.204	41°16.551	17°18.740
3	BC	338	41°17.125	17°10.048	41°16.746	17°10.348
4	BC	608	41°17.053	17°12.681	41°17.058	17°13.218
15	BC	601	41°16.294	17°19.389	41°16.023	17°20.966
16	BC	442	41°18.186	17°09.820	41°18.208	17°09.913
17	BC	314	41°17.244	17°10.050	41°17.188	17°10.108
18	BC	543	41°17.621	17°10.593	41°17.486	17°11.937
19	BC	544	41°17.245	17°18.218	41°17.136	17°18.619
20	BC	583	41°15.909	17°19.909	41°15.840	17°19.966
5	AA	421	41°33.320	17°04.340	41°32.717	17°04.821
6	AA	420	41°31.644	17°05.524	41°31.249	17°05.686
7	AA	494	41°33.289	17°08.038	41°33.210	17°07.963
8	AA	500	41°33.299	17°08.385	41°33.197	17°08.244
9	AA	544	41°33.092	17°10.106	41°32.987	17°10.276
10	AA	561	41°31.349	17°10.242	41°31.233	17°01.370
11	AA	296	41°36.533	16°59.960	41°36.470	16°59.968
12	AA	301	41°34.842	17°00.821	41°34.866	17°00.769
13	AA	598	41°36.771	17°12.699	41°36.628	17°12.889
14	AA	600	41°34.885	17°13.547	41°34.775	17°13.728

maturing, mature (including also the spent stage).

The effects of the *habitat* and *tool* factors on the relative abundance (N/1000 hooks) and biomass (kg/1000 hooks) of all species captured was investigated by means of boxplots and PERmutational Multivariate Analysis Of Variance (PERMANOVA) (Anderson, 2017). The latter is a

non-parametric Analysis of Variance based on a permutational procedure applied on Bray-Curtis dissimilarity matrices of the relative abundances of all considered species. Furthermore, a complementary analysis based on non-metric MultiDimensional Scaling (nMDS, Borcard et al., 2011) was implemented in order to highlight potential patterns or aggregations of species relative abundances, in a reduced dimension space. The same analysis was carried out considering only the six most abundant species for which the effects of the *habitat* and *tool* factors were also investigated individually using ANOVA (ANalysis Of VAriance).

The difference in the size between individuals collected in the canyon and those collected in the adjacent area was tested by means of the Wilcoxon test (Hollander et al., 2014).

### 3. Results

#### 3.1. Fish fauna composition and abundance

A total of 19 fish species were collected during the survey, 16 in the canyon and 13 in the adjacent area outside the canyon. No coral by-catch occurred. Considering the species with a demersal habitat, the teleost fish *Trigla lyra* represents a new record for the BC. The indices of abundance (N/1000 hooks) and biomass (kg/1000 hooks) were greater inside than outside the canyon, although a high variability in the catch was observed (Table 3, Fig. 2A). CPUEs, both in number and weight, obtained from J-hook 7 were greater than those obtained using J-hook 10 (Fig. 2B). PERMANOVA analysis (Table 4) provided significant differences between abundances for both areas and tools, while for biomass significant differences were only observed between the two investigated areas. Ordination of the stations by means of nMDS is presented in Fig. 3, from which the separation between the two areas is clearer for the relative abundance than for biomass.

The number of individuals captured was greater than 10/1000 hooks in both examined areas for the following species: *Galeus melastomus*, *Conger conger*, *Helicolenus dactylopterus*, *Merluccius merluccius*, *Pagellus bogaraveo* and *Phycis blennoides*. The highest abundance and biomass indices were detected for the blackmouth catshark (*Galeus*

*melastomus*) and the European hake (*Merluccius merluccius*), respectively. Other abundant species were the European conger (*Conger conger*), the blackbelly rosefish (*Helicolenus dactylopterus*), the greater forkbeard (*Phycis blennoides*) and the blackspot seabream (*Pagellus bogaraveo*). This latter species was exclusively collected inside the canyon and all these species were found to be more abundant, both in abundance and biomass, in the BC than in the AA (Table 3, Figs. 4 and 5). However, significantly greater abundance in the canyon than in the adjacent area were only observed for *C. conger* and *P. blennoides* (Fig. 4, Table 5) while significantly greater CPUEs in biomass in the canyon than in the adjacent area were only detected for *P. blennoides* (Fig. 5, Table 6). Significant differences in abundance and biomass indices between the two types of hooks were only obtained for *G. melastomus* (Fig. 6, Table 7, Fig. 7, Table 8).

#### 3.2. Size distribution and maturity

The length-frequency distributions of the most abundant species are reported in Fig. 8. Comparable size distributions were observed for *G. melastomus*, *H. dactylopterus* and *M. merluccius* inside and outside the BC, while the range of sizes for *C. conger* and *P. blennoides* was significantly broader inside the canyon than in the adjacent area (for *C. conger*,  $W = 109.5$ ,  $p = 0.004$ ; for *P. blennoides*,  $W = 300$ ,  $p < 0.001$ ). For these two species both small and large sizes were mostly found within the canyon. *P. bogaraveo* was exclusively collected in the BC with sizes between 184 and 364 mm TL.

The maturity stages of the gonads, examined for each sex of the most abundant fish species in the BC and AA, are reported in Fig. 9. All maturity stages of the gonads were observed in all the six most abundant species, with the exception of *P. blennoides* which was only captured with a noteworthy number of immature and maturing females in the BC. Mature individuals of both females and males in all other species were exclusively found in the BC, whereas only for *G. melastomus* and *H. dactylopterus* were mature individuals of both sexes also found in the AA. In *M. merluccius* no males at any maturity stages were collected in the AA. In *P. bogaraveo* immature, maturing and mature individuals were only caught in the BC.

**Table 3**

Average CPUE (N/1000 hooks and kg/1000 hooks) per species and average total CPUE obtained in the Bari Canyon (BC) and in the Adjacent Area (AA) during June 2015 (s.d. = standard deviation).

	N/1000 hooks				kg/1000 hooks			
	BC		AA		BC		AA	
	Average	± s.d.	Average	± s.d.	Average	± s.d.	Average	± s.d.
<b>Chondrichthyes</b>								
<i>Chimaera monstrosa</i>	0.40	0.84	–	–	0.32	0.68	–	–
<i>Etmopterus spinax</i>	1.00	1.70	1.00	1.41	0.10	0.19	0.10	0.17
<i>Galeus melastomus</i>	30.80	26.03	27.40	14.82	9.34	6.01	6.79	3.24
<i>Pteroplatytrygon violacea</i>	0.40	0.84	1.40	1.90	0.67	1.44	3.35	4.69
<i>Scyliorhinus canicula</i>	0.20	0.63	–	–	0.07	0.22	–	–
<b>Osteichthyes</b>								
<i>Brama brama</i>	1.00	1.94	0.20	0.63	1.72	3.28	0.52	1.64
<i>Conger conger</i>	5.20	4.83	1.40	1.65	11.18	16.00	4.78	7.37
<i>Coryphaena hippurus</i>	–	–	0.40	0.84	–	–	1.70	3.68
<i>Helicolenus dactylopterus</i>	22.00	17.05	18.60	22.98	4.81	4.14	4.25	5.11
<i>Lepidopus caudatus</i>	–	–	0.40	1.26	–	–	0.73	2.30
<i>Merluccius merluccius</i>	8.60	6.11	6.60	5.58	15.32	9.77	7.54	5.13
<i>Micromesistius pouassou</i>	1.80	3.19	0.40	0.84	0.41	0.68	0.11	0.23
<i>Pagellus bogaraveo</i>	3.20	6.68	–	–	1.59	3.42	–	–
<i>Phycis blennoides</i>	12.60	11.93	1.40	1.65	7.71	8.52	0.79	1.05
<i>Polyprion americanus</i>	–	–	0.20	0.63	–	–	0.48	1.52
<i>Scorpaena elongata</i>	0.40	1.26	–	–	0.40	1.26	–	–
<i>Trachurus picturatus</i>	0.20	0.63	–	–	0.10	0.30	–	–
<i>Trigla lyra</i>	0.40	0.84	–	–	0.25	0.54	–	–
<i>Xiphias gladius</i>	0.20	0.63	0.40	0.84	2.54	8.03	1.50	3.22
Average Total CPUE	88.40	40.78	59.80	32.92	54.05	31.49	32.62	10.82

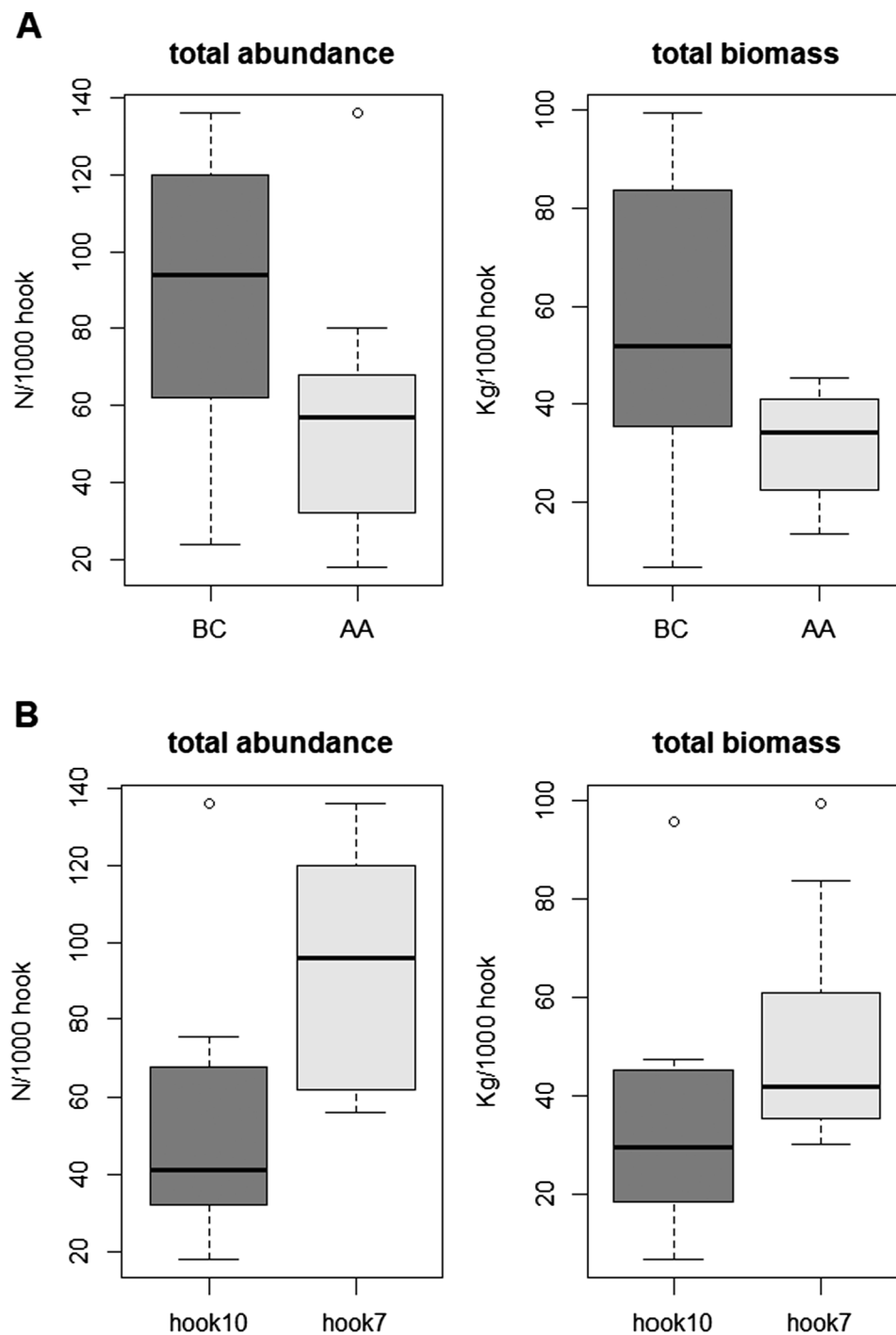


Fig. 2. Box-plots of the total abundance and the total biomass indices for habitat (A) and sampling tool (B). BC = Bari Canyon, AA = Adjacent Area.

#### 4. Discussion and conclusions

The present study is the first that aims to compare the distribution of fishes within the BC *versus* an adjacent area on the continental slope of the southern Adriatic Sea. The data suggest a canyon effect since both the abundance and biomass of the whole catch were significantly greater inside the canyon than on the open slope. In addition, all the most abundant species were captured with greater abundance, both in number and weight, inside the BC than in the AA, even though a significant output of the statistical analysis was only detected for *P. blennoides* and *C. conger*, while *P. bogaraveo* was only collected inside the canyon. This teleost fish confirms its exclusive occurrence in complex and heterogeneous habitats with cold-water corals (D'Onghia et al.,

2011, 2012, 2015b; Carluccio et al., 2014).

The size of the hook only influenced the capture of the blackmouth catshark, most probably due to the sub-ventral position of its mouth. In fact, the difference in behaviour between the species when biting the bait may partly be explained by a difference in mouth size (Løkkeborg et al., 1989). Considering that only one type of bait (*Sardina pilchardus*) was used in this study, most probably the difference observed in *G. melastomus* could be related only to the different size of hook. If this shark makes several attacks on the same bait, as observed in other fish species (Løkkeborg et al., 2014), the bait becomes smaller and the fish may finally bite the hook and be caught. Thus, the capture becomes most probable with a larger hook as observed in this and other studies (Løkkeborg and Bjørndal, 1992; Løkkeborg et al., 2014).



**Table 4**

PERMANOVA results based on Bray-Curtis dissimilarity matrices of abundance (A) and biomass indices (B): marginal effects of *habitat* and sampling *tool* factors on differences between inside and outside the BC in terms of fish assemblages. The table gives the degrees of freedom (df), the sums of squares (SS), the mean squares (MS), the values of the pseudo-F statistics and the P-values. Number of permutations 4999.

	df	SS	MS	pseudo-F	p-value
<b>A</b>					
Habitat	1	0.237	0.237	2.577	< 0.001
Tool	1	0.340	0.340	3.694	< 0.001
Residuals	17	1.564	0.092		
Total	19	2.140			
<b>B</b>					
Habitat	1	0.271	0.271	2.101	< 0.05
Tool	1	0.245	0.245	1.900	0.059
Residuals	17	2.189	0.130		
Total	19	2.704			

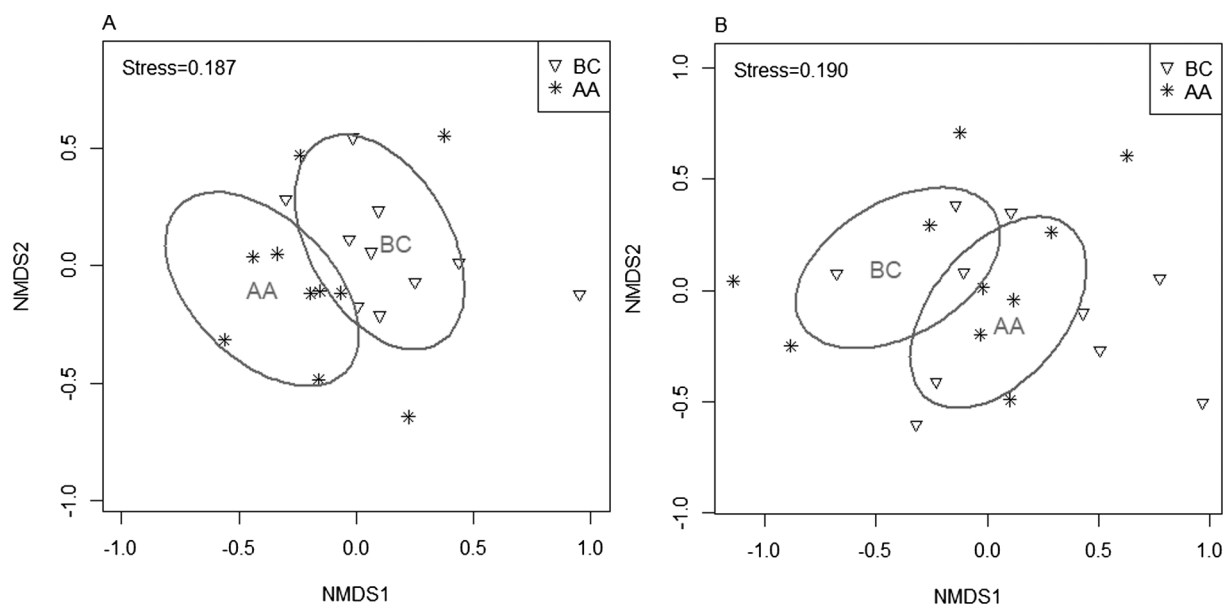
The greatest abundance of *G. melastomus*, *C. conger*, *H. dactylopterus*, *M. merluccius*, *P. bogaraveo* and *P. blennoides* confirms previous observations on the abundance of these fishes in the Bari Canyon (D'Onghia et al., 2016) and in other Mediterranean submarine canyons (Sabatini et al., 2007; Ramirez-Llodra et al., 2010b; Farrugio, 2012; Fabri et al., 2014). In particular, although no comparison can be carried out due to the different fishing gears used in the various studies, the species *G. melastomus*, *H. dactylopterus* and *P. blennoides* were the most frequently captured in the Quirra Canyon (Tyrrhenian Sea) (Sabatini et al., 2007). At the head of the Blanes submarine canyon *C. conger* and *P. blennoides* were the fish species captured with highest biomass (Ramirez-Llodra et al., 2010b). From the canyons in the eastern part of the Gulf of Lions, *G. melastomus* and *M. merluccius* were among the most abundant species (Farrugio, 2012). *G. melastomus*, *H. dactylopterus* and *P. blennoides* were the most frequently observed fish species in French Mediterranean submarine canyons (Fabri et al., 2014).

Although the used gear is not suitable for the capture of small individuals, in *P. blennoides* and *C. conger* a significantly greater number of both smaller and larger individuals were found in the Bari canyon than in the AA, confirming previous observations (D'Onghia et al., 2016). In this respect, Fernandez-Arcaya et al. (2013) report evidence

of juveniles of some deep-sea fishes (*Phycis blennoides* amongst others) that concentrate in the benthic intermediate nepheloid layers of the Blanes canyon which acts as a nursery area for these species. A noteworthy number of juveniles of *H. dactylopterus*, *M. merluccius* and *P. blennoides* have also been collected in the complex and heterogenous coral habitat of the Santa Maria di Leuca CWC province (northern Ionian Sea) (D'Onghia et al., 2010). Juveniles of *G. melastomus* and *H. dactylopterus* have also been collected at other CWC sites along the Apulian margin (D'Onghia et al., 2016). These two fishes are also the most common fish species caught close to corals in the eastern Ionian (Mytilineou et al., 2014).

Mature individuals were mostly collected in the canyon, corroborating previous observations (D'Onghia et al., 2016). The fact that during this study no mature individuals of *P. blennoides* were collected is due to the autumn-winter spawning of this fish (Matarrese et al., 1998). The presence of maturing, mature and juvenile individuals of different species would confirm that the Bari canyon acts as an Essential Fish Habitat (EFH) (Capezzuto et al., 2018b), that is “those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity” (Rosenberg et al., 2000). As reported in D'Onghia et al. (2016), this canyon, like the CWC sites distributed along the Apulian margin, is exposed to lower fishing pressure than neighbouring fishing grounds because of its complex topography. Thus, it can be considered both a refuge area and a renewal site for fish populations in relation to both the spill-over effect of individuals and the thistledown effect of eggs and larvae, which might contribute to the renewal of stocks in neighbouring fishing grounds (D'Onghia et al., 2016; Capezzuto et al., 2018b). In this regard, some nursery areas for hake have been identified near the BC, in a depth range between 100 and 500 m (Carlucci et al., 2009; Colloca et al., 2015; Druon et al., 2015). Moreover, the recovery of harvested populations that support fishing can be seen as an ecosystem service provided by the Bari canyon (Capezzuto et al., 2018a). This is even more important considering the overfishing condition of many demersal resources, such as *M. merluccius*, which is a species listed as Vulnerable on the Mediterranean IUCN Red List (Di Natale et al., 2011) and as Near Threatened on the Italian IUCN Red List (Relini et al., 2017). This fish, which is the most abundant demersal species in the Mediterranean, including the southern Adriatic (e.g. Marano et al., 1998; Carlucci et al., 2009; Spedicato et al., 2017), has been exploited since historical times.

Several studies in the Atlantic report the occurrence of the same



**Fig. 3.** nMDS ordination plot of the Bray-Curtis dissimilarity matrix of the abundance (A) and biomass (B) indices per species and per station distinguishing between the Bari Canyon (BC) and the Adjacent Area (AA). Habitat groups are identified by ellipses (90% confidence limit).

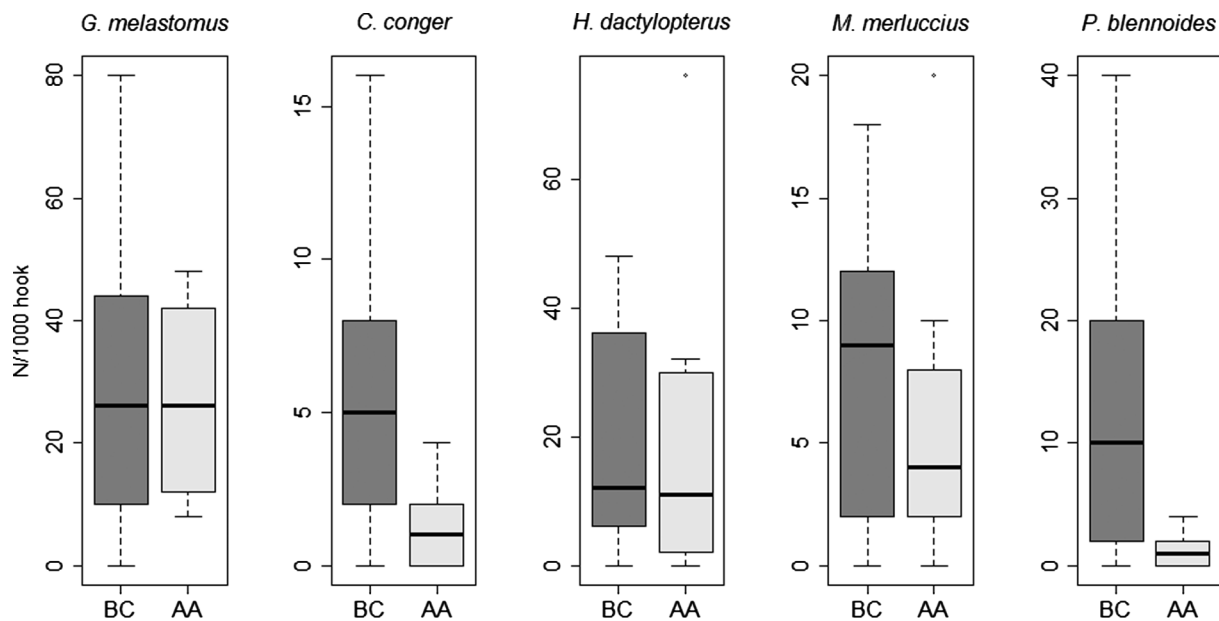


Fig. 4. Box-plots of selected species abundances in the Bari Canyon (BC) and in the Adjacent Area (AA). The solid horizontal line corresponds to the median value.

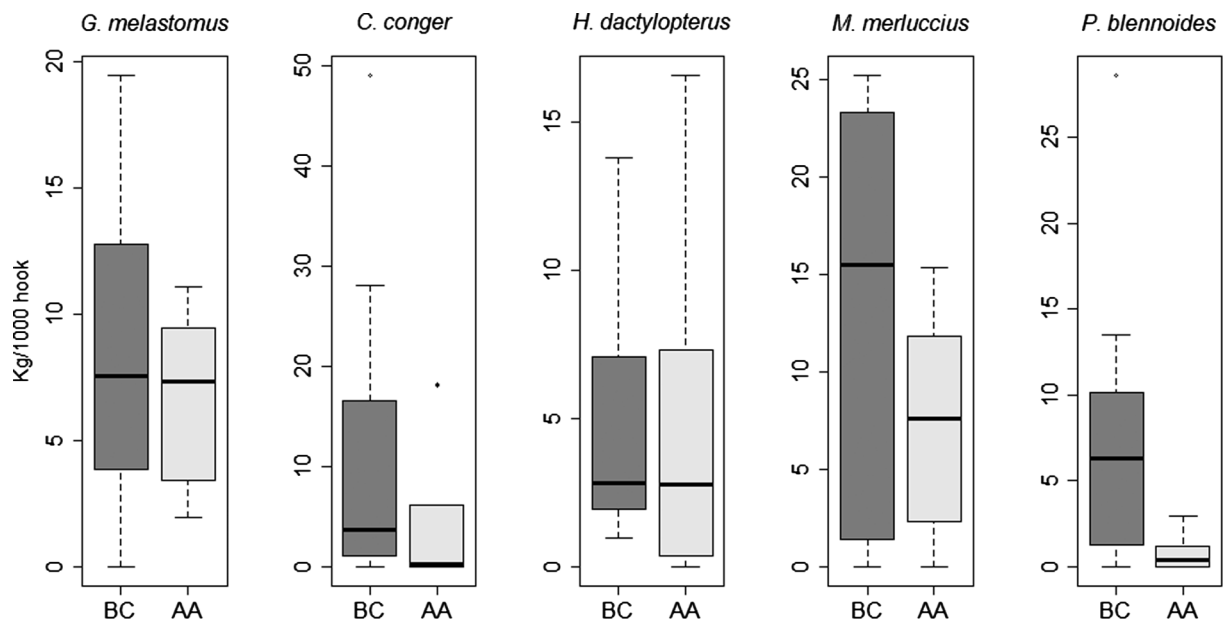


Fig. 5. Box-plots of selected species biomass in the Bari Canyon (BC) and in the Adjacent Area (AA). The solid horizontal line corresponds to the median value.

Table 5

ANOVA results for species abundances considering the habitat effect. The table shows the degrees of freedom (df), the sums of squares (SS), the mean squares (MS), the values of the F-statistics and the p-values (significant  $p < 0.05$ ).

		df	SS	MS	F	p-value
<i>G. melastomus</i>	Habitat	1	58.00	57.80	0.13	0.72
	Residuals	18	8074.00	448.60		
<i>C. conger</i>	Habitat	1	72.20	72.20	5.55	<b>0.03</b>
	Residuals	18	234.00	13.00		
<i>H. dactylopterus</i>	Habitat	1	24.00	24.02	0.06	0.82
	Residuals	18	7738.00	429.90		
<i>M. merluccius</i>	Habitat	1	33.80	33.80	0.93	0.35
	Residuals	18	656.40	36.47		
<i>P. blennoides</i>	Habitat	1	627.20	627.20	8.65	<b>0.01</b>
	Residuals	18	1304.80	72.50		

Table 6

ANOVA results for species biomass considering the habitat effect. The table contains the degrees of freedom (df), the sums of squares (SS), the mean squares (MS), the values of the F-statistics and the p-values (significant  $p < 0.05$ ).

		df	SS	MS	F	p-value
<i>G. melastomus</i>	Habitat	1	13.10	13.12	0.51	0.48
	Residuals	18	462	25.67		
<i>C. conger</i>	Habitat	1	204.80	204.80	1.32	0.27
	Residuals	18	2792.10	155.10		
<i>H. dactylopterus</i>	Habitat	1	1.60	1.59	0.07	0.79
	Residuals	18	388.80	21.60		
<i>M. merluccius</i>	Habitat	1	195.10	195.10	2.90	0.11
	Residuals	18	1211.40	67.30		
<i>P. blennoides</i>	Habitat	1	240.10	240.10	6.51	<b>0.02</b>
	Residuals	18	663.80	36.88		

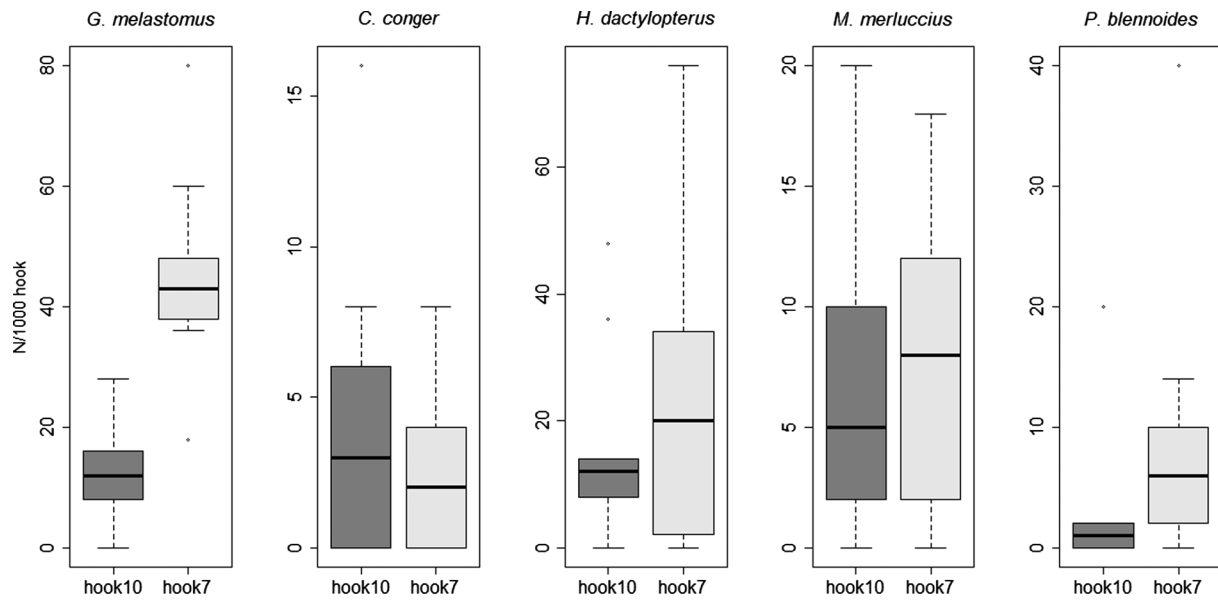


Fig. 6. Box-plots of selected species abundances for each sampling tool. The solid horizontal line corresponds to the median value.

Table 7

ANOVA results for species abundances considering the sampling tool effect. The table includes the degrees of freedom (df), the sums of squares (SS), the mean squares (MS), the values of the F-statistics and the p-values (significant  $p < 0.05$ ).

		df	SS	MS	F	p-value
<i>G. melastomus</i>	Tool	1	5184.00	5184.00	31.66	< 0.001
	Residuals	18	2948.00	164.00		
<i>C. conger</i>	Tool	1	9.80	9.80	0.60	0.45
	Residuals	18	296.40	16.47		
<i>H. dactylopterus</i>	Tool	1	304	304.2	0.73	0.40
	Residuals	18	7458	414.3		
<i>M. merluccius</i>	Tool	1	9.80	9.80	0.26	0.62
	Residuals	18	680.40	37.80		
<i>P. blennoides</i>	Tool	1	115.20	115.20	1.14	0.30
	Residuals	18	1816.80	100.90		

Table 8

ANOVA results for species biomass considering the sampling tool effect. The table shows the degrees of freedom (df), the sums of squares (SS), the mean squares (MS), the values of the F-statistics and the p-values (significant  $p < 0.05$ ).

		df	SS	MS	F	p-value
<i>G. melastomus</i>	Tool	1	249.40	249.42	19.89	< 0.001
	Residuals	18	225.70	12.54		
<i>C. conger</i>	Tool	1	16.40	16.36	0.10	0.76
	Residuals	18	2980.50	165.58		
<i>H. dactylopterus</i>	Tool	1	33.20	33.20	1.67	0.21
	Residuals	18	357.20	19.84		
<i>M. merluccius</i>	Tool	1	31.20	31.24	0.41	0.53
	Residuals	18	1375.30	76.40		
<i>P. blennoides</i>	Tool	1	52.20	52.20	1.10	0.31
	Residuals	18	851.70	47.31		

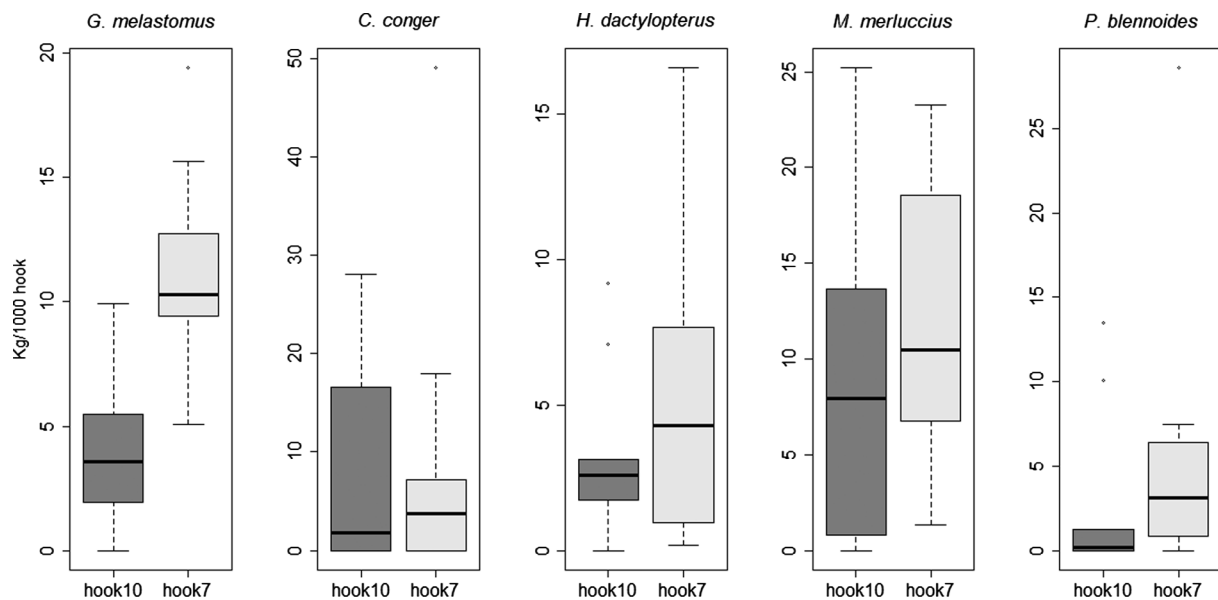


Fig. 7. Box-plots of selected species biomass for each sampling tool. The solid horizontal line corresponds to the median value.



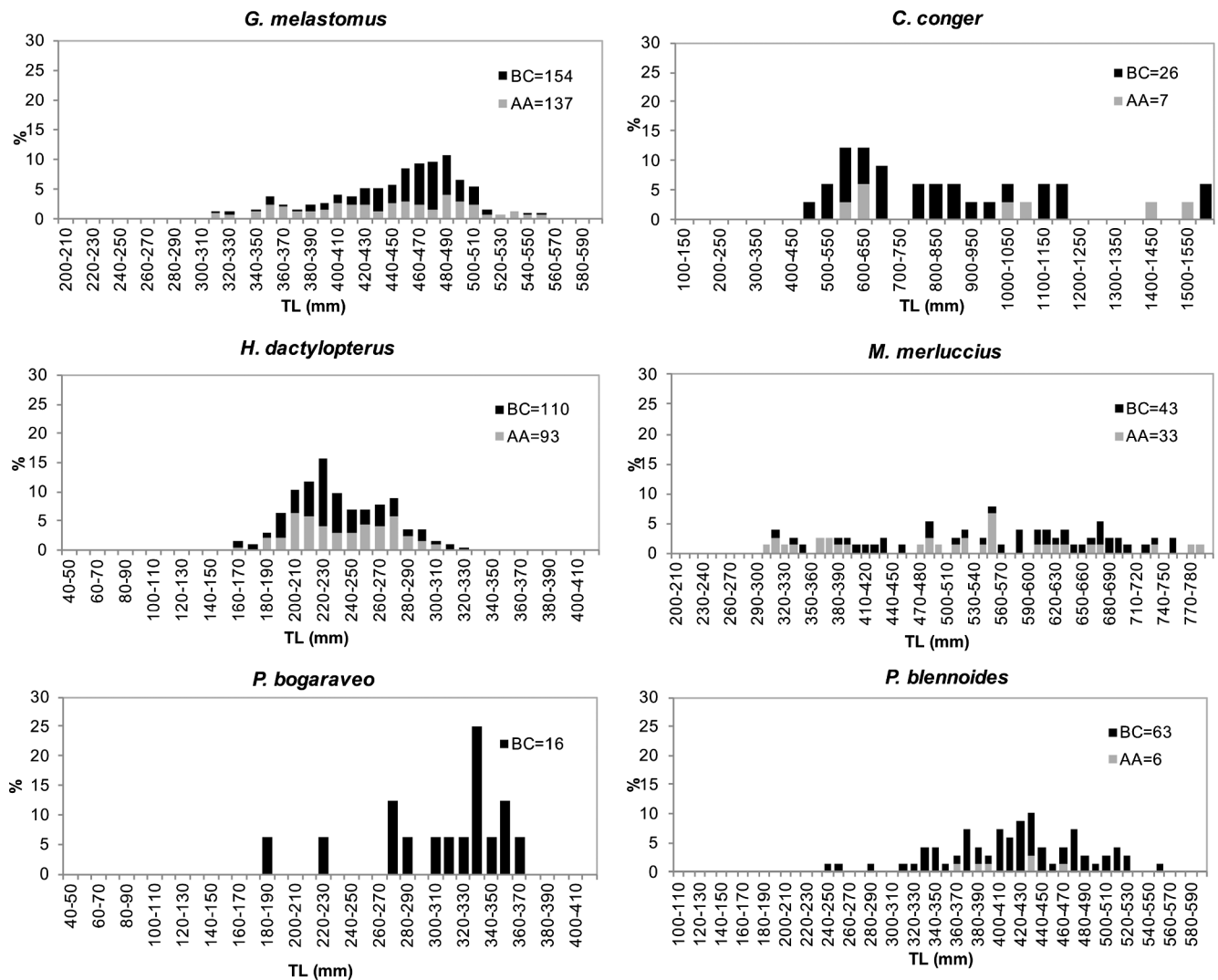


Fig. 8. Length-frequency distribution of the most abundant fish species collected in the Bari Canyon (BC) and in the Adjacent Area (AA).

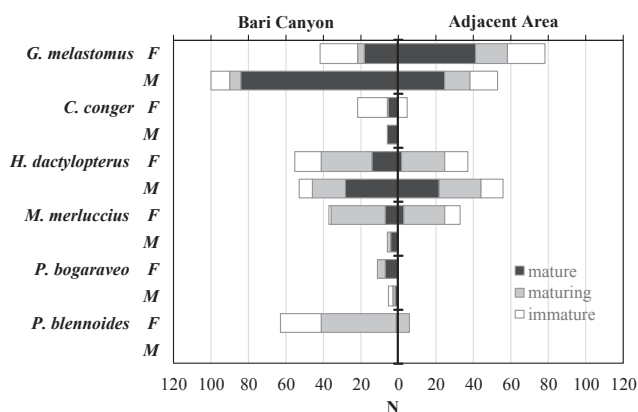


Fig. 9. Number of individuals by maturity stages of the gonads, for females (F) and males (M), of the most abundant fish species collected in the Bari Canyon and in the Adjacent Area.

species found in the present study, which found shelter, feeding and spawning sites in coral habitats and canyons (D'Onghia, 2018). For example, *G. melastomus* has been observed on *Lophelia* reefs (Roberts et al., 2008; Duran Muñoz et al., 2009; Kutti et al., 2014). Egg cases of *G. melastomus* have been found nested in live *Lophelia pertusa* corals at

depths between 165 and 172 m in the Mingulay Reef Complex (in the Sea of the Hebrides west of Scotland) and the mean abundance of this shark was six times higher in trawl sets located nearer a coral reef than those located further away (Henry et al., 2013). *C. conger* has been observed as a large opportunistic predator living and foraging close to rocky areas where it finds refuge during the day (Morato et al., 1999; Xavier et al., 2010). *H. dactylopterus* has been observed to use a wide range of habitats, including CWC habitats and submarine canyons (e.g. Uiblein et al., 2003; Costello et al., 2005; Ross and Quattrini, 2007, 2009; Soffker et al., 2011; Biber et al., 2014; Milligan et al., 2016). On hard substrate and *Lophelia* coral biotope in the northern Gulf of Mexico (Vioska Knoll), Sulak et al. (2007) observed, among the most dominant fish species, *H. dactylopterus* as a sit-and-wait ambush meso-carnivore and *C. oceanicus* as an ambush predator. *H. dactylopterus* and *G. melastomus* have been observed in different types of macro-habitat, including coral rubble, coral framework and rock macro-habitats on Hatton Bank (Roberts et al., 2008). The former species is also commonly observed at Rockall Bank sitting relatively motionless on top of corals. The association of this fish with the coral framework can be explained by the fact that it is considered a protection seeker (Biber et al., 2014). *P. blennoides* has been observed among the dominant fish species in coral habitats of the Belgica Mound Province (Lavaleye et al., 2017; Linley et al., 2017).

From all the above, the Bari Canyon, like most Mediterranean canyons, can be said to play an important role as a refuge and EFH for

many species, including those of fishing interest. To date, apart from the Gulf of Lions, there are no protection measures in place for Mediterranean submarine canyons (Marin and Aguilar, 2012), although UNEP-MAP-RAC/SPA (2010) suggests that canyons, together with other deep-sea features, should be protected through implementation of a Precautionary Principle as they are great reservoirs of biodiversity. The role of canyons and CWC ecosystems in marine biodiversity highlights the need for a representative network of Marine Protected Areas in the Mediterranean (Tudela et al., 2004; de Juan and Leonart, 2010; Micheli et al., 2013 and references therein).

The present study highlights the role of the Bari Canyon as an EFH for several fish species, providing further data for the establishment of a Fisheries Restricted Area (FRA), as recently proposed at the Working Group on VME held in Malaga (2017) and at the AdriaMed – MedReact Workshop on EFH and Sensitive Habitats in the Adriatic Sea held in Rome (2018). The BC is among the “jewels of the Mediterranean” for which urgent measures should be undertaken.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pcean.2018.10.015>.

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