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The demersal fish assemblages of the infra and circalittoral coastal rocky bottoms of the Aeolian Archipelago (Central Mediterranean Sea) studied by Remotely Operated Vehicle (ROV)

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Abstract

Demersal fish assemblages on the rocky bottoms of the Aeolian Archipelago were investigated using a Remotely Operated Vehicle (ROV) within the framework of research activities aimed at drawing up the zoning proposal for a new Italian national marine protected area. Visual assessments were conducted around the seven main islands by means of 36 ROV transects. The video material was divided into 3 parts belonging to 3 Archipelago sectors (Western, Central and Eastern) and into 3 depth ranges (20-50, 51-120, 121-190). Thirty taxa of teleosts (29 species and 1 genus) belonging to 16 families were recorded. The assemblages were numerically dominated by some schooling fishes, such as *Anthias anthias*, *Callanthias ruber* and *Chromis chromis* that exhibited a depth-related partitioning of space, and three non-gregarious species, namely *Serranus cabrilla*, *Coris julis* and *Lappanella fasciata*. In terms of species composition, the assemblages observed in the sectors of the Archipelago largely overlapped. No significant sector-related differences were detected in fish species richness, diversity and total density. Species composition and the investigated assemblage parameters were significantly affected by depth. The pattern of variation in species richness among depth ranges differed from one archipelago sector to another. No significant interaction between the depth range and sector factors was observed in terms of species diversity and total density. Diversity values at 20-50 and 121-190 m depth were similar and significantly higher than at 51-120 m depth. Fish total density showed a clear downward trend with increasing depth, although significant differences were detected between the 20-50 and 51-120 depth layers and the deepest one. Overall, the demersal fish assemblage of the Aeolian Archipelago was poorly diversified and depleted, most likely due to overfishing. This information highlights the importance of adopting specific measures aimed at the recovery of overexploited resources and the restoration of entire marine ecosystems.

Keywords: Demersal fish assemblages; MPA; Mediterranean Sea; Remotely Operated Vehicle.

Introduction

A variety of remotely operated video-based tools and methodologies have been developed over the years to study benthic environments (Bicknell *et al*., 2016), based on the use of fixed cameras (Cappo *et al*., 2007; Langlois *et al*., 2018), or mobile systems such as towed cameras or remotely operated vehicles (ROVs) (Sward *et al*., 2019).

One of the main advantages of ROVs and others camera-based methodologies is linked to their non-invasive nature that enables exploration of fragile marine ecosystems and those found in marine protected areas (MPAs) (Harter *et al*., 2009; Karpov *et al*., 2012; Auster *et al*., 2016). In addition, ROVs can operate across a broad bathymetric range, well below the safety limit imposed on visual observations based on SCUBA diving (Busby *et al*., 2005; Boavida *et al*., 2015). Nevertheless, some limitations are inherently associated with the use of ROVs to investigate fish, mainly related to the different species-specific reaction to the noise and light associated with the use of these vehicles (Ryer *et al*., 2009; Sward *et al*., 2019). Attraction or escape from ROVs could lead to a bias in species observation and incorrect estimates of fish population abundance (Trenkel *et al*., 2004; Lorance & Trenkel, 2006; Stoner *et al*., 2008).

Results from several investigations performed in different natural and artificial mesophotic habitats suggest that substrate type and depth might considerably influence fish assemblage structure (Bryan *et al*., 2013; Pacunski *et al*., 2013; Ajemian *et al*., 2015; Laidig & Yoklavich, 2016; Smith & Lindholm, 2016). Fish assemblages associated with structurally complex rocky habitat with a high relief morphology have frequently been found to be more diverse than those recorded on low relief rocky beds or sandy-muddy bottoms (Bryan *et al*., 2013; Laidig & Yoklavich, 2016; Ross *et al*., 2015). According to the review of Sward *et al*. (2019), very few investigations involving the collection of data on demersal fishes using ROVs have been carried out in the Mediterranean mesophotic realm. Some studies include information on the whole fish assemblage, either in natural environments, such as banks (Consoli *et al*., 2016), or in artificial habitats, such as offshore gas platforms (Andaloro *et al*., 2013) and shipwrecks (Consoli *et al*., 2015).

As part of a multidisciplinary environmental research programme, ROV surveys were carried out in the waters of the Aeolian Archipelago (ISPRA, 2019). As in other preliminary studies for the establishment of new MPAs, demersal fish fauna was one of the main faunal component investigated through field surveys, also in relation to their role as ecological indicators of environmental change (Stephens *et al*., 1988) and climate change (Roessig *et al*., 2004). Indeed, knowledge of the distribution pattern of fishes, especially those of high commercial and/or conservation value, might have crucial implications for the design of a new MPA (Curley *et al*., 2002), including the regulation and management of fishing activities (Roberts & Polunin, 1991).

Scientific data on the fish assemblages of the Aeolian Archipelago are scanty and outdated, especially as regards the circalittoral zone. Some information on coastal benthic and nectobenthic fishes was collected within a shallow depth range (2-28 m) by underwater visual census (Vacchi *et al*., 1997), whereas more recent data concerns the composition of local artisanal fisheries catches (Battaglia *et al*., 2010 and references therein; Di Natale & Navarra, 2019). Fishing represents one of the most characteristic activities in the Aeolian Archipelago, involving over 400 professional fishermen (30% of the local population), most of them being multi-license owners, adopting a seasonal rotation of different fishing gears (Co. Ge.P.A., 2013). During the last two decades and especially after the ban of the driftnet “Spadara” in 2002, the Aeolian fishery has undergone significant changes, such as a shift of fishing effort from pelagic to coastal grounds, with an increase of fishing pressure on demersal species that has led to a progressive decline of trammel net catches (Battaglia *et al*., 2010; Di Natale & Navarra, 2019).

The aim of this study was to characterize the demersal fish assemblages inhabiting the infra and circalittoral zones of the Aeolian Archipelago by means of ROV surveys, mainly focusing on the coralligenous rocky reefs, a key habitat for Mediterranean coastal fish diversity. The collected data were analysed to test for differences in the distribution pattern of fish and in the assemblage parameters across geographic sectors and depth ranges, and to contribute to defining environmental elements useful for delimiting the zoning of the future MPA (Villa *et al*., 2002).

Materials and Methods

Study area

The Aeolian Archipelago (Fig. 1) is one of the most fascinating island complexes of the Central Mediterranean Sea. It encompasses a large area characterized by a complex geomorphological system linked to the presence of volcanoes, underwater canyons and hydrothermal springs (Chiocci *et al*., 2008), most of which are located around the islands of Vulcano (Sedwick & Stube, 1996), Stromboli (Kokelaar & Romagnoli, 1995) and Panarea (Tudino *et al*., 2014). The Aeolian Archipelago is located in the south Eastern Tyrrhenian Sea, off the north Eastern coast of Sicily, and covers a total area of 116.3 km^2. The Archipelago is composed of seven main islands (Lipari, Vulcano, Salina, Stromboli, Panarea, Filicudi and Alicudi) and five islets located around the island of Panarea (Basiluzzo, Dattilo, Lisca Nera, Bottaro and Lisca Bianca), round in shape. Since 2001, the Aeolian Islands have been included on the UNESCO World Heritage list, as an area of outstanding natural landscapes. The Aeolian Archipelago is also on the list of the sites identified by Italian national legislation (Italian Law 979/82, Art. 31) as a candidate MPA.

The seabed surrounding the islands consists of steep rocky cliffs or boulder fields rarely interspersed with gently sloping sandy areas. The distribution of *Posidonia oceanica* meadows, from a few metres down to 35-40 m depth, both on rocky substrate and volcanic sands containing biogenic detritus, is generally patchy, except in some coastal stretches of Salina, Lipari, and Filicudi (ISPRA, 2019). Precoralligenous formations are rare. The circalittoral zone, characterized by coralligenous habitats, shows a strong heterogeneity of the benthic assemblages. According to their relative location within the Archipelago, the islands were ascribed to three main sectors: Western (Alicudi and Filicudi), Central (Lipari, Salina and Vulcano) and Eastern (Panarea and Stromboli) (Fig. 1).

The local fishing fleet is mainly artisanal and small-scale, usually operating within the 12 nm limit, and comprises about 150 small polyvalent boats, most of which are located at Lipari (70%), Salina (11%) and Stromboli (10%) (Battaglia *et al*., 2010).

Data collection

Data on the demersal fish assemblages of the Aeolian Archipelago were collected during a research cruise carried out with R/V Astrea between August and September 2017. Geophysical data of the island coasts were collected during the cruise using a Kongsberg EM240 Multibeam echosounder in order to produce high resolution morpho-bathymetric maps and identify the most interesting rocky areas to investigate by ROV transects. Investigation of fish assemblages by ROV transects is one of the most frequently used methodologies (Sward *et al*., 2019). The entire Archipelago was surveyed by means of

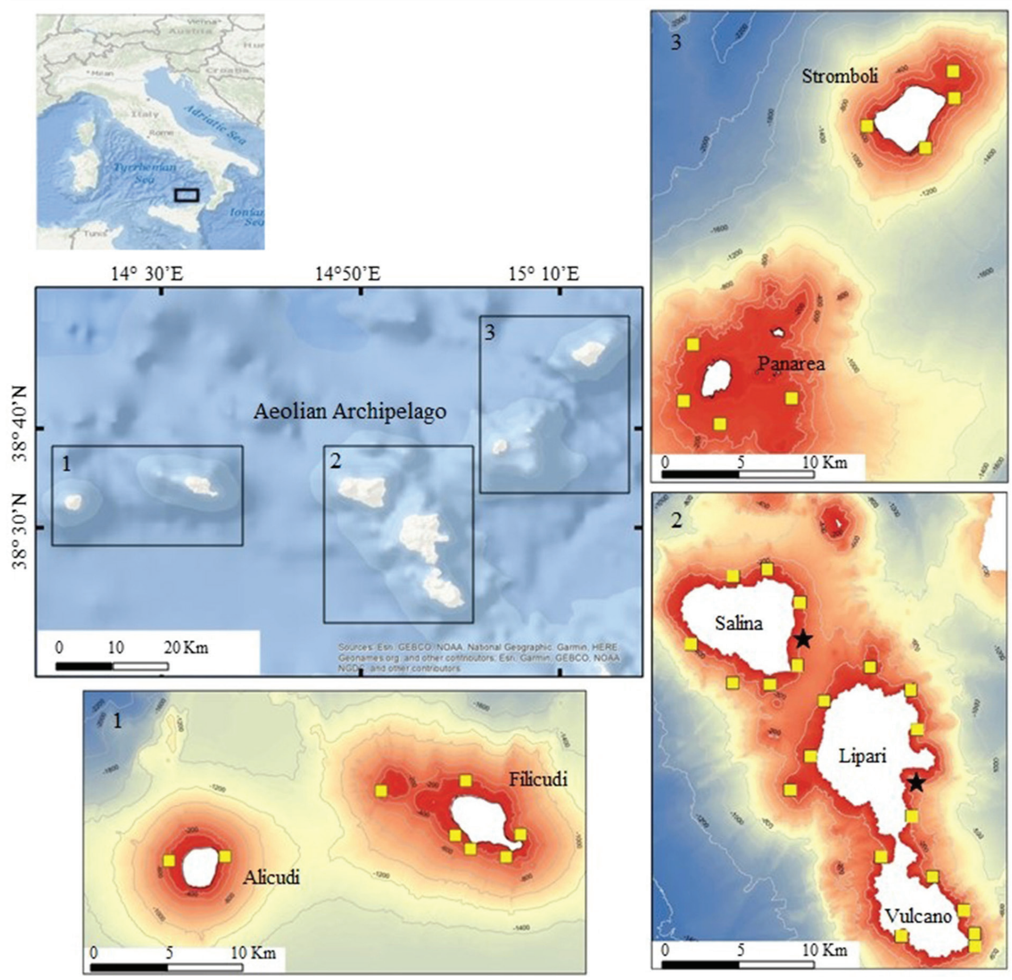

***Fig. 1**: Map of the study area in the southern Tyrrhenian Sea. The three sectors of the Aeolian Archipelago (1=Western sector; 2=Central sector; 3=Eastern sector) and locations of the ROV transects (🟨) and the main fishing ports (★) are indicated in the inset maps.*

36 strip transects running perpendicular to the shore (Fig. 1) and providing around 34 h of imagery (Table 1).

Data on fish assemblages were collected during daylight hours by means of a ROV (MAG98) equipped with a full HD navigation camera and a Blackmagic microstudio 4k cinematographic camera, with a Panasonic Luminex 25-45mm lens and four LED lights (lasers). The camera was located at the front of the ROV oriented at a 45-degree angle to the seafloor yet able to move up and down. ROV equipment also included an underwater acoustic positioning system (Tracklink 1500 MA, Linquest USBL system), providing the georeferenced location of the ROV every second.

Using a standardised protocol, the ROV was deployed in the deepest point of the transect and, after reaching the seafloor, moved towards the shoreline following the seabed profile with a separation of 0.30-1 m. A relatively constant speed of 0.3 m/s was maintained along the route, which is compatible with the presence of vertical cliffs or large boulders and outcrops. Transect length was estimated by mean of GIS (Geographic Information 183 System) software (ESRI ArcMAP 10.1), applied to the ROV track data. A graphic representation of each transect path and location around the coasts of the Archipelago is given in Supplementary Figure S1.

Video transect analysis

Processing of video transects was performed using the VLC Media Player platform (v.3.0.11, www.videolan.org/vlc) and required multiple steps. Firstly, video segments with poor quality images (i.e. out of focus, too far from the seafloor, clouded by suspended sediment) or collected in open water or over sandy/muddy bottoms were removed from the analysis. Secondly, video from each transect was divided into segments, which were homogeneous in terms of depth and type of hard substrate and thus taken as sampling units. Substrate type was classified into three categories, according to its mesoscale attributes: large rocky outcrops (RO), large boulders (LB), and small blocks (<50 cm height) field (SB). All segments were then stratified into three depth intervals: from the infralittoral (20-50 m) down to the upper (51-120 m) and lower circalittoral (121-190 m) zones (Table 1).

All fishes observed within each segment were recorded and identified to the lowest possible taxonomic level (Fischer *et al*., 1987). In some cases, digital video frames and video at reduced speed were used to help identify fish species. Fish abundance was estimated by counting single specimens or, with schools larger than 30 individuals, using abundance classes (31-50, 51-100, 101-200, 201-500, >500 individuals). The number of individuals in

Table 1. Characteristics of ROV transects carried out in the three sectors of the Aeolian Archipelago. The number of segments (sampling units) at each transect and depth range are shown. LB=large boulders, SB=small boulders, RO=rocky outcrops. ALDGF=Abandoned, lost or otherwise discarded fishing gear.

Sector	**Transect**	**Depth (m) (min-max)**	**Position (start)**		**Duration (min)**	**Substrate type**	**No. of segments by depth range**			**No. of ALDFG**
			Latitude	**Longitude**			**20-50 m**	**51-120 m**	**121-190 m**	
Western	22	59-166	38°33’2.5» N	14°34’51.9» E	63	LB, RO		2	1	4
Western	23	31-145	38°33’14.1» N	14°33’17.8» E	62	SB, RO	1	1	1	4
Western	24	65-116	38°33’45.5» N	14°32’39.1» E	71	LB, RO		2		3
Western	25	59-99	38°33’47.1» N	14°35’42.2» E	63	LB, RO		2		3
Western	26	66-135	38°32’40.4» N	14°19’42.1» E	52	RO		1	1	1
Western	27	22-151	38°32’54.4» N	14°22’13.7» E	78	LB, RO	1	2	1	2
Western	28	107-250	38°35’15.1» N	14°29’10.9» E	34	RO			1	1
Western	29	43-125	38°35’44.1» N	14°32’59.7» E	50	RO	1	1		1
Central	1	25-147	38°25’30.9» N	14°56’34.4» E	77	LB, RO	1	2	1	2
Central	2	44-162	38°22’39.2» N	14°57’22.4» E	37	LB, RO		2		
Central	3	85-200	38°27’49.0» N	14°52’15.0» E	59	LB, SB, RO		1	2	
Central	4	42-154	38°26’57.1» N	14°57’52.7» E	54	LB, RO	1	2	1	1
Central	5	53-123	38°29’55.3» N	14°58’4.6» E	29	LB, SB, RO		3		1
Central	6	42-160	38°22’29.6» N	15°00’53.9» E	97	LB, RO	1	2	1	1
Central	7	28-163	38°23’31.2» N	15°00’21.2» E	81	LB, RO	1	1	1	1
Central	8	26-126	38°32’21.7» N	14°52’35.5» E	39	LB	1	1		1
Central	9	54-128	38°34’31.7» N	14°52’47.9» E	27	RO		1		2
Central	18	39-112	38°32’17.3» N	14°55’53.6» E	29	LB	1	1		5
Central	19	95-131	38°31’30.8» N	14°51’23.2» E	97	LB		1	1	4
Central	20	28-53	38°31’24.8» N	14°57’46.8» E	38	LB	1	1		3
Central	21	28-130	38°24’48.9» N	14°58’45.8» E	38	LB, RO	1	2		4
Central	30	60-113	38°37’53.1» N	14°54’22.5» E	50	RO		1		2
Central	31	39-81	38°35’39.0» N	14°51’18.8» E	40	LB, RO	1	2		1
Central	32	71-100	38°35’24.4» N	14°49’58.4» E	37	RO		1		1
Central	33	75-113	38°33’3.7» N	14°47’58.7» E	21	LB		1		1
Central	35	84-106	38°30’55.6» N	14°53’47.7» E	29	LB, SB		2		
Central	36	49-89	38°29’1.2» N	14°53’14.1» E	23	LB		1		

Continued

Table 1 continued

Sector	Transect	Depth (m) (min-max)	Position (start)		Duration (min)	Substrate type	No. of segments by depth range			No. of ALDFG
			Latitude	Longitude			20-50 m	51-120 m	121-190 m	
Central	37	63-112	38°22’39.1» N	15°00’45.8» E	88	LB, SB		2		1
Eastern	10	20-144	38°48’13.8» N	15°15’3.3» E	50	LB, SB	1	2	1	3
Eastern	11	74-100	38°49’11.4» N	15°14’58.6» E	65	LB		1		
Eastern	12	81-100	38°47’15.8» N	15°10’58.6» E	51	LB, SB		2		2
Eastern	13	22-115	38°46’30.2» N	15°13’42.5» E	55	LB	1	1		2
Eastern	14	69-79	38°37’24.2» N	15°07’27.8» E	51	RO		1		
Eastern	15	71-180	38°39’30.2» N	15°02’50.5» E	140	LB, SB, RO		2	1	2
Eastern	16	57-129	38°37’12.4» N	15°02’27.8» E	58	LB, SB, RO		3		
Eastern	17	85-115	38°36’24.2» N	15°04’9.5» E	59	RO		1		

schools was then calculated by considering the midpoint of each abundance class (e.g. 40 individuals for the 31-50 abundance class) (Harmelin-Vivien *et al.*, 1985).

Fish densities (number of individuals/10 m^2) were determined by estimating the area viewed (herein referred to as swept area) during each video segment from segment length and width. Segment length was calculated from the latitude and longitude recorded by the ROV tracking system. To estimate segment width, we used the laser spots in the navigation camera images. The space between the paired lasers (measured laser width) was measured with a ruler on the video screen once every 30 seconds. Width estimates were then obtained using the following equation:

width = (measured screen width/measured laser width) x laser width

where laser width = 50 cm and measured screen width = the horizontal width of the video screen through the laser spots (Laidig & Yoklavich, 2016). The average of the width measures taken for each segment was finally used as segment width.

The trophic level of each species and its membership to a specific functional trophic group were assessed following the review of Stergiou & Karpouzi (2002).

Along each ROV transect, number and distribution of abandoned, lost or otherwise discarded fishing gear (ALDFG) (Macfadyen *et al.*, 2009) were recorded, in order to obtain indirect information on fishing pressure.

Data analysis

Multivariate and univariate statistical analyses were carried out to assess differences in fish assemblages in relation to two main factors, Archipelago sector and depth range. Before running the analyses, the homogeneity of the distribution of substrate types across sectors and depth ranges was tested by χ^2 analysis, to assess any confounding effect of substrate.

Multivariate differences in the species composition of fish assemblages among sectors and depth ranges were assessed using fish density data. The influence of each variable was evaluated by constrained ordination (with sector or depth as constraining factor) using Canonical Analysis of Principal coordinates, (CAP), based on Bray-Curtis dissimilarities (Anderson & Willis, 2003). The canonical correlations were tested using 4999 random permutations of the raw data. Distinctness of groups was assessed using leave-one-out allocation success (Anderson & Robinson, 2003). The product-moment correlations of the 30 species variables with the two canonical discriminant axes ($\rho1$ and $\rho2$) were calculated and only those having relatively strong correlations (i.e. $\sqrt{\rho1^2 + \rho2^2} > 0.30$) were considered as valuable and included in the plot.

Univariate analyses were carried out using the same data set in order to ascertain differences in fish species richness, total density and diversity (by the Shannon-Wiener index, H’) among sectors and depth ranges.

These differences were tested by two-way permutational analysis of variance (Permutational ANOVA) (Anderson, 2001a; McArdle & Anderson, 2001), with the experimental design consisting of factor Sector (3 levels, fixed) and Depth (3 levels, fixed). The analysis was based on the Bray-Curtis similarity matrix using 4999 unrestricted permutations of raw data (Anderson, 2001b).

Differences in the number of transects with ALDFG among the islands of the Archipelago were tested by χ^2 analysis. Multivariate and univariate analyses were carried out using PRIMER v6 + PERMANOVA (Plymouth Marine Laboratory, UK).

Results

General description of fish assemblages

Thirty taxa of teleosts (29 species and 1 genus, *Trachurus*) belonging to 16 families, were recorded during the study (Table 2). Omnivores with preference for animals (Omnivores 2) was the most represented trophic group (15 out of 29 species), followed by carnivores feeding preferentially on decapods and fishes (Carnivores 1) or on fishes and cephalopods (Carnivores 2) (8 and 5 species, respectively). The total number of taxa found in the Central sector (n=26) and in the intermediate depth range (51-120 m) (n=24) was higher than those observed in the other sectors and bathymetric intervals, likely as a result of differences in sampling effort (i.e., number of dives and sampling units). The families with the largest number of species were Labridae and Scorpaenidae (5 and 4 species, respectively), followed by Sparidae and Serranidae (3 species).

The assemblage was quantitatively dominated by some fishes, such as *Anthias anthias*, *Callanthias ruber* and *Chromis chromis* usually observed in large schools, and three non-gregarious species, i.e. *Serranus cabrilla*, *Coris julis* and *Lappanella fasciata*, which in total accounted for 96% of the assemblage.

The lower limit of the bathymetric distribution of the seven species observed during the surveys was noteworthy: *Chelidonichthys obscurus* was recorded down to 232 m depth; *C. chromis*, down to 59 m; *C. julis*, down to 130 m; *Gobius kolombatovici*, down to 109 m; *Symphodus mediterraneus*, down to 91 m; *Symphodus melanocercus*, down to 67 m; and *Thorogobius ephippiatus*, down to 232 m.

Multivariate and univariate analyses of fish assemblages

No significant differences were detected by Chi-square analysis of the distribution of substrate types with respect to archipelago sector (χ^2=8.51, d.f.=4, p=0.07) or depth range (χ^2=0.52, d.f.=4, p=0.97).

The results of the canonical analysis of principal coordinates indicated that sampling units belonging to different sectors largely overlapped (squared canonical correlations δ_1^2 = 0.14 and δ_2^2 = 0.004; P = 0.42; 39% of sampling units correctly classified) (Fig. 2a), sug-

Table 2. List and densities (mean number of individuals per10 m^2 ± SE) of fish taxa recorded in the Eolian Archipelago within sectors and depth ranges. Trophic groups: Omnivores 1=preference for vegetable material; Omnivores 2=preference for animals; Carnivores 1=preference for decapods and fishes; Carnivores 2=preference for fishes and cephalopods (Stergiou & Karpouzi, 2002).

Taxa	Trophic group	Sector			Depth range		
		Western	Central	Eastern	20-50	51-120	121-190
Aulopidae							
Aulopus filamentosus	Carnivores 2	0.08±0.06	0.14±0.09	0.05±0.04		0.03±0.01	0.53±0.28
Callanthidae							
Callanthias ruber	Carnivores 1	1.93±1.49	2.22±1.41	0.43±0.43		1.31±1.14	5.41±2.30
Carangidae							
Trachurus sp.			1.18±1.01			0.15±0.15	3.29±3.29
Engraulidae							
Engraulis encrasicolus	Omnivores 2		0.66±0.54	0.37±0.37		0.23±0.16	1.73±1.73
Gobiidae							
Gobius kolombatovici	Omnivores 2	0.03±0.01	0.04±0.02	0.03±0.02		0.06±0.02	
Thorogobius ephippiatus	Omnivores 2	0.04±0.03	0.04±0.02	0.07±0.04		0.02±0.01	0.19±0.08
Labridae							

Continued

Table 2 continued

Taxa	Trophic group	Sector			Depth range		
		Western	**Central**	**Eastern**	**20-50**	**51-120**	**121-190**
Coris julis	Omnivores 2	0.55±0.19	1.01±0.61	0.34±0.18	3.73±1.90	0.19±0.05	0.03±0.03
Lappanella fasciata	Omnivores 2	0.27±0.08	0.64±0.63	0.05±0.02		0.10±0.03	2.16±2.07
Symphodus mediterraneus	Omnivores 2	0.003±0.003	0.90±0.89	0.03±0.03	0.03±0.03	0.01±0.01	2.94±2.94
Symphodus melanocercus	Omnivores 2		0.001±0.001			0.001±0.001	
Symphodus tinca	Omnivores 2	0.03±0.03	0.94±0.94	0.01±0.01	0.06±0.04		3.11±3.11
Mullidae							
Mullus barbatus	Omnivores 2			0.01±0.01		0.003±0.003	
Mullus surmuletus	Omnivores 2	0.01±0.01	0.68±0.68	0.01±0.01	0.02±0.02	0.002±0.002	2.25±2.25
Muraenidae							
Muraena helena	Carnivores 2	0.005±0.005	0.04±0.02		0.02±0.02	0.01±0.01	0.07±0.07
Phycidae							
Phycis phycis	Carnivores 2	0.02±0.01	0.73±0.73	0.02±0.01		0.01±0.01	2.43±2.42
Pomacentridae							
Chromis chromis	Carnivores 1	6.28±4.98	5.71±2.54	7.16±4.97	29.37±8.76	1.35±1.33	1.38±1.38
Scorpaenidae							
Scorpaena elongata	Carnivores 1		0.01±0.01	0.02±0.02			0.06±0.04
Scorpaena notata	Omnivores 2	0.002±0.002	0.81±0.79	0.02±0.02		0.02±0.01	2.59±2.59
Scorpaena porcus	Carnivores 1		0.001±0.001	0.01±0.01		0.003±0.002	
Scorpaena scrofa	Carnivores 1	0.01±0.01	0.85±0.84	0.02±0.01		0.01±0.006	2.77±2.77
Sebastidae							
Helicolenus dactylopterus	Carnivores 1	0.09±0.06	0.10±0.09	0.02±0.02			0.49±0.28
Serranidae							
Anthias anthias	Carnivores 1	48.66±7.57	55.37±11.59	51.04±10.27	67.50±30.99	61.74±6.17	4.28±1.96
Serranus cabrilla	Omnivores 2	0.28±0.05	0.88±0.57	0.36±0.07	0.29±0.09	0.36±0.04	2.02±1.89
Serranus scriba	Carnivores 1	0.01±0.01			0.02±0.02		
Sparidae							
Boops boops	Omnivores 1		0.37±0.37	2.77±2.77	3.36±3.36		1.21±1.21
Dentex gibbosus	Carnivores 2		0.52±0.47		0.16±0.16		1.55±1.55
Diplodus vulgaris	Omnivores 2	0.01±0.01	0.01±0.01	0.05±0.03	0.07±0.04	0.01±0.01	
Triglidae							
Chelidonichthys obscurus	Omnivores 2		0.32±0.32			0.01±0.01	1.04±1.04
Trigla lucerna	Omnivores 2		0.001±0.001			0.001±0.001	
Zeidae							
Zeus faber	Carnivores 2	0.004±0.003	1.06±1.05	0.03±0.01		0.01±0.01	3.46±3.46

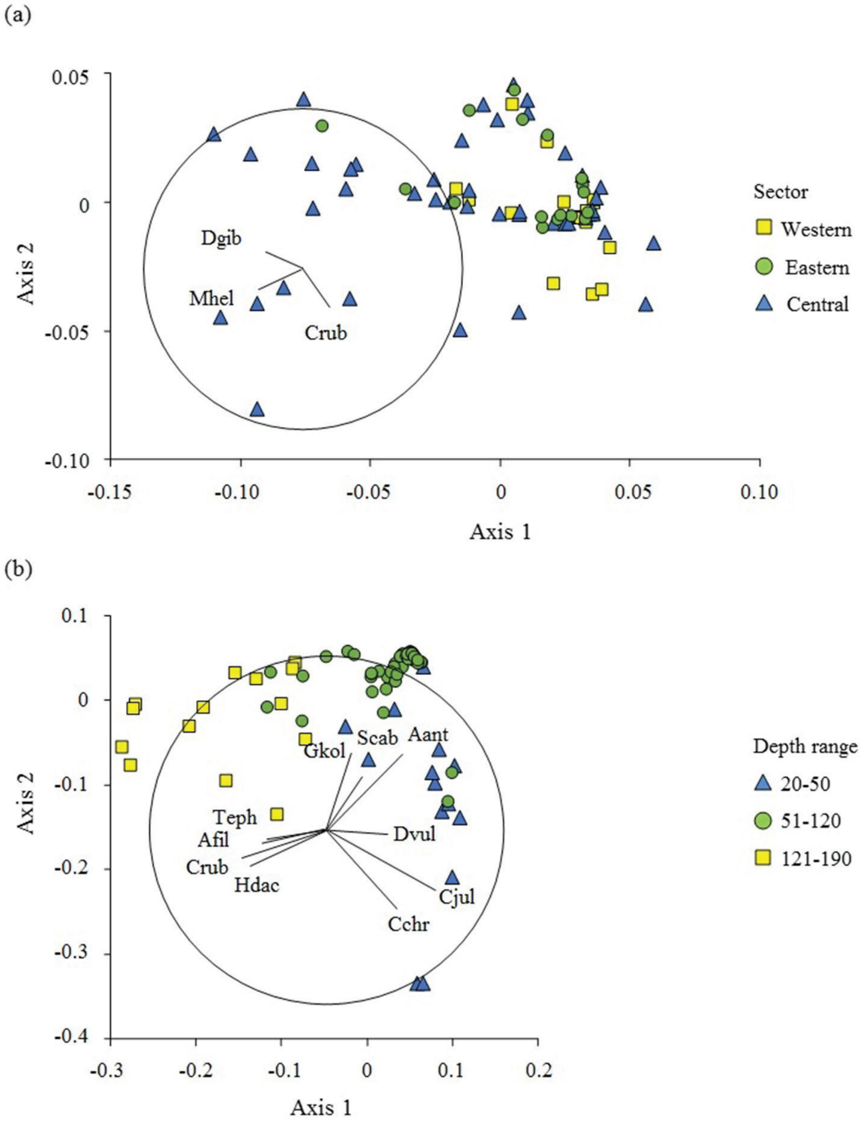

***Fig. 2**:* Scatter plot of the canonical discriminant analysis on the effects of (a) sector and (b) depth range. Species contribution to the observed patterns is shown with directional vectors. Aant=*Anthias anthias*, Afil=*Aulopus filamentosus*, Crub=*Callanthias ruber*, Cchr=*Chromis chromis*, Cjul=*Coris julis*, Dgib=*Dentex gibbosus*, Dvul=*Diplodus vulgaris*, Gkol=*Gobius kolombatovici*, Hdac=*Helicolenus dactylopterus*, Mhel=*Muraena helena*, Scab=*Serranus cabrilla*, Teph=*Thorogobius ephippiatus*.

gesting no clear sector-related differences in fish assemblage structure. The Leave-one-out allocation procedure showed that the assemblage recorded in the Western sector was less variable and easier to predict than those inhabiting the Central and Eastern sectors (percentage of points correctly allocated to each group: Western sector = 52.6%; Central sector = 41.3%; Eastern sector = 17.7%).

The species contributing mostly to the pattern observed in relation to the archipelago sector were *Muraena helena* and *Dentex gibbosus* that were most frequently or exclusively recorded in the Central sector, in contrast to *C. ruber* (occurring also in the Western and Eastern sectors).

The results from CAP obtained using depth as the independent variable revealed a clear separation among sampling units belonging to different depth ranges. Along the first axis, the sampling units of the deepest range (121-190 m) segregated from those located at the other depth ranges (20-50 m and 50-120 m), which in turn were separated along the second axis (squared canonical correlations $\delta_1^2 = 0.72$ and $\delta_2^2 = 0.52$; P = 0.0002; 84.1% of sampling units correctly classified) (Fig. 2b).

Three groups of species contributed mostly to the depth-related differences observed in the assemblage structure. One group included 4 species (*Helicolenus dactylopterus*, *Aulopus filamentosus*, *C. ruber* and *T. ephippiatus*) that showed a negative correlation with the first axis (i.e. arrows pointing to the left side of the plot) and occurred preferentially in the deepest layer (121-190 m). Another group of species (i.e., *C. chromis*, *C. julis* and *Diplodus vulgaris*) plotted in the lower right side of the plot in relation to their preferences for the shallowest depth range (20-50 m). Finally, the arrows for *S. cabrilla*, *A. anthias* and *G. kolombatovici* that were mostly recorded at 51-120 m depth, pointed to the upper right of the plot.

The patterns of variation in species richness (S), diversity (H') and total density across sectors and depth ranges are given in Figure 3. The results of Permutational

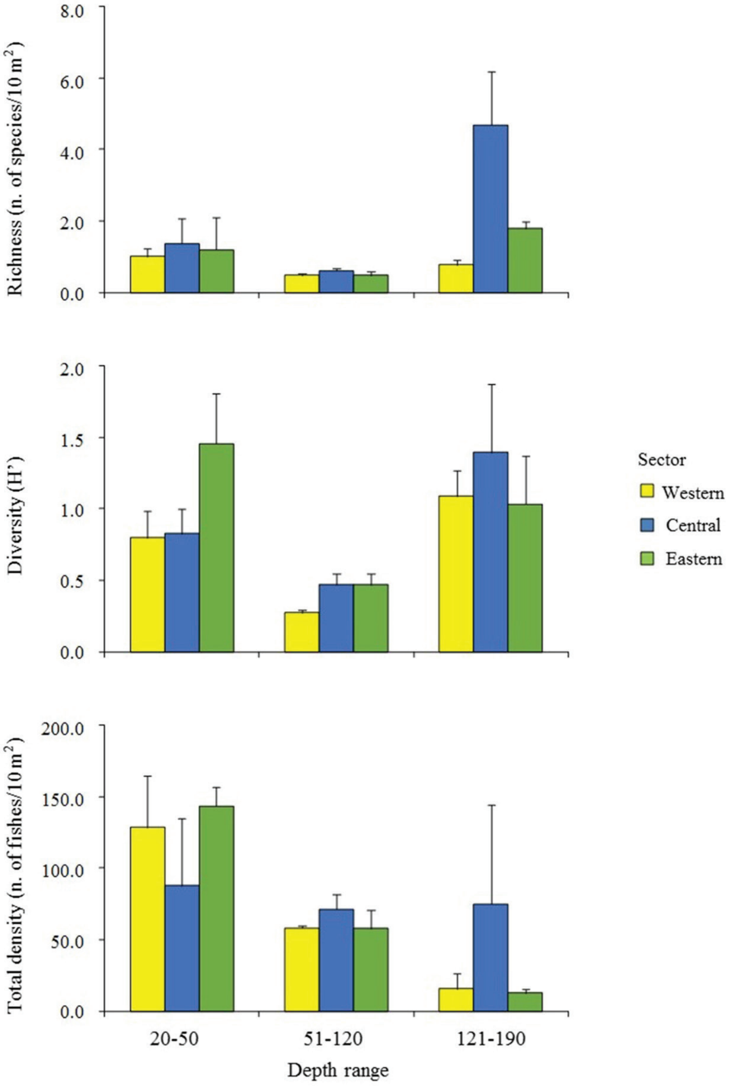

Fig. 3*:* Variation (mean ± S.E.) in species richness, diversity (H') and total density among sectors and depth ranges.

ANOVA indicate significant variability of S among depth ranges, but also a significant interaction between the factors Depth and Sector (Table 3). Pairwise comparisons between sectors revealed significant differences in species richness only in the deepest depth range (121-190 m), between the Central and Western sectors. The highest values of S were always observed at 121-190 m depth, even though significant differences were detected only when compared with the other depth layers and the intermediate layer (51-120 m) in the Central and Eastern sectors, respectively.

Neither species diversity nor total density of fish differed significantly among sectors, whilst they did when compared across depth ranges (Table 3). The H' values at 20-50 and 121-190 m depth were comparable and significantly higher than those recorded at intermediate depth.

Table 3. Results of Permutational ANOVA (PERMANOVA) testing for differences in species richness, diversity (H') and total density among sectors and depth ranges. The test was done on the basis of Bray-Curtis similarities, using 4999 unrestricted permutations of raw data. * P < 0.05, *** P < 0.001, ns: non-significant (P > 0.05).

Effect	**df**	**Richness**		**Diversity (H')**		**Total density**	
		MS	**Pseudo-F**	**MS**	**Pseudo-F**	**MS**	**Pseudo-F**
Sector (S)	2	1782.4	16.7ns	33.9	0.8ns	2419.6	14.2ns
Depth (D)	2	7357.1	69.0***	628.7	14.2***	13898.0	81.5***
S x D	4	2279.5	21.4*	28.5	0.6ns	1905.8	11.2ns
Residual	73	1065.8		44.3		1704.2	
Total	81						

Fish total density shows a clear decreasing trend with increasing depth, but the pairwise comparisons detected significant differences only between the first two depth layers (20-50 and 51-120 m) and the deepest one.

A total of 59 ALDFG, including mainly nets, longlines and handlines, were recorded during the surveys (Table 1). They were located along most transects, in the intermediate depth range (51-120 m) in particular, and frequently interacting with sessile macro-invertebrates. As suggested by the χ^2 analysis, the differences in the proportion of dives with and without ALDFG among the islands were just below the significance threshold (χ^2=12.58, d.f.=6, p=0.0501). The highest contributions to the observed variation were made by the number of dives without gears, which at Lipari and Salina and at Panarea were respectively fewer and more abundant than expected.

Discussion

The analysis of data collected within the framework of this work provided the opportunity to increase knowledge on deep demersal fish assemblages inhabiting the coastal rocky seabed of the Aeolian Archipelago.

The list of fishes recorded during our surveys encompassed 30 taxa of teleosts, a relatively low number of species compared to similar studies conducted in other areas. An ROV investigation carried out by Consoli *et al*. (2016) on some banks located in the Strait of Sicily provided a list of 52 demersal fish species. The higher number of species reported by these authors is likely due to two reasons. Firstly, several species reported by Consoli *et al*. (2016) were recorded only in the upper infralittoral zone, i.e. outside the depth range explored in our surveys. Secondly, the banks are frequently reported as biodiversity hotspots and aggregation areas for large predators (Sahyoun *et al*., 2013; La Mesa *et al*., 2017), such as groupers, which were absent from our inventory. From a methodological point of view, some limitations in terms of fish species detection were inherently associated with the ROV. As documented in other works, the catchability of fishes is largely influenced by species-specific mobility and reaction to the ROV system (Sward *et al*., 2019). Some fish species, especially those characterized by high mobility (e.g. large top-predators) or cryptic behaviour might be drastically underestimated or completely overlooked in ROV surveys (Andaloro *et al*., 2013; Porteiro *et al*., 2013).

Most of the demersal fishes recorded in this study belong to common species of Labridae, Sparidae and Serranidae, commonly observed along the Mediterranean coasts (Quignard & Tomasini, 2000). The records of two rare species, *Lappanella fasciata* and *Gobius kolombatovici*, which were represented by a conspicuous number of individuals, are noteworthy. Specimens of *L. fasciata* were always seen close to gorgonian colonies, as previously documented by Sartoretto *et al*. (1997) and Dulčić *et al*. (2006). Kovačić & Miller (2000) described *G. kolombatovici* as a bottom-dwelling and secretive species, usually inhabiting mixed habitats with rocks and soft sediment. In agreement with the typical habitat reported by Kovačić & Miller (2000), boulders and rocky walls characterised all the sighting locations of *G. Kolombatovici* in our study area. *G kolombatovici* has been reported in the Adriatic Sea (Kovačić & Miller, 2000) and the north-western Mediterranean (Francour & Mangialajo, 2007).

The low number of species recorded in this study, those of commercial interest in particular, is an indication of a depleted population due to overfishing, as also suggested by data on catch and landings of commercial species in the Archipelago (Battaglia *et al*., 2010; Di Natale & Navarra, 2019).

It was not possible to assess the level of fishing pressure in the study area accurately, since no scientifically sound data on the use of the coasts of the Archipelago by fishing activities were available. According to the data on the type, presence, and distribution of ALDGF, which we used as a *proxy* of fishing pressure, it is reasonable to assume that the entire Archipelago is used as fishery grounds by both professional and recreational fishermen. No data on the extent of recreational fishing activity in the Aeolian Islands are currently available; nevertheless, illegal activities (e.g., non-compliance with the regulations on bag limit and permitted gears) are probably an additional challenge for the management of halieutic resources (Álvarez *et al*., 2019).

The overexploitation of both demersal (*Dentex dentex, Mullus surmuletus, Phycis phycis, Sciaena umbra, Scorpaena scrofa*) and pelagic species (*X. gladius, C. hippurus, Thunnus alalunga* and *Todarodes sagittatus*) belonging to high trophic levels, could explain the considerable abundance of species belonging to low trophic levels (Ashworth & Ormond, 2005), such as *A. anthias*, *C. chromis* and *C. ruber*. The distribution of these gregarious zooplanktivorous (Carnivores 1, according to Stergiou & Karpouzi, 2002) species showed a clear habitat partitioning by depth: *C. chromis* in the upper depth range (20-50 m), *A. anthias* and *C. ruber* in the deeper ranges (51-120 m and 121-190 m depth, respectively).

Numerical dominance of zooplanktivorous fish, such as *A. anthias* and *C. ruber*, has been reported in several studies focused on the fish fauna of seamounts in the Mediterranean and the Atlantic (Pakhorukov, 2008; Christiansen *et al*., 2009; Porteiro *et al*., 2013 and references therein; Consoli *et al*., 2016).

Zooplanktivorous fish have been found to play a major role in the transfer of energy from the water column to the benthic environment, where they represent an important food resource for benthic and benthopelagic piscivores (Weaver *et al*., 2001; Porteiro *et al*., 2013). Predation by the scorpionfish *H. dactylopterus* on *A. anthias* and *C. ruber* has been reported by Gomes-Pereira *et al*. (2014). Few piscivorous fishes (Carnivores 2, according to Stergiou & Karpouzi, 2002), potentially benefitting from preying on the huge amount of gregarious zooplanktivorous, were recorded during our surveys. In this group, the most abundant were *A. filamentosus* and *Zeus faber*, followed by *P. phycis* and *Muraena helena*.

The multivariate analysis did not discriminate between the three sectors of the Aeolian Archipelago with respect to their fish assemblage composition. Similarly, the sector-related differences in species richness detected in the univariate analysis were very weak, except in the deepest depth range. It should also be noted that no fish species of conservation concern was recorded in the Archipelago during our surveys; hence, we did not have robust empirical evidence to support a differentiation between sectors in terms of conservation needs.

In agreement with similar studies (D'Onghia *et al*., 2004; Busby *et al*., 2005, Consoli *et al*., 2016, Porteiro *et al*., 2013), depth was the most significant variable influencing the structure of the Aeolian demersal fish assemblages. The most evident boundary line seems to be located around 120 m depth, where a drastic change in species composition and a significant decrease in overall abundance did occur, similarly to the trend of fish abundance already reported by Consoli *et al*. (2016).). The variability in species richness and diversity with depth displayed quite a similar pattern. After a decrease in the transition from the infralittoral to the upper circalittoral zone, both parameters increased to a different extent depending on the archipelago sectors.

Although depth has been recognised as one of the most important drivers influencing the distribution of fish fauna in the marine environment, the results of this work demonstrate that knowledge of the bathymetric distribution of some species remains incomplete, mainly due to the scarcity of exploration studies in deep-water environments. Indeed, the lower limit in the vertical zonation of seven species observed during the surveys fell outside their known depth range (Froese & Pauly, 2020).

In conclusion, despite the high structural heterogeneity and morphological diversity of the seabed of the Aeolian Archipelago, our findings indicate a poorly diversified demersal fish assemblage, most likely reflecting a high fishing pressure situation, extending to the sectors furthest away from the main fishing ports. Such a widespread depletion of fish diversity did not allow the identification of areas of greater value but stressed the need for sustainable use of halieutic resources in the Archipelago, through the enforcement of specific fishing regulations (Guidetti & Claudet, 2010). The considerable variation in the general structure of demersal fishes driven by depth suggests the inclusion of some deep environments within the boundaries of the future MPA, thus broadening the spectrum of species potentially benefiting from specific management of human activities.

Finally, it is important to point out that several ecological and socioeconomic aspects must be assessed to identify zones requiring more restrictive protection measures (e.g., no entry/no take zones) and, ultimately, to make a meaningful zoning proposal. Spatially related information on benthic habitats and other faunistic groups apart from fishes, as well as often conflicting, human uses of marine space should be given due consideration. Indeed, the involvement of stakeholders at the early stages of MPA designing has been recognised as a key element for defining a zoning proposal aimed at environmental protection and the development of sustainable activities and avoiding conflicts between conservation requirements and socioeconomic interests.

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Supplementary data

The following supplementary information is available online for the article:
Fig. S1: Path and location of ROV transects around the coasts of the Aeolian Archipelago.