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Improving the knowledge base of Vulnerable Marine Ecosystems' distribution in the Amendolara Bank (Ionian Sea)

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Abstract

The Amendolara Bank was recently designated as a Site of Community Importance; however, information on its ecosystems remains limited, with a particular dearth of knowledge regarding the deeper zone (>100 m). Previous studies have discovered the existence of Vulnerable Marine Ecosystems (VMEs) within the bank, underscoring the necessity for more comprehensive data and its significance in terms of conservation in the Ionian Sea. This study aims to investigate various aspects of the bank using Remotely Operated Vehicles (ROVs) to shed light on the possible presence of VME indicator species, their relationship with environmental variables, their connection with the observed fish, and to assess anthropogenic impact via the identification of fishing gear within the study area. This present research provides new information on the biodiversity of the Amendolara Bank, revealing the presence of four VME indicator species including the first sightings of black coral *Antipathella subpinnata* and the precious red coral *Corallium rubrum*. Moreover, it provides evidence on the interaction between fish fauna and VME indicator species as well as signs of anthropogenic impact from abandoned, lost, or otherwise discarded fishing gear (ALDFG). These findings highlight the urgent need for additional research to improve the knowledge base on the biodiversity of this unique spot in the Ionian Sea which would in turn ensure the development and implementation of more effective conservation and management measures.

Keywords: VME indicator species; Central Mediterranean Sea; Anthropogenic impact; Essential fish habitats; fish assemblage.

Introduction

Banks and seamounts are deep-sea topographic structures characterized by a vertical elevation of more than 100 m from the sea bottom influencing the direction and flow of ocean currents and in turn, food availability for suspension filter feeder species (Watling *et al.*, 2017; Goode *et al.*, 2020). These topographic structures provide a hard substrate for the settlement and growth of several habitat-forming species (Clark & Tittensor, 2010; Watling *et al.*, 2017; Goode *et al.*, 2020) and favourable conditions for diverse fish fauna (Vassallo *et al.*, 2018; Bo *et al.*, 2020a). For instance, seamounts (from this point forward this term also includes Banks) are considered good fishing areas for recreational and commercial fisheries (Würtz & Rovere, 2015) thanks to their characteristics, and are recognised worldwide as biodiversity hot-spots (Bo *et al.*, 2020a). That said, Mediterranean seamounts have received little attention, particularly compared to their oceanic counterparts (Würtz & Rovere, 2015). Only a few of the seamounts present in the Mediterranean Sea have been thoroughly studied, highlighting their biological and ecological role (Bo *et al.*, 2011, 2020a; Danovaro *et al.*, 2010; Morato *et al.*, 2013; Würtz & Rovere, 2015). This is the case of the Amendolara Bank (Italy, Ionian Sea), where only the shallower zone (upper portion of the euphotic zone) has been studied to date, providing significant information mainly on coralligenous habitat (Rossi & Colantoni, 1976; Panetta *et al*., 1985; Perrone, 1985; Strusi *et al*., 1985; Cecere & Perrone, 1988). However, information about the deeper zone, below 100 m depth, is still scarce. This zone is known to be suitable for mesophotic and deep-sea suspension feeders (Bo *et al*., 2012), and among these species it is possible to recognize Vulnerable Marine Ecosystems (VMEs) indicator species (e.g., corals and sponges) (Watling *et al*., 2017; Goode *et al*., 2020) which play an important role in enhancing biodiversity in the deep sea (Beazley *et al*., 2013, 2015; Ashford *et al*., 2019). VMEs harbour groups of species characterized by peculiar life history traits (e.g., slow growth rate, late age of maturity, low fecundity, high longevity) that make them particularly vulnerable to different impacts, such as fishing activities (FAO, 2009; FAO, 2016; Aguilar *et al*., 2017).

The great habitat complexity provided by VME indicator species promotes greater richness and biodiversity and enhances ecosystem function (Cerrano *et al*., 2010; de la Torriente *et al*., 2020). Habitats created by these ecosystems provide shelter from predators and adverse hydrological conditions (Amsler *et al*., 2009; Ashford *et al*., 2019), as well as serving as nursery and aggregation areas for a wide range of taxa, including those of commercial interest (Baillon *et al*., 2012; Ashford *et al*., 2019).

The Amendolara Bank has been established as a Site of Community Importance (SCI) (Natura 2000, Sites, European Environment Agency – EEA) and designated as a Special Conservation Area (DM 27/06/2017 – G.U. 166 del 18-07-2017) thanks to the results yielded from studies conducted in shallow water. Recently the Calabria Region decided to include the Amendolara Bank in the list of Regional Marine Parks (Legge Regionale 16 Dicembre 2022, n°46) increasing the need to study and better understand its biodiversity and importance in the Ionian Sea.

The principal aims of the present study are to i) investigate the main characteristics of the mesophotic zone of the Amendolara Bank, ii) highlight the presence of VME indicator species, iii) investigate their relationship with environmental variables, iv) study their associated fish fauna, and v) evaluate anthropogenic impacts through the assessment of abandoned, lost or otherwise discarded fishing gear (ALDFG).

Materials and Methods

Study area

The Amendolara Bank is located in the northern Ionian Sea, within the Gulf of Taranto (Ferranti *et al*., 2012; Würtz & Rovere, 2015) and is characterized by an irregular morphology due to the presence of peaks and valleys (Cecere & Perrone, 1988). The top of the bank ranges in depth from 21 - 50 m and the sloping sides reach the bottom between 125 and 250 m. The most shallow point is located on the western side of the bank, while to the east the rock formation slopes more steeply towards the muddy bottom. To the southeast, a separate outcrop rises to approximately 140 m. The survey was conducted between the 9th to 19th of March 2021 in the Amendolara Bank (39. 86838°N, 16.72344°E) (Fig. 1) on board the ISPRA Research Vessel, *Astrea*.

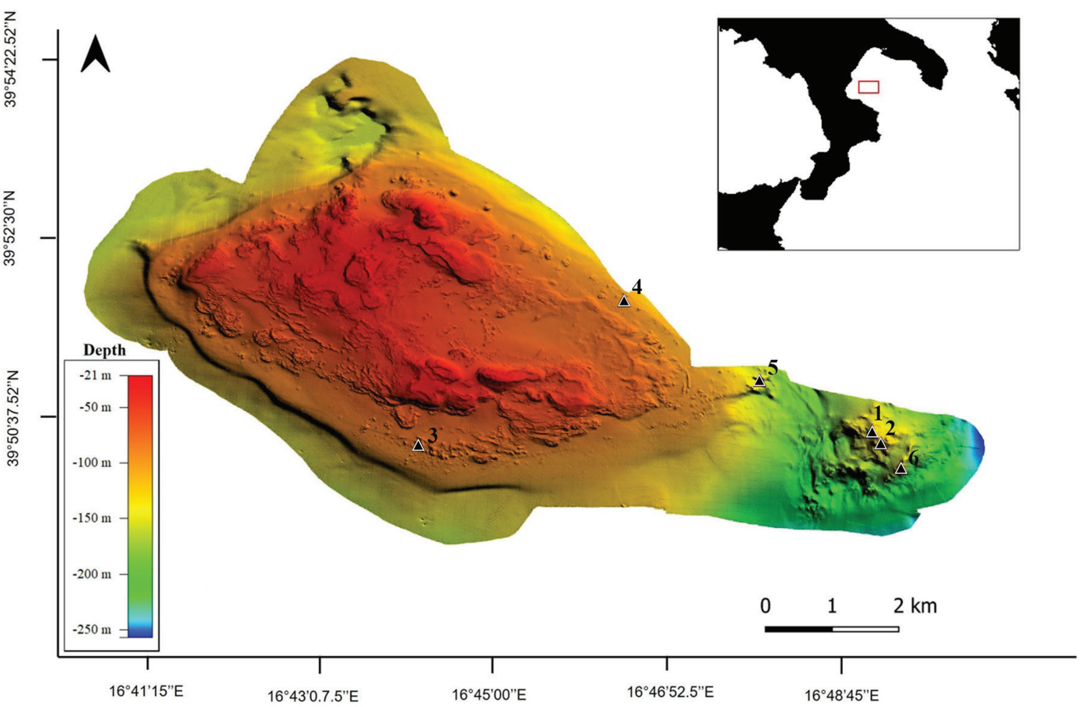

Fig. 1: High-resolution bathymetry data map of the Amendolara Bank. Black triangles show the points where the six ROV dives were performed.

Data collection

Bathymetric data were obtained with a Kongsberg EM 2040 Multibeam echosounder, which produced 512 beams per ping at 300 kHz. Seafloor Information Systems (SIS) software was utilized for data acquisition, and Qimera Qps software was employed for post-processing to generate digital terrain mapping with a resolution of 3 x 3 m.

Dive locations were based on the bathy-morphological map of the seabed with a preference for those parts of the seabed with greater heterogeneity (i.e., frequent variations in depth and slope). The dives were performed using Remotely Operated Vehicles (ROV) Pollux III equipped with a digital camera, strobe, and high-definition video camera (HD SONY HDR- CX405). The depth sensor and underwater acoustic tracking position system (Ultra Short Baseline Linquest Tracklinq 1500 MA) on the ROV provided a geographic position every second during the dives. In total six dives were carried out at a depth range of 80-166 m.

Data analysis

During the survey, video data logging was performed using OFOP (Ocean Floor Observation Protocol) software (van den Beld *et al*., 2007) and then processed using VLC software. Three environmental variables (slope, aspect and roughness) were extracted from high-resolution Multibeam bathymetry (3 m) data through the package “raster” and function “terrain” in the R software (Hijmans, 2023). The type of seabed substrate (i.e., rocky, muddy detritic bottom, muddy, muddy rock), VME indicator species, fish species, and other relevant megafauna were recorded on each dive. Muddy rock is defined as a rocky substrate partially covered with mud. For VME indicator species, the density, defined as the number of colonies (col/m) or number of individuals per metre (ind/m) observed during the entire dive was calculated.

To assess the relationship between VME indicator species, fish species, and environmental variables a Redundancy Analysis (RDA) was performed. This multivariate analysis assumes that each species’ reaction and the ordination axes follow a linear relationship (Gori *et al*., 2011). For the RDA, dives were divided into segments based on the substrate type (Fig. 2). Each segment was characterized by the abundance (n° of colonies – n° individuals) of the VME indicator species and the abundance of the fishes. The number of each organism was standardized according to the length of each segment as number of organisms per metre (n° organisms – n° individuals m^{-1}). The mean value of each environmental variable considered in the analysis (depth, slope, aspect, and roughness) was also calculated in every segment. The statistical contribution of each variable in the model was calculated using the Monte Carlo permutation test with 999 permutations. This process was performed using the “vegan” package in R software (Oksanen *et al*., 2019). The results of the RDA identify the environmental factors that explain the variation in the presence and abundance of the species (Gori *et al*., 2011).

For each dive, the number of ALDFG was recorded to assess anthropogenic impacts and entanglement events.

Results

Presence of VME indicator species in the Amendolara Bank

The dives were characterized by four types of substrates: muddy, muddy rock, rocky, and muddy detritic bottom, and in total we obtained 60 segments. Twelve segments (20%) for muddy detritic bottom, 17 (28.3%) for muddy, 15 (25%) for muddy rock, and 16 (26.7%) for rocky substrates. Video analysis showed the presence of four VME indicator species (Fig. 3), discontinuous-

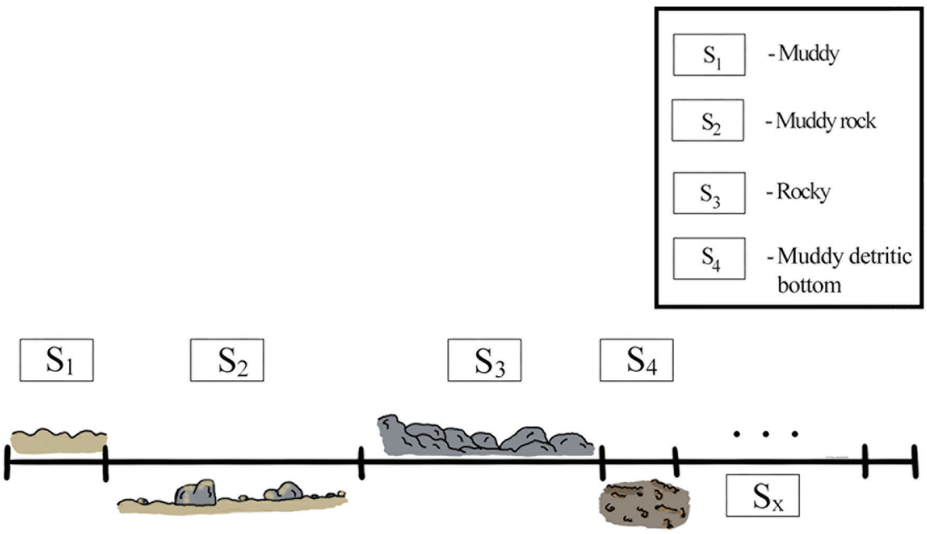

Fig. 2: Graphical representation of how segments were obtained based on substrate type. “S” stands for segment.

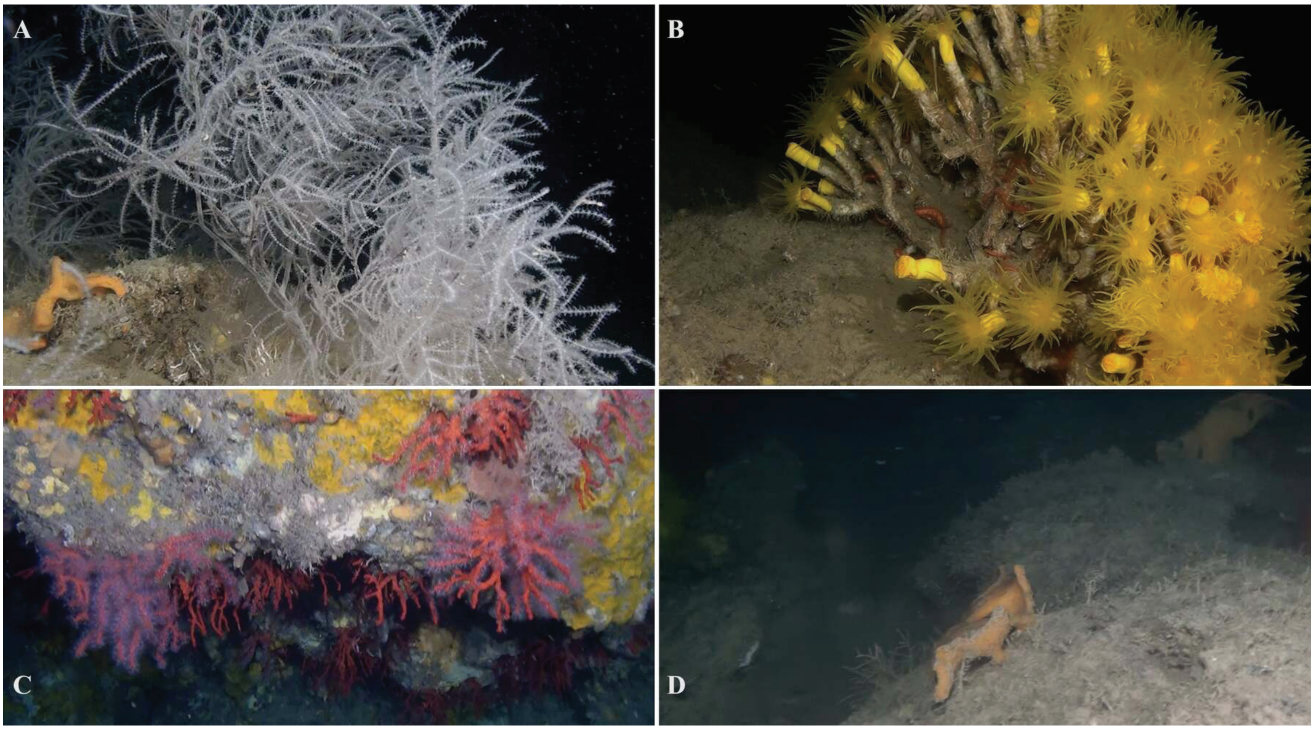

Fig. 3: VME indicator species observed in the Amendolara Bank: black coral *Antipathella subpinnata* (148 m depth) (A), yellow coral *Dendrophyllia cornigera* (136 m depth) (B), red coral *Corallium rubrum* (82 m depth) (C) and orange fan-shaped sponge *Poecillastra compressa* (149 m depth) (D).

ly distributed or in patches: the black coral *Antipathella subpinnata* (Ellis & Solander, 1786), the red coral *Corallium rubrum* (Linnaeus, 1758), the yellow coral *Dendrophyllia cornigera* (Lamarck, 1816), and the orange fan-shaped sponge *Poecillastra compressa* (Bowerbank, 1866). These species were observed at a depth range of about 147-164 m, 82-96 m, 122-150 m, and 125-150 m respectively.

The black coral *A. subpinnata* was observed in the deepest area investigated in the south-eastern part of the Bank (Dive 6). This species was recorded exclusively on a muddy rock substrate where it formed a forest with a density of 2.8 col/m, in relation to the segment's length (40 m), and a density of 0.15 col/m relative to the dive's total length.

Corallium rubrum was only observed on rocky substrates, mainly on vertical walls in two dives in the western and eastern parts of the Amendolara Bank. The distribution of this species was patchy with a density of 0.2 col/m in the western side (Dive 3) and a density of 0.11 col/m in the eastern side (Dive 4) (Table 1).

Dendrophyllia cornigera was observed only on muddy rock substrate in four different dives located in the south-eastern part of the Amendolara Bank (Dive 1: 0.01 col/m; Dive 2: 0.006 col/m; Dive 5: 0.07 col/m; Dive 6: 0.03 col/m). This species showed a scattered distribution and was most observed in Dive 5 (Table 1).

The orange fan-shaped sponge *P. compressa* was observed to be scattered on the muddy sediment in two different sites in the south-eastern part (Table 1), Dive 2 (0.002 ind/m) and Dive 6 (0.06 ind/m). In Dive 6 this sponge was recorded as being associated with the *A. sub-*

Table 1. ROV dives carried out in the Amendolara Bank (Ionian Sea). The number of observed colonies or individuals is reported for each VME indicator species.

Dive	Lat	Long	Mean Depth (min-max)	Dive Length (m)	*Antipathella subpinnata* (n°)	*Corallium rubrum* (n°)	*Dendrophyllia cornigera* (n°)	*Poecillastra compressa* (n°)
1	39.84131°	16.81221°	97 (20-128)	268			3	
2	39.83987°	16.81342°	112 (20-133)	948			6	2
3	39.83918°	16.73576°	83 (31-90)	1582		315		
4	39.86349°	16.77031°	90 (22-98)	658		73		
5	39.85002°	16.79394°	123 (25-152)	536			37	
6	39.83526°	16.81709°	133 (21-166)	730	113		23	46

pinnata forest on muddy rock substrate.

In Dive 6, at a depth of 148 m, the occurrence of the echinoderm *Coronaster briareus* (Verrill, 1882) was recorded inside a crevice of a small rocky outcrop (Fig. 4A, B).

A total of 22 fish species were observed in the explored sites (Table 2) with the most common species being *Anthias anthias* (Linnaeus, 1758). Only seven species were of commercial interest: *Conger conger* (Linnaeus, 1758), *Helicolenus dactylopterus* (Delaroche, 1809), *Lepidorhombus boscii* (Risso, 1810), *Mullus barbatus* Linnaeus, 1758, *Phycis phycis* (Linnaeus, 1766), *Scorpaena scrofa* Linnaeus, 1758, and *Zeus faber* Linnaeus, 1758.

Table 2. List of fish fauna observed in each dive and their abundance.

Fish species	Abundance (n° individuals)					
	Dive 1	**Dive 2**	**Dive 3**	**Dive 4**	**Dive 5**	**Dive 6**
Anthias anthias (Linnaeus, 1758)	5	29	127	496	44	33
Aulopus filamentosus (Bloch, 1792)	1	2			1	
Boops boops (Linnaeus, 1758)		1				
Callanthias ruber (Rafinesque, 1810)				3	1	3
Chelidonichthys lucerna (Linnaeus, 1758)			2		1	1
Conger conger (Linnaeus, 1758)		1		1		
Coris julis (Linnaeus, 1758)					1	
Gadella maraldi (Risso, 1810)			1	1		1
Helicolenus dactylopterus (Delaroche, 1809)					6	10
Labrus mixtus Linnaeus, 1758						1
Lappanella fasciata (Cocco, 1833)						1
Lepidorhombus boscii (Risso, 1810)						1
Macroramphosus scolopax (Linnaeus, 1758)		169	1	2		3
Mullus barbatus Linnaeus, 1758				1		
Muraena helena Linnaeus, 1758		1	3	1		
Pagellus bogaraveo (Brünnich, 1768)					1	
Phycis phycis (Linnaeus, 1766)			2	15	1	2
Scorpaenodes arenai Torchio, 1962				3		
Scorpaena scrofa Linnaeus, 1758			1			
Serranus cabrilla (Linnaeus, 1758)		1	5	5	1	
Serranus scriba (Linnaeus, 1758)			1			
Zeus faber Linnaeus, 1758						1

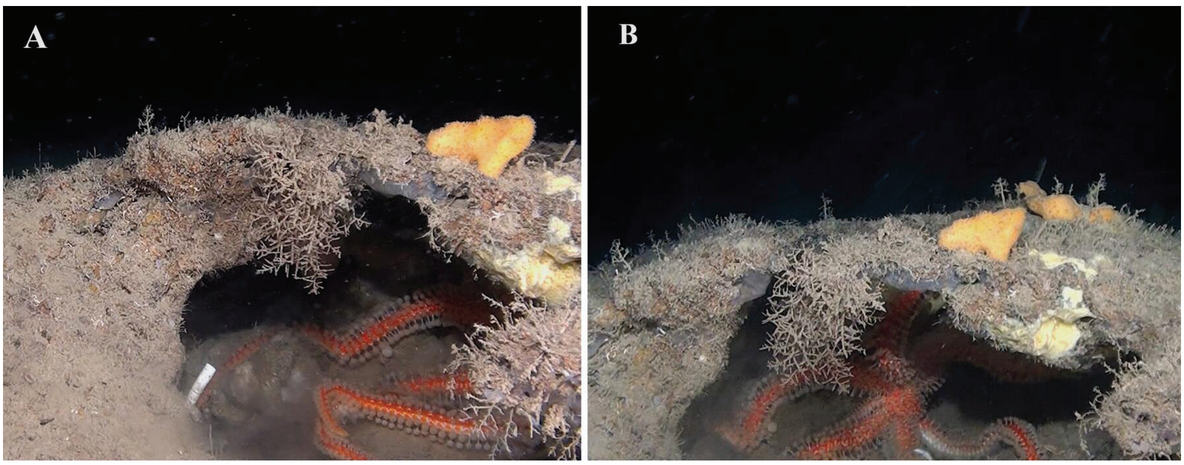

Fig. 4: ROV image of the echinoderm *Coronaster briareus* observed inside a burrow (148 m depth) (A, B). On the top of the outcrop, it is possible to observe specimens of *Poecillastra compressa* and encrusting sponges.

Redundancy analysis (RDA)

The first two axes of the RDA model ($P_{value}<0.05$) explained 44% of the species data variance; the first and second axes explained 29% and 15%, respectively (Fig. 5).

The RDA analysis (Fig. 5) showed that seabed substrate type and morphology significantly influenced the distribution of VME indicator species. More specifically, *A. subpinnata, D. cornigera* and *P. compressa* were associated with muddy rock substrate. The distribution of red coral *C. rubrum* was more probable in areas of rocky substrate and with high values of slope and roughness.

The analysis also showed the association between fish species and VME indicator species. *Aulopus filamentosus* (Bloch, 1792), *Boops boops* (Linnaeus, 1758), *Helicolenus dactylopterus*, *Labrus mixtus* Linnaeus, 1758, *Lappanella fasciata* (Cocco, 1833), and *Macroramphosus scolopax* (Linnaeus, 1758) were associated with the species *A. subpinnata*, *D. cornigera* and *P. compressa*. The fish species *Anthias anthias*, *Callanthias ruber* (Rafinesque, 1810), *Gadella maraldi* (Risso, 1810), *Phycis phycis*, *Scorpaenodes arenai* Torchio, 1962, and *Serranus cabrilla* (Linnaeus, 1758) were associated with the red coral (*C. rubrum*). *Helicolenus dactylopterus* and *P. phycis* are the only two species of commercial value that were found to be associated with the VME indicator species.

Anthropogenic impacts

Thirty one longlines were counted in totals, most of which were entangled on muddy rock (22 longlines) and rocky substrate (7 longlines) (Fig. 6). The most impacted species was *A. subpinnata* (Fig. 6) with four longlines observed entangled on black coral colonies in the deepest part of the Amendolara Bank (Fig. 7).

The other species impacted by fishing activities were *D. cornigera* and *P. compressa*. Two longlines were observed to be entangled around the orange fan-shaped sponge *P. compressa*, and one around *D. cornigera* colonies.

No ALDFG were observed around the colonies of *C. rubrum*.

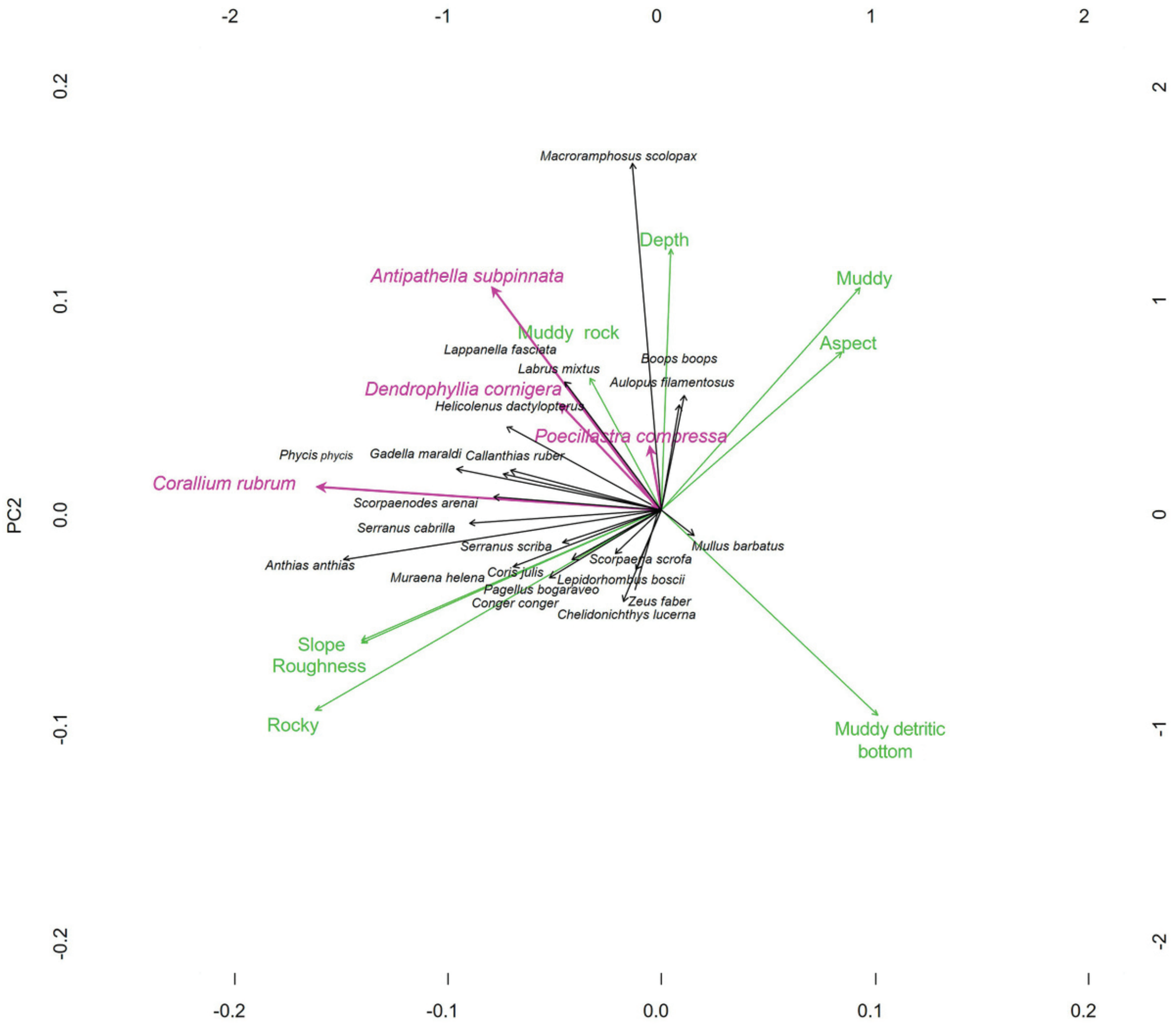

Fig. 5: RDA analysis showing the relationship of VME indicator species with environmental variables (depth, slope, roughness, aspect), substrate type (muddy, muddy rock, rocky, muddy detritic bottom) and associated fish fauna.

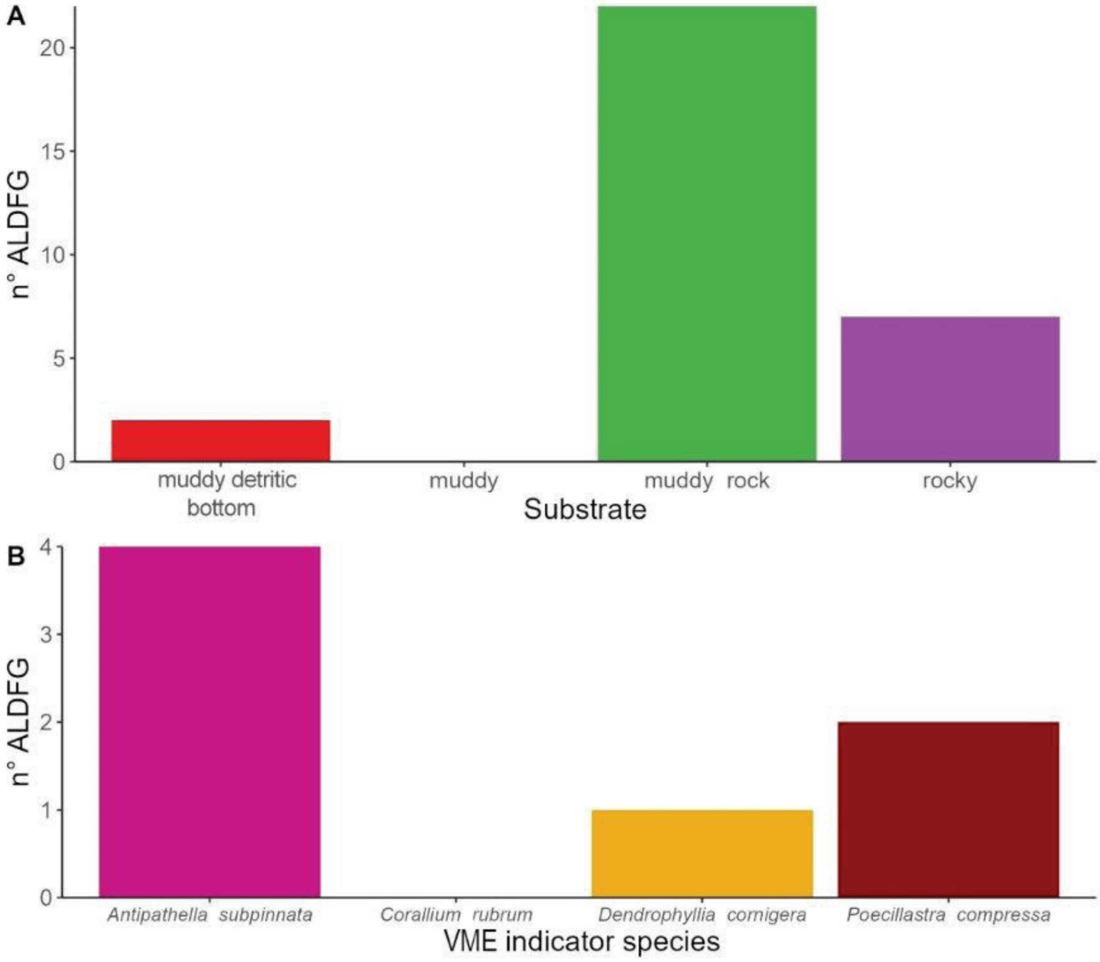

Fig. 6: ALDFG in relation to the type of substrate (A) and VME indicator species (B).

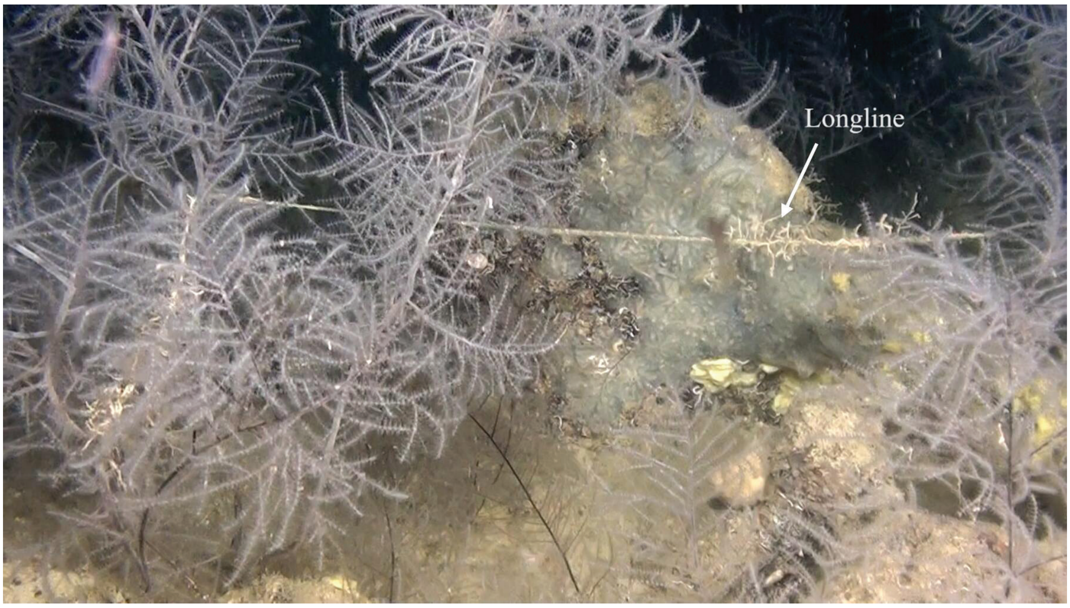

Fig. 7: Longline entangled around *Antipathella subpinnata* colonies (149 m depth).

Discussion and Conclusions

Mesophotic and deep-sea VMEs represent one of the most significant Mediterranean ecosystems, which are also extremely sensitive to fishing activity (Cerrano *et al*., 2019; Chimienti *et al*., 2020a). Increasing the knowledge base on mesophotic habitats represents an essential step to ensure proper management and protection measures are designed and implemented to improve their conservation status (Palummo *et al*., 2023). In the present study, ROV surveys documented the presence of four different species classified as indicators of VMEs belonging to two phyla and four different orders: the cnidarians *Antipathella subpinnata* (Antipatharia), *Corallium rubrum* (Scleralcyonacea), and *Dendrophyllia cornigera* (Scleractinia), and the sponge *Poecillastra compressa* (Astrophorida).

The Amendolara Bank is the westernmost Ionian site known to host the black coral *A. subpinnata* and the red coral *C. rubrum*. Previous records of *A. subpinnata* in the Ionian Sea were restricted to the Apulian coast (Bo *et al*., 2008). Observations of the red coral, *C. rubrum*, in the Ionian Sea have been documented along the Apulian coast, in the Greek seas, and the most southern Ionian tip of Calabria (Dounas *et al*., 2010; Toma *et al*., 2022). *Dendrophyllia cornigera* and *P. compressa* have previously been observed in the area (Bo *et al*., 2012; Castellan *et al*., 2019; Salomidi *et al*., 2022; Enrichetti *et al*., 2023).

The main habitat-forming species on the bank are Cnidaria and Porifera which play an important role in marine ecosystems contributing to the recovery of fish populations by serving as Essential Fish Habitats (EFHs). Providing shelter from predators, spawning and nursery grounds, and greater availability of prey are only a few of the hypotheses that have been put forward to explain the association between fish and VMEs (D'Onghia *et al*., 2019a). The orange fan-shaped sponge *P. compressa* can create three-dimensional habitats thanks to its morphology, acting as appropriate refuges for both sessile species and vagile fauna (Bo *et al*., 2012), providing a similar ecological role to the deep water corals (Hogg *et al.*, 2010). As shown by the RDA results, it seems that several fish species are associated with the presence of *P. compressa*. Despite their important ecological role, sponge grounds are less studied than coral habitats, possibly due to the inherent difficulty in classifying sponge species using video surveys (Bo *et al*., 2012). This present work confirms a relationship between VME indicator species and the fish community. As reported by D'Onghia *et al*. (2019a, 2019b) VME indicator species can play an important ecological role for the fish fauna. Both commercially valuable (*H. dactylopterus* and *P. phycis*) and non-commercially valuable fish species (e.g., *L. fasciata*, *G. maraldi*, *S. arenai*, *S. cabrilla*, *A. anthias*, *C. ruber*) seem to be associated with the four VME indicator species recorded. *Helicolenus dactylopterus* is known to be associated with Cold Water Corals (including black corals), gorgonians, and sponges (Gomes-Pereira *et al*., 2014; Capezzuto *et al*., 2018; Kapiris *et al*., 2022). The species *L. fasciata*, *A. anthias* and *C. ruber* have been observed around coral habitats (Gomes-Pereira *et al*., 2014, 2017).

Concerning the substrate type preference in the area, *A. subpinnata*, *D. cornigera* and *P. compressa* were associated with muddy rock substrate while *C. rubrum* was associated with rocky substrate with a steep slope and high values of roughness. As reported in previous studies *D. cornigera* can form aggregations on rocky substrate but also on soft sediment (Smith *et al*., 2022; Enrichetti *et al*., 2023), and *P. compressa* has been observed on both rocky and muddy rock substrates (Bo *et al*., 2012). *Corallium rubrum* is typically associated with a rocky substrate characterized by steep walls (>60), as already described in the bibliography which defines the slope as a key factor for the distribution of this species (Carugati *et al*., 2022; Toma *et al*., 2022).

Another interesting finding of this study was the record of the echinoderm *C. briareus.* This species is mostly known in the Atlantic Ocean and the first observation in the Mediterranean Sea was reported from the Alboran Sea (Hebbeln *et al*., 2009) and then in Maltese waters during an ROV survey in which 26 individuals were observed (Evans *et al*., 2018). This work provides the third record of *C. briareus'* presence in Italian waters, with the previous ones reported from Amendolara bank and Dohrn Canyon (Bo *et al*., 2020b; Angiolillo *et al*., 2023). With this new observation, the total number of *C. briareus* observations in the entire Mediterranean Sea rises to 30 specimens.

Banks and seamounts are ecologically and biologically significant marine regions that play an essential role in the functioning of deep-sea ecosystems, principally contributing to offshore benthic and pelagic biodiversity (Bo *et al*., 2020a). Several studies have focused on Mediterranean seamounts, highlighting the presence of VMEs (such as coral and sponge) and their vulnerability to anthropogenic pressure e.g., from fishing activities (mainly trawling and longline) (Bo *et al*., 2014a, 2020a; Goode *et al*., 2020; Palummo *et al*., 2023). The Amendolara Bank appears to be highly impacted by ALDFG from artisanal fishing (e.g., longlines) which can cause various types of impacts to benthic communities (predominantly on arborescent species), such as abrasion and/or entanglement (Bo *et al*., 2014b; Angiolillo & Fortibuoni, 2020). Although the impact of trawling generally affects large surfaces, it is generally limited to muddy bottoms. The damage caused by longlines can affect rare or structuring benthic species since it can remove, break or abrase the tissue of benthic organisms due to strong currents or during recovery operations. Fishing gear is estimated to account for 98% of the total litter in certain areas (Angiolillo *et al*., 2015; Cau *et al*., 2017; Consoli *et al*., 2019) and is known to cause degradation to marine habitats, sediment re-suspension, reduction of habitat-forming species, and decreases in fish abundance and diversity (Valderrama Ballesteros *et al*., 2018; Consoli *et al*., 2019).

The geomorphology of Amendolara Bank favours the presence of arborescent and branched benthic species with a major risk of entanglement (Gori *et al*., 2017; Angiolillo & Canese, 2018; Consoli *et al*., 2019; Moccia *et al*., 2021). Many VME indicator taxa, such as corals and sponges, have three-dimensional growth and are thus more vulnerable. The use of longline fishing gear in VMEs should be prohibited (Chimienti *et al*., 2020b). In this study, the black coral *A. subpinnata* was found to be more vulnerable and more highly impacted by anthropogenic pressure as more than half of the longlines were observed entangled around this species. Other studies reported similar results with *A. subpinnata* being the most impacted species, easily getting entangled due to their arborescent morphology, colony size, and flexible skeleton (Angiolillo & Fortibuoni, 2020; Terzin *et al*., 2021).

The present study reports new information about the biodiversity in the Ionian Sea with the first records of the black coral *A. subpinnata* and the red coral *C. rubrum* species in the westernmost Ionian site. Moreover, evidence of the association between fish and VME indicator species together with records of anthropogenic impact caused by fishing activities emphasizes the urgent need for further research in the area that aims to increase the biodiversity knowledge base. This information is essential to make the Amendolara Bank protection measures effective as well as to plan the extension of the actual perimeter of the Site of Community Importance (SCI) to ensure inclusion of the recorded VME indicator species.

Author Contributions

VP: Investigation, Analysis, Validation, Writing – original draft. **GM:** Investigation, Analysis, Writing – Review & Editing. **SC:** Project administration, Investigation, Writing – Review & Editing. **ES:** Investigation, Writing – Review & Editing. **DP:** Analysis, Writing – Review & Editing. **NS:** Project administration, Supervision. **TR:** Funding acquisition, Project administration, Supervision. **SG:** Funding acquisition, Project administration, Supervision**.**

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