

ALMA MATER STUDIORUM UNIVERSITA' DI BOLOGNA

Scuola di Scienze Ambientali

Corso di Laurea Magistrale in Biologia Marina

**Typology and distribution of deep-sea epibenthic
Echinodermata in the Australian canyons: integrating
data from Falkor's expeditions.**

Tesi di laurea in Pianificazione spaziale e Monitoraggio dell'ambiente marino

Relatore

Prof.ssa Federica Foglini

Presentata da

Sara Zavagli

Controrelatore

Dott. Giorgio Castellan

Dott.ssa Valentina Grande

Sessione Anno Accademico 2021/2022

Index

Abstract.....	1
1. Introduction.....	3
1.1 Deep-water submarine canyons as biodiversity hotspots	3
1.1.1 Cold-water Corals as habitat formers.....	4
1.2 Deep-water Echinodermata.....	4
1.2.1 Echinodermata in the South-Western Australian submarine canyons ...	5
1.3 Aim of the study.....	6
2. Materials and method.....	7
2.1 Study area: Bremer Canyon System (BCS).....	7
2.2 Data collection.....	9
2.2.1 ROV data collection: fauna and seawater data.....	9
2.2.2 Geophysical data	10
2.3 Data processing.....	11
2.3.1 Video analysis	11
2.3.2 Statistical analysis	12
3. Results	13
3.1 Abiotic variables	13
3.2 Biodiversity of BCS benthic communities.....	14
3.3 Association between echinoderms and cnidarians	15
4. Discussion.....	25
5. Conclusion	28
6. References.....	29
7. Supplementary information.....	35

Abstract

The southern Australian continental slope is engraved by a series of submarine canyons. Approximately 80 km east of Albany city, the Bremer Marine Park covers an area that includes a system of canyons, the Bremer Canyon System (BCS). Between January and February 2020 it was explored, for the first time, during the oceanographic cruise “FK200126” lead by the Schmidt Ocean Institute, the Institute of Marine Sciences and the Institute of Polar Science of the Italian National Research Council (CNR-ISMAR, CNR-ISP) scientific team, during the RV Falkor expedition. The BCS is known to host a rich biodiversity, thanks to its geomorphology, current circulation and nutrient flow. Studies on biodiversity in this area documented the presence of a diversified community of cold-water corals (CWC) and a rich associated fauna encompassing different taxonomic components. Among these, Echinodermata represents an important component.

Echinodermata is a cosmopolitan and worldwide-spread Phylum, populating both soft and hard bottoms from shallow waters to the deep sea. However, information regarding the variables influencing the distribution of specimens within the Phylum Echinodermata in deep-sea environments is scarce in the literature. The aim of this thesis is to provide the first assessment of the factors influencing the distribution, the taxonomic diversity and abundance of Echinodermata in the Bremer Canyon System.

Three ROV (Remote Operated Vehicle) dives were selected from a set of videos collected during the RV Falkor exploration of the BCS, performed between January and February 2020 by Schmidt Ocean Institute, the Institute of Marine Sciences and the Institute of Polar Science of the Italian National Research Council (CNR-ISMAR, CNR-ISP), and analyzed for taxonomical identification.

A total of 1252 ± 1.76 organisms belonging to 62 different taxa have been individuated in the transects, within the classes Crinoidea, Ophiuroidea, and Echinoidea. The depth of dives and the concentration of dissolved oxygen in water were tested to explore the contribution of environmental conditions to the distribution of the identified specimens of Echinodermata. No statistically significant relations were observed, confirming the cosmopolitan nature of this Phylum.

A strong correlation between the Echinodermata richness and Cnidaria richness was, however, obtained, with the highest values of both abundance and taxonomic richness of echinoderms documented in sites of occurrence of black corals, scleractinians and octocorals.

The results suggest that biotic factors may play a major role in influencing the distribution of echinoderms in the BCS, with some specimens, especially crinoids, ophiuroids and echinoids, potentially benefiting from the presence of some Cnidaria's order, in terms of refuge availability, as well as food supply and suitable substrate provided.

1. Introduction

1.1 Deep-water submarine canyons as biodiversity hotspots

Submarine canyons are common geomorphic features that could be found on the margin of many ocean-facing countries. They were firstly described by marine geologists for their role as conduits for sediment export from continental shelf to the deep sea over geologic timescales (Puig et al., 2014; Fernandez-Arcaya et al., 2017).

These geological formations are also known to influence oceanographic processes such as sediment and nutrient transport and currents flow.

Such a role is related to their complex geomorphology: steep walls, heterogeneous seafloor, from rocky outcrops to soft sediment (Latras et al., 2007; Mc Clain et al., 2010; Huang et al., 2014) and a complex sea-bottom morphology (Porter-Smith et al., 2012; Fernandez-Arcaya et al., 2017).

The peculiar and complex oceanographic conditions related to submarine canyons increase primary productivity and particulate concentrations (Skirris et al., 2006; Amaro et al., 2016), making canyons hotspots of biodiversity and biomass (Bouchet et al., 2018; Bergain et al., 2018; Salgado Kent et al., 2021).

Numerous studies demonstrated the presence of rich benthic communities populating submarine canyons, including highly diverse megafauna (De Leo et al., 2010; Currie & Soroki, 2014, Davies et al., 2014).

Benthic richness arguably depends on multiple factors (Schlacher et al., 2007, Mc Clain & Barry, 2010), primarily suitable physical-chemical conditions and substrates, and food (Bett et al. 2001, Ruhl & Smith 2004, Mc Clain & Barry, 2010).

However, the information about the biodiversity characterizing submarine canyons is constantly growing due to the advent of new technologies, for example remotely operated vehicles (ROV) (Mc Clain & Barry, 2010).

1.1.1 Cold-water Corals as habitat formers

Among the benthic habitats that populate submarine canyons are Cold-water corals (Van Rooij et al. 2010°; Huvenne et al. 2011; Robert et al., 2015). Roberts et al., 2006, provides a clear definition: “Cold-water corals (CWCs) are azooxanthellate, lacking symbiotic algae, filter-feeders, from the anthozoan orders Scleractinia (stony corals), Octocorallia (soft corals), Anthipatharia (black corals) and the hydrozoan family Stylasteridae (hydrocorals)”.

Cold-water corals can build carbonate reef-like structures in the deep-water seabed, modifying the seafloor topography, water currents flow, nutrient and carbon cycling (White et al. 2012). In this way, they could serve as habitat to a rich associated fauna, supporting the food chain, promoting species interaction and providing refuges (Roberts et al.,2006; Cairns, 2007; Wagner et al.,2011; Morris et al., 2013, Henry & Roberts, 2017). The study of these species started whit the development of underwater technologies, such as ROV, that allowed to investigate deep-sea environments (Freiwald et al.,2004; Robert et al.,2015). Most of the information about these taxa are limited to Mediterranean and Atlantic regions, to date (Angeletti et al., 2014; Cordes et al., 2017; Taviani et al., 2017).

1.2 Deep-water Echinodermata

A group of organisms that can be easily observed in correspondence of the CWCs habitats is within the Phylum Echinodermata. It is a cosmopolitan highly-diversified Phylum of invertebrates that are morphologically characterized by a pentaradiated symmetry during the adult stage. There are five classes belonging to this Phylum: Crinoidea, Asteroidea, Ophiuroidea, Holothuroidea and Echinoidea (Arnone et al., 2015).

Echinoderms may take advantage from the complex architecture of CWCs habitats, which offer both sheltered cavities often containing organic rich sediments, and high water flows with little sedimentation on the outer parts of CWCs colonies (Roberts et al., 2009; Henry et al., 2017). A proof of this interaction is bioerosion traces left by Echinoidea and Asteroidea on the CWCs skeleton (Krieger & Wing, 2002; Stevenson & Rocha, 2016). The Phylum Echinodermata encompasses, however, extremely diverse organisms with different preferences. Holothuroidea and Crinoidea are widely present

in most of deep-water environments, but they seem to prefer substrates composed of coral rubble and mobile sediments (Smith & Stockley, 2005).

Crinoids, suspension feeders, take direct advantages from the presence of CWC, as they modify local hydrodynamics food particles transport nearby the reef (Henry et al., 2013a).

Ophiuroids, instead, display a wide range of feeding strategies, such as suspension-feeding, deposit-feeding, scavenging and predation. They are often found on the branches of hard corals belonging to Scleractinia order and soft corals like Alcyonacea (Miyamoto et al., 2017). For example basket stars use corals as supports to better catch plankton with their multi-branched arms, while several species in the Family Ophiuridae hide between corals branches and directly prey on their polyps (Stöhr et al., 2012).

Also, Asteroidea and Echinoidea are frequently observed in CWC habitats. These Classes include a variety of omnivorous and carnivorous species that prey on coral biofilm (Van Oevelen et al. 2009) or directly feed on live corals and coral skeletons. Echinoids have been documented to use CWC interior base or skeleton as a refuge, in presence of predators such as fish and decapods (Stevenson et al., 2014).

Knowledge about the nature of these associations is, however still scarce, with little evidence about the relationships between deep-water corals and echinoderms in the literature (Mortensen 2001, Roberts et al., 2006).

1.2.1 Echinodermata in the South-Western Australian submarine canyons

Australian mainland is surrounded by 713 submarine canyons, with the greatest number in the southern margin, because of its narrow and steep continental shelf (Heap & Harris, 2008). These submarine canyons are very ancient, maybe originated during the Mesozoic rifting of Southern Australia from the Indo-Antarctic (Heap et al., 2008; Huang et al., 2014) and differ from the other worldwide submarine canyons because they aren't directly connected to the landward (Trotter et al., 2021).

Due to their morphology and local currents, such as the northern limb of the Southern Ocean circulation system (Sarmiento et al., 2004; Pattiaratchi 2007), SW Australian submarine canyons are associated with periodic upwelling phenomena which contribute to the ecological functioning and integrity of this area (Pattiaratchi 2007; Taviani et al.,

2023). These narrow-spaced canyons, allow high amounts of organic matter to reach the abyssal plain, sustaining a high biodiversity (Richardson et al. 2005; Hill et al., 2005). Data about the distribution and diversity of Echinodermata in SW Australian canyons are sparse. Currie & Sorokin, 2014 found that Echinoderms were the most wide-distributed Phylum in two different Australia's southern continental margin submarine canyons. More was discovered by Trotter et al., 2019 during the first deep-sea ROV exploration in the Perth Canyon that occurred in 2015 and the Falkor expedition cruise performed in 2020 in the Bremer canyon systems, Perth Canyon and Mount Gabi.

1.3 Aim of the study

The aim of the study is to explore the distribution and the biodiversity, in terms of taxonomic richness and abundance, of Echinodermata in the Bremer Canyon system (BCS) by analyzing a set of ROV videos collected at different depths. The thesis also investigates patterns in the distribution of echinoderms considering both abiotic factors, such as depth, dissolved oxygen and substrate types, and biotic factors, for instance, the presence of other taxa.

2. Materials and method

2.1 Study area: Bremer Canyon System (BCS)

The Bremer Canyon region is located in the center of the inshore Southwest Integrated Marine and Coastal Regionalization of Australia province (IMCRA) (Meeuwig & Turner, 2017), situated 80 km east of Albany city.

This region covers an area of over 4380 km², whose seabed is engraved and deeply incised from the upper slope by a series of submarine canyons. Among these is the Bremer Canyon System (BCS) within the Bremer Marine Park.

A series of ROV dives have been conducted in and around the four main submarine canyons into which this system is divided: Bremer canyon, Hood canyon, near the mouth of the Henry and Knob canyons (Exton et al., 2005; Trotter et al., 2022), oriented roughly perpendicular to the continental margin and directly facing the Southern Ocean (Fig.1).

Specifically, the three ROV dives considered in the thesis were recorded in correspondence of the Bremer and Hood canyons.

The first has five main V-shaped branches extending from 140 m to 380 m deep in the shelf break and joining each other at about 2200 m into the flat and U-shaped Bremer channel. This main channel runs obliquely in a southwest direction to the continental shelf, instead, the orientation of the canyon branches runs from southwest to the southeast (Trotter et al., 2022). The canyon slope angle is maximum inside the canyon mouth, about 60°, with the flanks on the west side becoming steep walls.

The head of the Hood canyon has numerous inlets which converge in a 5 km wide central channel that is around 2500 m deep and runs perpendicular to the Australian continent. The Hood Canyon deeply incises the continental slope and its wide mouth extends from 500 m to 600 m deep, for about 40 km. At this point, there is an abrupt increase in seafloor grade, from around 10° up to 65°, and then progressively decreases towards the South (Trotter et al., 2022).

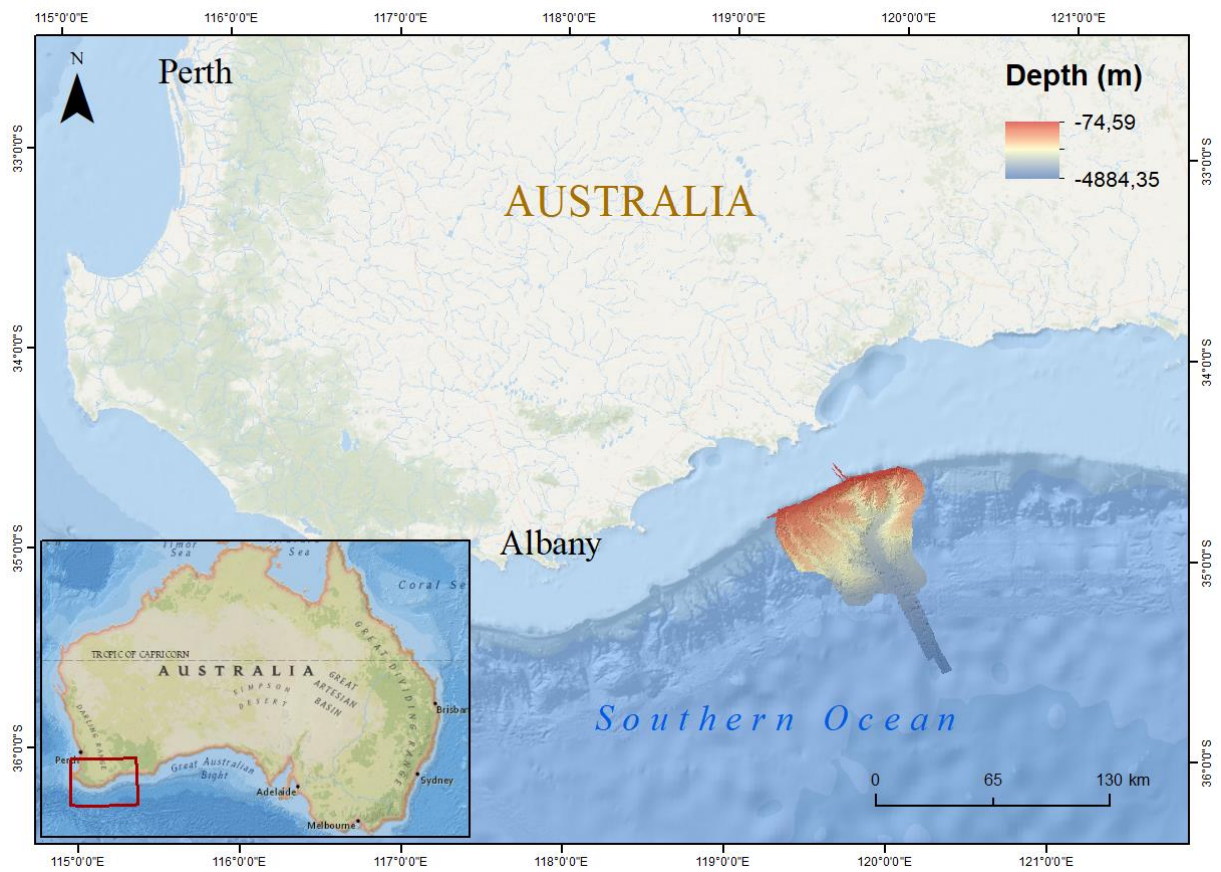


Fig.1. Study area overview, showing the location of the Bremer Canyon Systems. The map was realised with ArcMap 10.7 (© ESRI).

2.2 Data collection

2.2.1 ROV data collection: fauna and seawater data

From 26th January 2020 to 26th February 2020, the R/V Falkor of the non-profit foundation the Schmidt Ocean Institute explored the BCS's deep-water habitats during the oceanographic cruise "FK200126" lead by the National Research Council Institute of Marine Environmental Research (CNR-ISMAR), National Research Council Institute of Polar Sciences (CNR-ISP) located in Bologna and the University of Western Australia (UWA).

The survey has been conducted through the use of SuBastian, the Schmidt Ocean Institute's ROV, with the aim to collect samples and collected data during 17 dives for post-cruise geochemical and faunal analysis, especially about CWC habitats and CWC species distribution.

SuBastian is a robotic vehicle capable of diving to 4500 meters, designed and built specifically for ocean science off of Research Vessel Falkor. The ROV is outfitted with a suite of sensors and specialized equipment to support scientific data and sample collection, as well as interactive research, experimentation, and technology development.

During this expedition, the ROV was equipped with HD and 4K UHD cameras, which allowed to collect high-resolution visual recording of the seabed's benthic fauna, along the transect routes.

The vehicle descended rapidly to a pre-determined depth and covered the transect from deeper to shallower areas searching for suitable habitats.

Squidle+ and Sealog software were used to register samples and observation's data from the bottom-depth.

During its surveys, SuBastian collected also seawater data, with a 12 L Niskin bottle mounted on a Rosette system provided with a Seabird SBE 911plus CTD and Wet Labs ECO-FLNTU which allowed to collect information about temperature, salinity, and dissolved oxygen. See FK200126 cruise report for further details (Trotter et al., 2021).

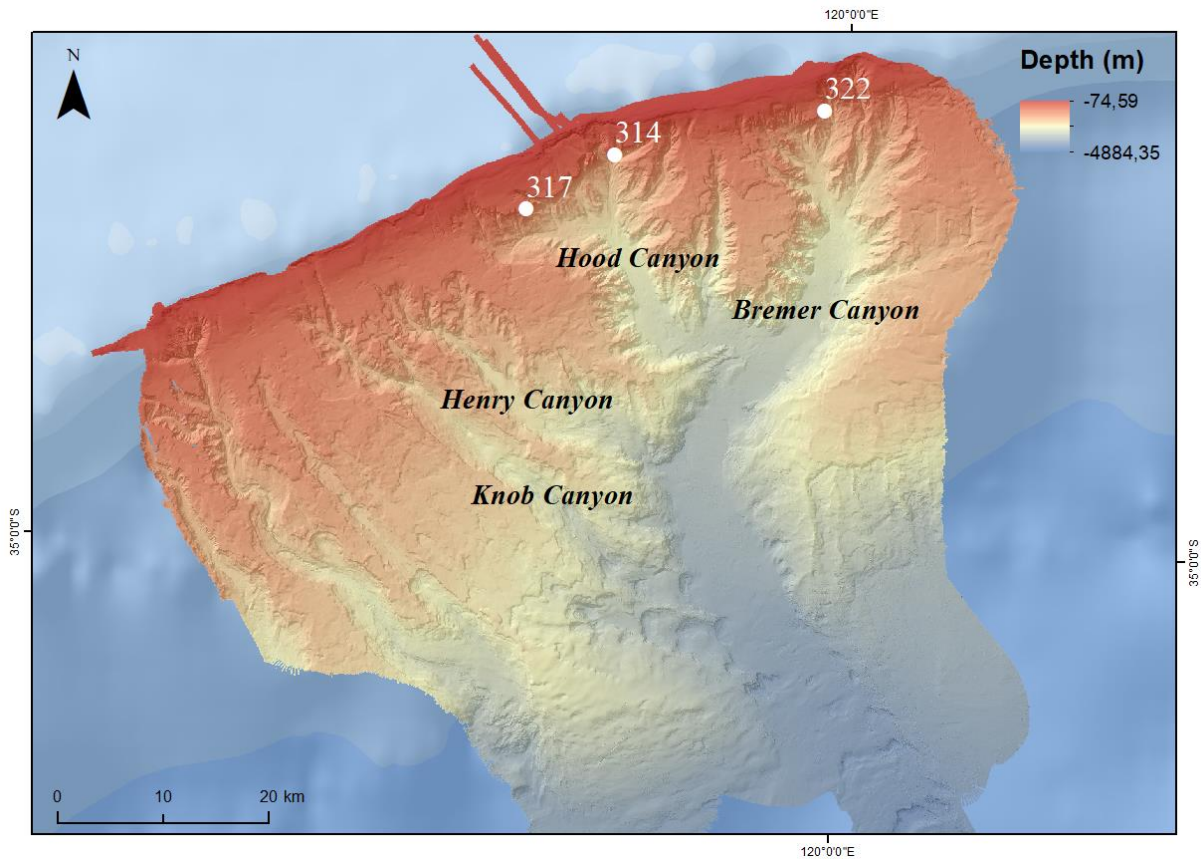


Fig.2. The Bremer Canyon System with the location of the selected ROV dives. The map has been realised with ArcMap 10.7 (© ESRI).

2.2.2 Geophysical data

High-resolution bathymetric data, which encompassed an area of more than 11,000 km² (Trotter et al., 2022), have been obtained using Falkor’s multibeam sonar systems Kongsberg EM 302 and 710 and processed both onboard and post-cruise using Qimera software, by CNR-ISMAR scientific staff.

An interactive process of selecting and rejecting sounding, furthermore, a detection function which automatically rejected outliers, have been used to “cleaned” the data using the Swath Editor.

Finally, a Digital Terrain Model (DTM) was generated at 30 m resolution for each canyon, and one, at the higher resolution for the ROV dive areas. The models were exported in ASCII files and analyzed using ArcGIS 10.5 (© ESRI).

2.3 Data processing

2.3.1 Video analysis

Three videos (S0314, S0317, S0322) were selected from the entire dataset for the taxonomic analysis, with a special focus on Echinodermata. The videos had a duration that varied from 7 to 10 hours. Adelie Video 3, a software developed to visualize, handle, and enhance images, videos and data recorded during underwater vehicle dives, was used to georeference the videos using their navigation files, which were smoothed through Adelie GIS software developed for ArcGIS. A frame every 10 seconds were extracted from the videos, obtaining about 8,000 images (Tab. 1).

The frames were analyzed by counting and identifying Echinodermata specimens at the lowest possible taxonomic rank, starting from the moment in which the ROV reached the bottom. Corals and other associated fauna were also identified and reported as presence-absence. Images have been matched with the corresponding high-definition video to improve the efficiency of recognition when needed.

A large dataset reporting the abundances and taxonomic diversity of Echinodermata and presence-absence of other benthic fauna (Annelida, Arthropoda, Chordata, Cnidaria, Mollusca and Porifera) has been obtained.

Tab 1. Metadata of the three dives considered in the study

DIVE	DIVE LOCATION	START POSITION Lat - Long (ddeg)	END POSITION Lat - Long (ddeg)	START DEPTH (m)	END DEPTH (m)	BOTTOM TIME	LENGTH (m)	TOTAL FRAME
S0314	Hood Canyon	-34.67 - 119.76	-34.67 - 119.76	1401.42	664.64	07:23:43	1685.54	2798
S0317	Hood Canyon	-34.71 - 119.67	-34.71 - 119.67	1094.97	756.46	05:38:30	1412.49	1958
S0322	Bremer Canyon	-34.63 - 119.97	-34.62 - 119.97	1089.70	632.70	08:51:05	2105.98	3212

2.3.2 Statistical analysis

In order to compare ROV videos with different lengths and frames numbers, species accumulation curves, which show the increase in the new species observed as a function of sampling effort (Uglad et al., 2003), were used to randomly sub-samples the videos transect and generated three sub-transect for each dive. The analysis was performed in R Studio software (Team R Core, 2020) using the function “specaccum” (method “random”, 1000 permutations, version 2.5–7) of the package *vegan*. The number of frames needed to document the 70% of the noted taxa were extracted, 809 for Dive S0314, 547 for Dive S0317 and 322 for Dive S0322, and used to sub-sample the videos. The taxonomic richness was calculated as the average number of benthic taxa in each ROV track. Ecological index, such as Shannon’s index, which estimates the diversity of species within a community (Shannon, 1948).

Significant differences in the abundances of echinoderms, and Crinoidea, Ophiuroidea and Echinoidea among the three sites were tested using Analysis of Variance (ANOVA) or Kruskal-Wallis in R Studio software using package “vegan”. The same technique was used to test for differences in the abundances in presence and absence of Cnidaria, specifically, Antipatharia, Scleractinaria and Octocorallia. The Normal distribution and variance’s homogeneity assumptions for the ANOVA test have been checked using Levene’s test (package *car*) and Shapiro-Wilk test (package *stats*).

If significant differences between groups were obtained, pairwise comparisons were performed using Tukey Honestly Significant Difference (package “*stats*” with Bonferroni p-value adjustment method).

When the ANOVA assumptions have been not fulfilled, Kruskal-Wallis test and Dunn's test (package “*dunn.test*” with Bonferroni p-value adjustment method) were used.

Also, a correlation test between Echinodermata richness and Cnidaria richness was conducted, using “*cor.test()*” function on R Studio Software.

3. Results

3.1 Abiotic variables

No significant differences in the depth of the dives were detected by Kruskal-Wallis test. The two dives collected in the Hood Canyon, S0314 and S0317, showed respectively an average depth of 983.7 ± 1.2 m and 934.8 ± 1.7 m, while S0322, recorded in Bremer Canyon, had an average depth of 896.7 ± 1.7 m (Fig.3.A). Differences in the dissolved oxygen were detected ($p < 0.05$), with S0314 and S0317 showing similar values, respectively 227.6 ± 0.1 $\mu\text{mol/L}$ and 227.4 ± 0.1 $\mu\text{mol/L}$, while S0322 has a lower level of 190.5 ± 0.1 $\mu\text{mol/L}$ (Fig.3.B).

All the dives imaged similar situations in terms of substrate, constituted mainly by four typologies according to the predominant component: soft, soft+hard, hard+soft and hard. The hard substrate was the typology observed the most and was colonized by the highest Echinodermata richness ($p < 0.05$), presenting also the highest abundance of individuals belonging to this Phylum ($p < 0.05$; Fig.3.C,D).

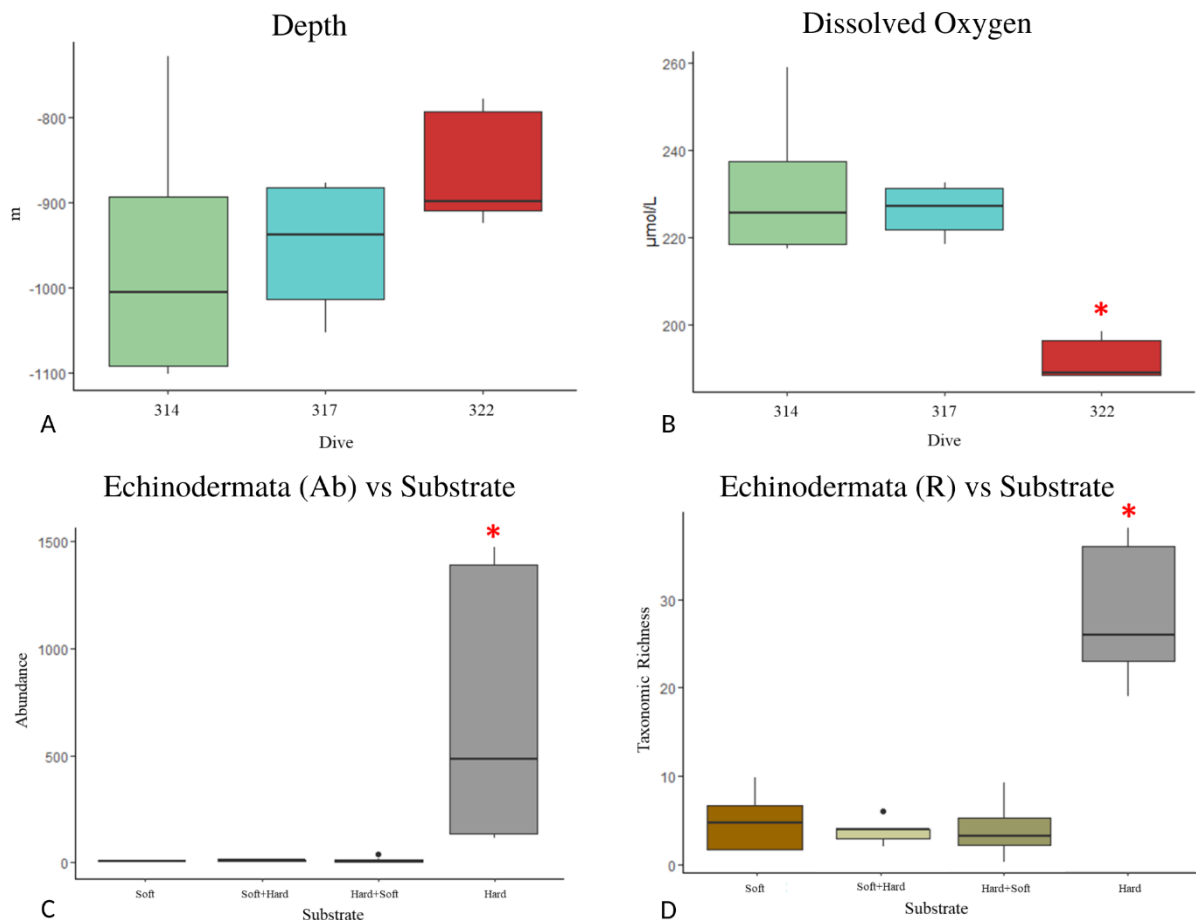


Fig.3. Boxplot showing the differences of the abiotic variable, considered in the study, between the three dives: depth (A), dissolved oxygen (B) substrate (C;D).

3.2 Biodiversity of BCS benthic communities

A total of 189 taxa were observed during the taxonomy analysis of the extracted frames, the communities were different, composed of Echinodermata, Cnidaria, Mollusca, Porifera, Arthropoda, Brachiopoda and Annelida. Despite the main habitat builders were represented by CWC, individuals of *Acesta excavata* were found in association with CWC, forming aggregation on hard substrates (Fig.4a. C).

Dive S0314 presented the largest number of taxa (34.7 ± 6.3), similar to S0322 with 33.75 ± 10.8 taxa on average, while S0317 reported a statistically significant lower value taxonomic richness (23.6 ± 2.5 taxa), as confirmed by Kruskal-Wallis statistical test ($p < 0.05$) and Dunn test (Fig.5a.A).

Echinoderms were a major component in the explored communities. Crinoidea, Ophiuroidea and Echinoidea were the most observed Classes in all three ROV tracks. Holothuroidea and asteroids were also observed, being common on soft substrate (Fig.4a.A; fig.4b.A).

Crinoids have been found in both solitary or forming groups, often in presence of other taxa (e.g., Cnidaria), both in Bremer Canyon with 1220.3 ± 40.1 individuals in a depth range from 700m to 930m and in the Hood Canyon with 229 ± 72.5 individuals between 653m and 1280m (Fig.4c.E).

Groups of ophiuroids have been found clinging on cnidarians, especially on Antipatharia and Octocorallia (e.g., *Corallium*, Paragorgiidae), in all the dives within the depth range 654-1338m. About 226.3 ± 24.2 ophiuroids have been counted in the Bremer Canyon, while 73 ± 13.3 were in the Hood Canyon (Fig.4a. C,D; Fig4c. C,E).

Also, echinoids were common, with the highest value of about 27 ± 4.5 individuals in S0322, while 26 ± 3.6 individuals were in S0314 and only 5 ± 1.7 in S0317. Often, they were leaned on the hard bottom or stuck on Antipatharia's branches (Fig.4b. D; Fig.4c. B).

Of interest, was the presence of the echinoids *Dermechinus horridus* in Dive S0314 and Dive S0322, found on hard bottom or on Antipatharia's branches where individuals seem to form a kind of aggregation (Fig.4a. E; Fig.4b. D; Fig.4c. B,E).

Holothuroids and asteroids were less abundant, rarely found on hard substrate, they seemed to prefer the soft one, except the sea star *Brisingiidae* family, found clinging in group on *Antipatharia* branches in Dive S0314 (Fig4a. E; Fig.4b. D).

Quantitatively, echinoderms were equally abundant and presented a similar taxonomic richness in the three analysed dives. The largest abundance was found in the shallowest Dive S0322, about 1489.6 ± 38.7 individuals, while 515 ± 32.3 individuals in Dive S0317 and 160 ± 15.4 have been recorded in the deeper Dive S0314 (Fig.5.C). Identified specimens appertained to 62 taxa, among which were crinoids, ophiuroids, echinoids, holothurians and asteroids. The taxa were differently distributed in the dives: S0314 and S3017 presented 9.6 ± 0.62 taxa, while 13.5 ± 1.20 taxa were identified in S0322 (Fig.5.B). The differences in abundance and taxonomic richness of echinoderms among the dives were not statistically significant according to the Kruskal-Wallis test.

Significant differences ($p < 0.05$) were observed in the Shannon's index for the echinoderms, with the highest value resulted in 1.78 ± 0.18 for dive S0314, 1.53 ± 0.11 in S0322 and 0.93 ± 0.04 in dive S0317 (Fig.5.D).

3.3 Association between echinoderms and cnidarians

During the frames analysis, echinoderms were often observed in association with cnidarians in the three dives.

About 76 taxa of cnidarians have been identified in all three explored dives, comprising antipatharias, scleractinians and octocorals: 39 ± 3.6 taxa in dive S0322, 30.6 ± 2.5 taxa in S0317 and 30 ± 3.6 taxa in S0314 (Fig.6a.A). Cnidarians often formed forests (Arnone et al., 2015) characterized by the presence of abundant Echinodermata (Fig.4a.F). Ophiuroids and crinoids often were found colonizing living and dead colonies of *Solenosmillia variables* and aggregating in correspondence of individuals of the genres *Narella* and *Desmophyllum* (Fig.4a.C).

Even when not forming forests, solitary individuals of *Antipatharia* on rocky bottom, for instance, *Leiopathes* and *Sticopathes*, were colonized by a large number of different taxa such as the echinoids *Dermechinus horridus*, sea stars in the family *Brisingiidae*, numerous small ophiuroids, basket stars and different species of crinoids (Fig.4.a.E; Fig.4.c.E).

Following the previous observations, a correlation test was made and it confirmed a strong correlation between Cnidaria taxonomic richness and Echinodermata taxonomic richness, with a Pearson correlation coefficient of $r=0.94$ ($p<0.05$)(Fig.6a.B). This correlation may be due to the presence of some Cnidaria Orders such as Antipatharia, Scleractinia and Octocorallia, as echinoderms were observed more often with them. To do a detailed exploration, Kruskal-Wallis tests between absence-presence of these Cnidarian Orders and Echinodermata abundance or taxonomic richness were conducted. Echinoderms individuals resulted significantly more abundant where Antipatharia, Scleractinia and Octotocorallia were present along the tracks ($p<0.05$), as well as they seemed to have a greater influence on echinoids taxonomic richness ($p<0.05$)(Fig.6b.). As Crinoidea, Ophiuroidea and Echinoidea were the Echinodermata Classes observed forming associations with these three Cnidaria orders, other statistical tests were conducted.

Sites with the occurrence of antipatharians reported significantly higher abundances for Crinoidea and Echinoidea ($p<0.05$)(Fig.6c.A,E) and significantly higher taxonomic richness for all three considered echinoderms Classes ($p<0.05$)(Fig.6c.B,D,F).

The presence of coral specimens belonging to order Scleractinia favoured higher values of abundance and richness of Echinoidea, and a higher taxonomic richness of Ophiuroidea, as reported by Kruskal-Wallis ($p<0.05$)(Fig.6d. D,E,F).

Similar results were also obtained for Octocorals, whose presence supported significantly higher values of abundance and richness of Ophiuroidea and Echinoidea, and a higher taxonomic richness of Crinoidea ($p<0.05$)(Fig.6e.)

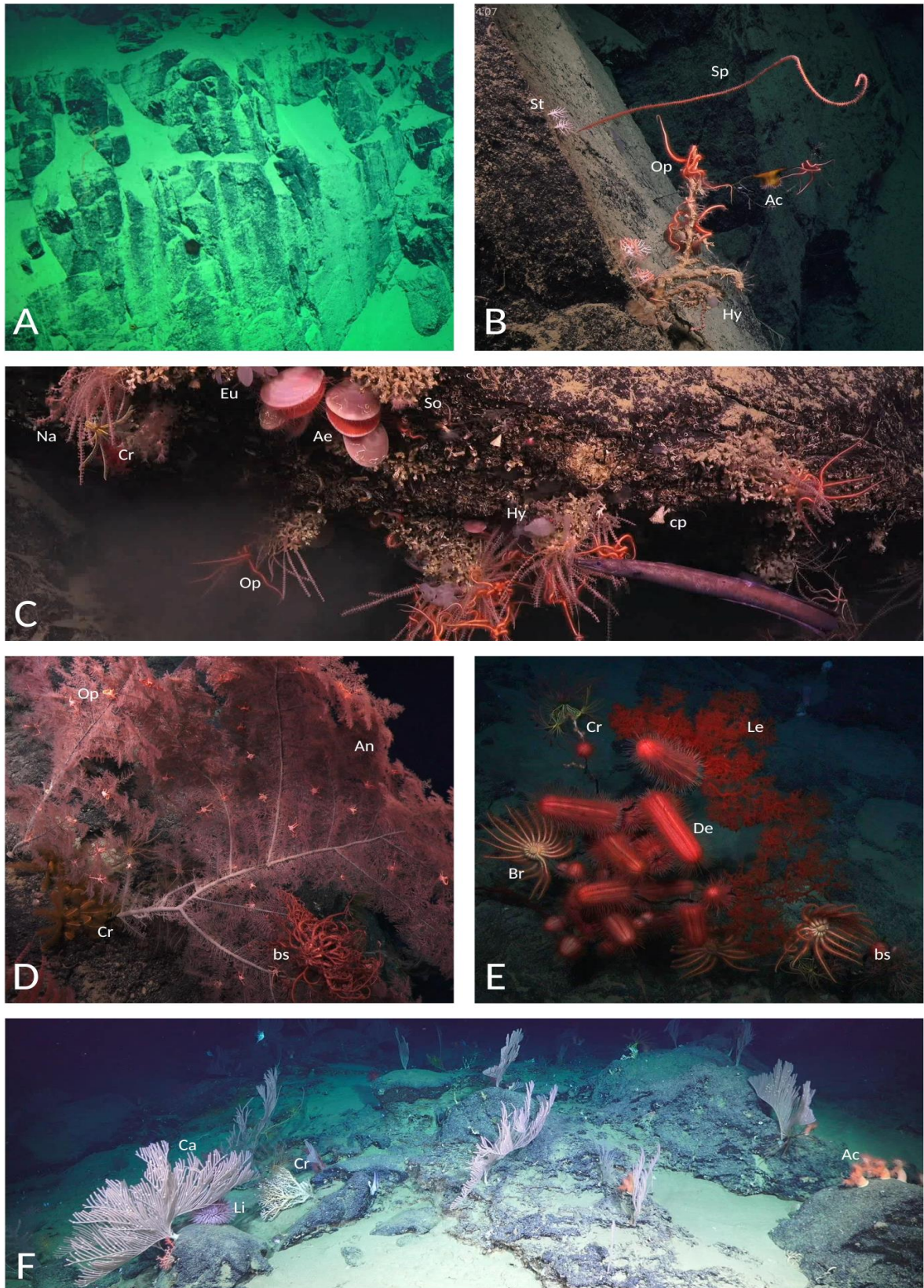
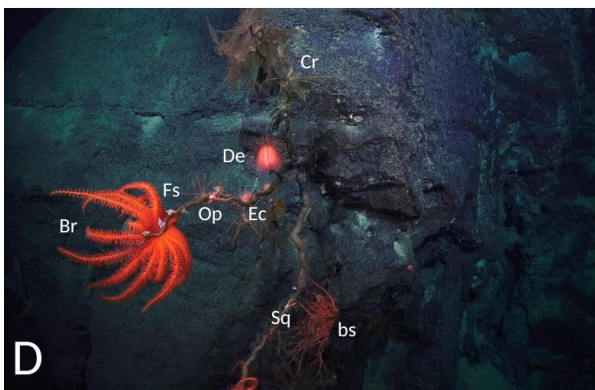
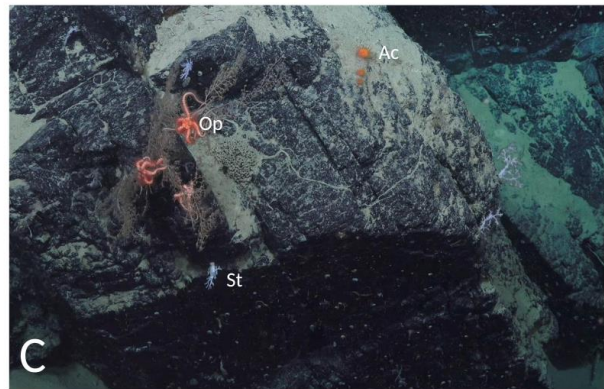
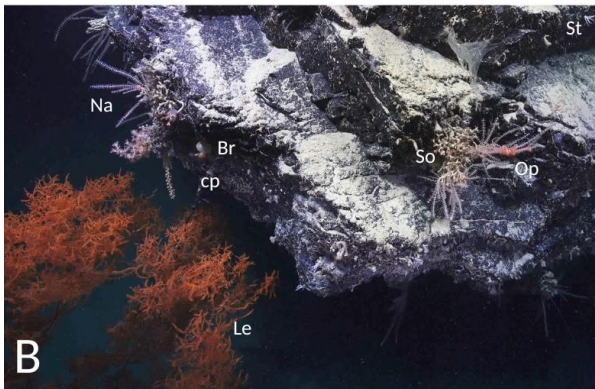
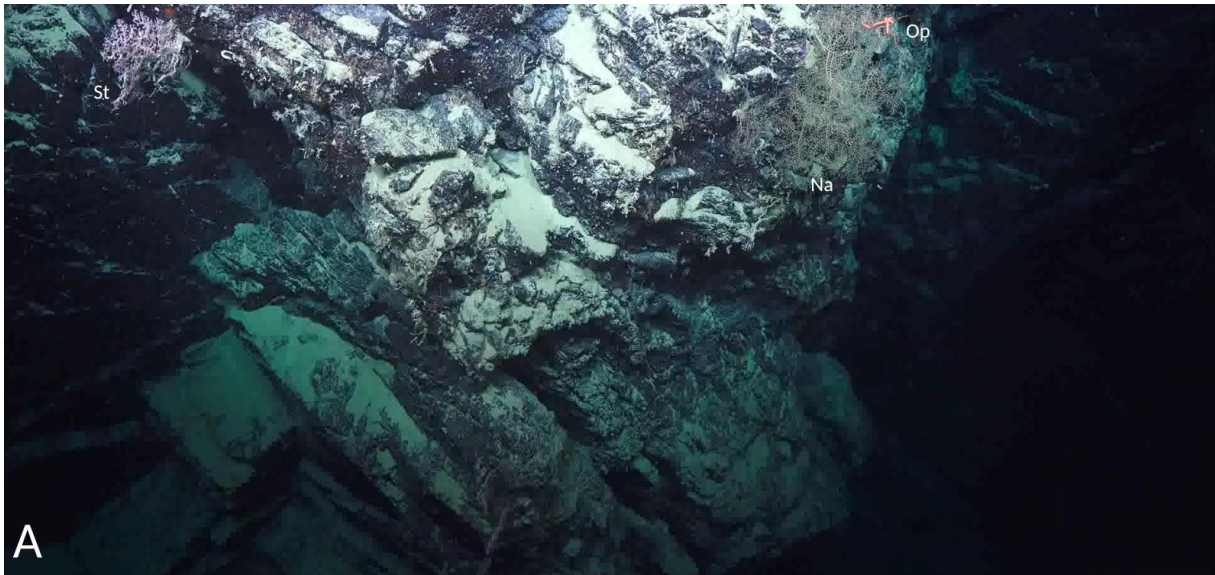


Fig.4a. Rocky substrate of Dive S0314 (A), ophiuroids(Op) on a dead coral with *Stichopates*(Sp), *Stylasteridae*(St), Actinaria(Ac) and a little *Hyalospongiae*(Hy)(B), aggregation of *Narella*(Na), *Solenosmillia variabilis*(So), ophiuroids(Op), the clam *Acesta excavata*(Ae) and some cup coral(cp), some *Hyalospongiae* (Hy) and *Euplectella* (Eu)(C), *Antipatharia* (An) colonized by little ophiuroids(Op), crinoids(Cr) and basket stars(bs)(D), a *Leiopathes* colonized by *Brisingidae*(Br) and *Dermechinus horridus*(De)(E), Bremer Canyon System community, with *Paragorgiidae*(Pr), crinoids(Cr), Actinaria(Ac) and *Liponema*(Li)(F).



4b. Rocky substrate of DiveS0317 (A), ophiuroids(Op) on *Narella*(Na) and *Solenosmillia variabilis*(So), an orange *Leiopathes*(Le), an individual cup coral(cp) and Brachiuroidea(Br)(B), ophiuroids individuals(op), little *Stylasteridae*(St) and Actinaria(Ac)(C), a big *Brisingidae*(Br) on a dead coral with ophiuroids(Op), crinodis(Cr), echinoids(Ec), *Dermochinus horridus*(De) and a basket star(bs), a snail belonging to *Fusitron* genera(Fs)(D), a closer imagine of a cup coral *Desmophyllum*(De) and a crinoids(Cr), with a little *Stylasteridae*(St)(F).

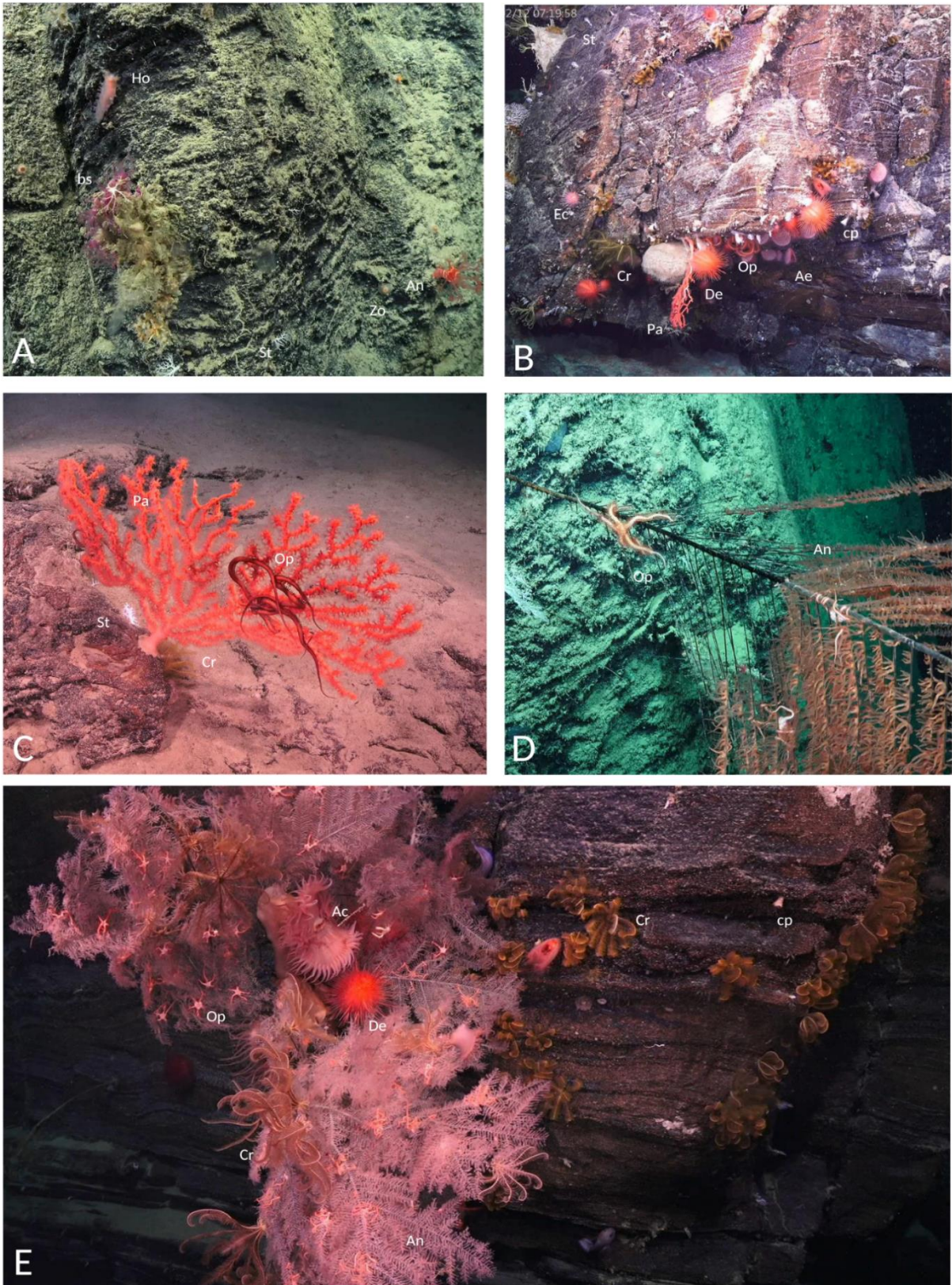


Fig.4c. Rocky wall colonized by *Stylasteridae*(St), *Zoantaria*(Zo), a red *Aantomasthus*(An), little basket star(bs) and holothuroid(Ho)(A), an aggregation of crinoids(Cr), the clam *Acesta excavate*(Ae), ophiuroids(Op), echinoids(Ec) and *Dermechinus horridus*(De) on a *Paragorgidae* individual (Pa)(B), an ophiuroid(Op) hidden between a *Paragorgidae*(Pa) branches, on the substrate crinoids(Cr) and *Stylasteridae*(St)(C), Antipatharia(An) with some ophiuroids(Op) on it (D), a big Antipatharia(An), colonised by ophiuroids(Op), crinoids(Cr), *Dermechinus horridus*(De), a big pink Actinaria (Ac), in the middle, smaller crinoids (Cr) on the rocky wall with cup corap(cp)(E).

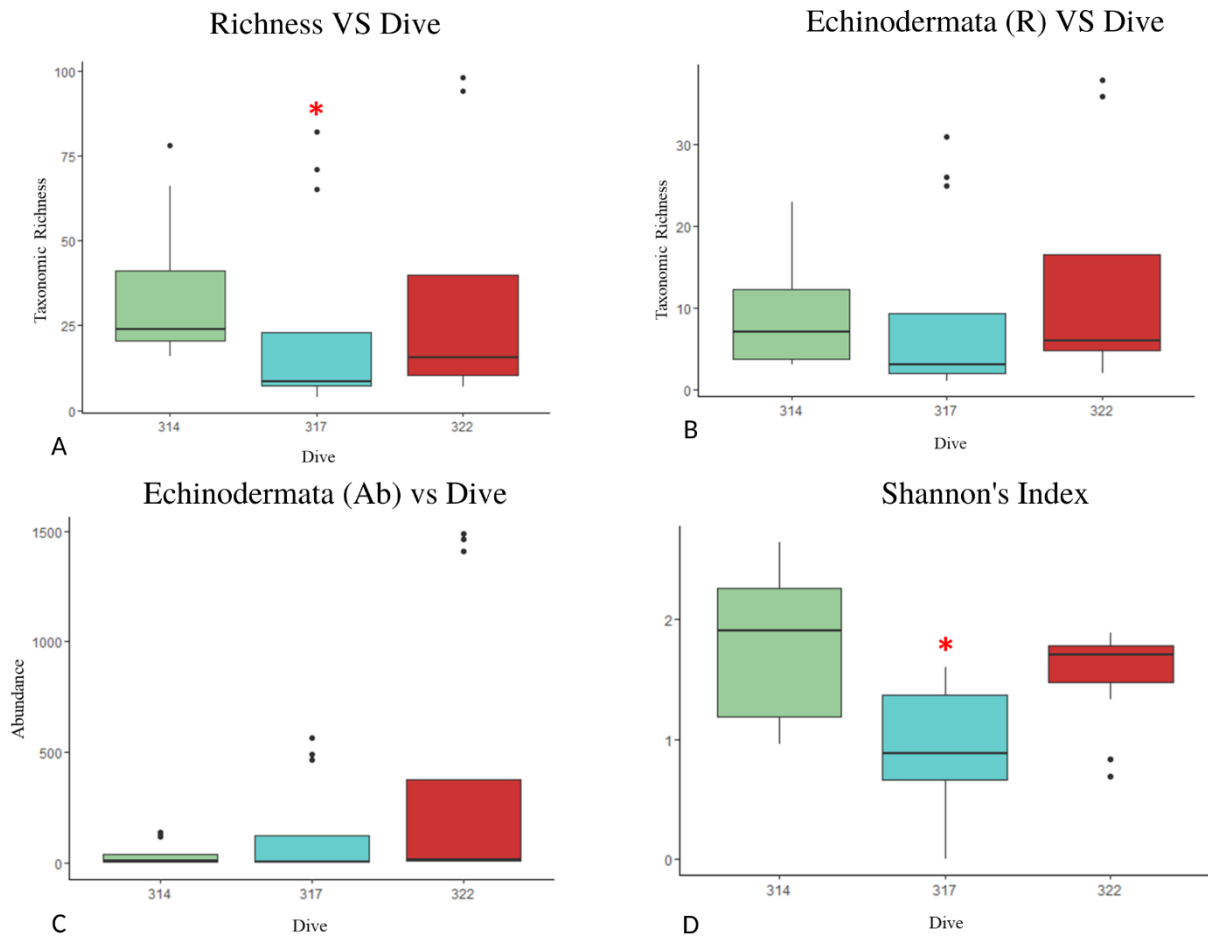


Fig.5. Boxplot differences in Richness, considering all the taxon recorded in the Dive (A), Echinodermata taxonomic richness among Dive (B) and abundance (C), Shannon's index (D) of the explored dives' community.

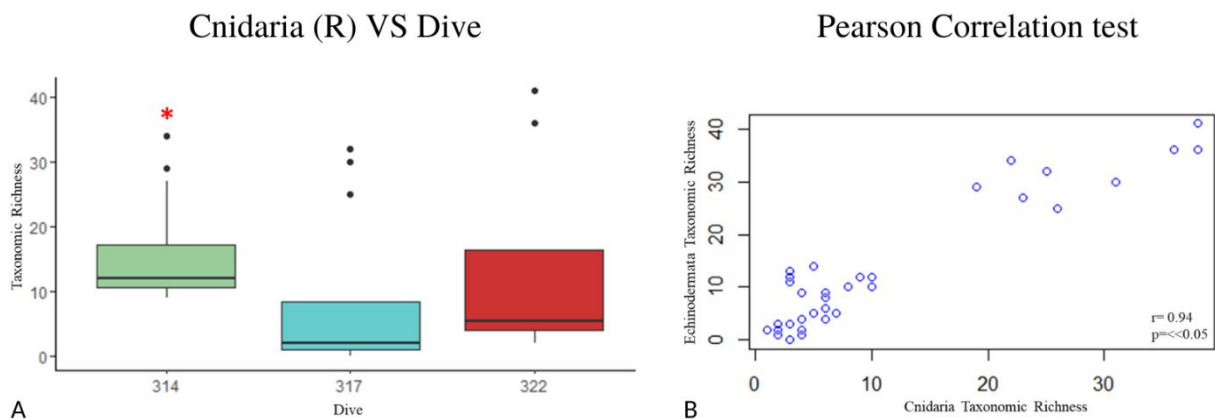


FIG.6a. First boxplot shows the Taxonomic Richness of Cnidaria among Dive (A), a strong and significant correlation between Echinodermata Taxonomic Richness and Cnidaria Taxonomic Richness ($r=0.94$) was confirmed (D).

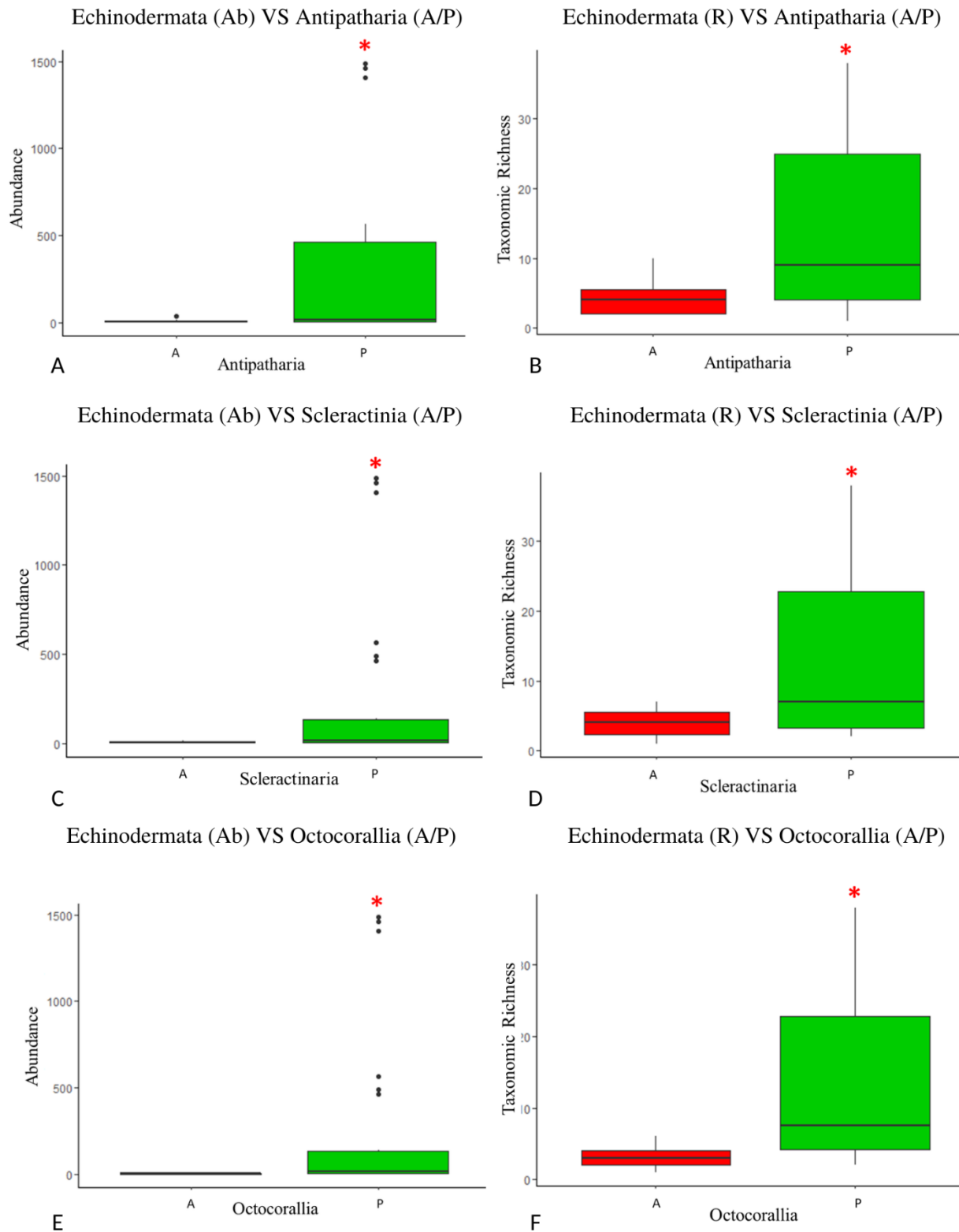


Fig.6b. Boxplot showing Echinodermata abundance variations between absence or presence of different Cnidaria's orders (A, C, E) on the right boxplot showing Echinodermata Taxonomic Richness variations between absence or presence of different Cnidaria's orders (B, D, F).

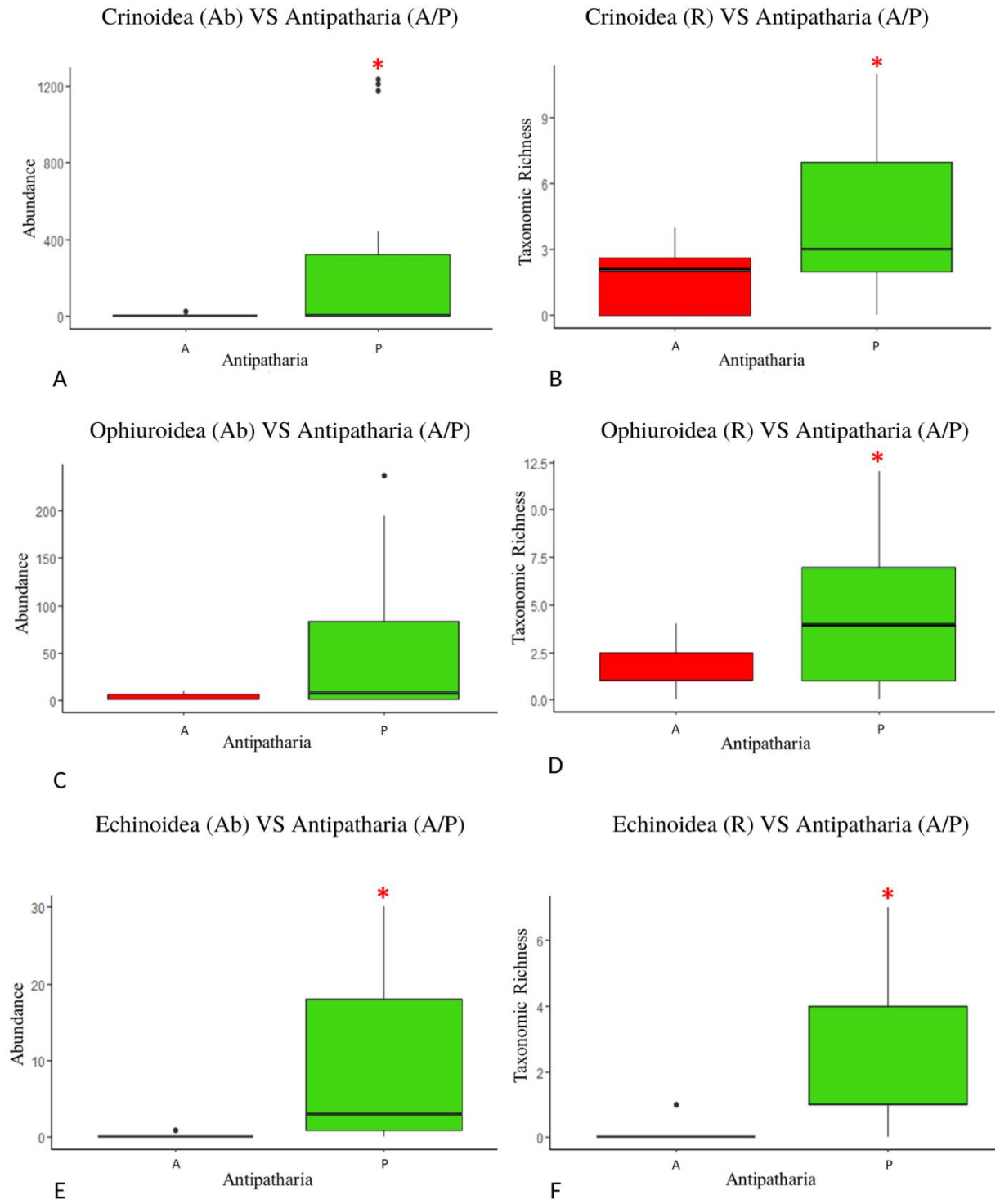


Fig.6c. Boxplot showing Crinoidea, Ophiuroidea and Echinoidea abundance variations between absence or presence of Antipatharia (A, C, E) on the right boxplot showing Crinoidea, Ophiuroidea and Echinoidea Taxonomic Richness variations between absence or present of Antipatharia (B, D, F).

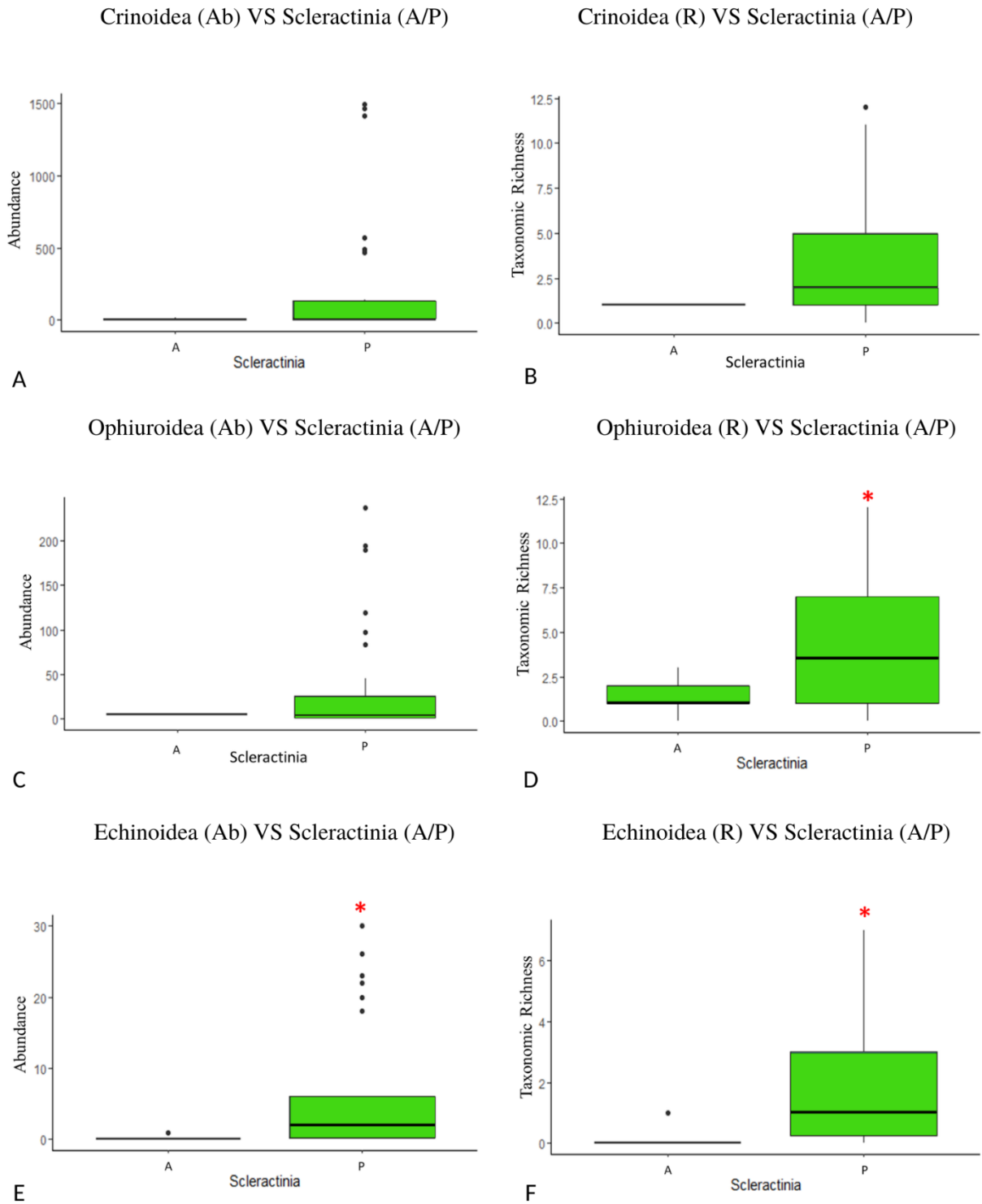


Fig.6d. Boxplot showing Crinoidea, Ophiuroidea and Echinoidea abundance variations between absence or presence of Scleractinaria (A, C, E) on the right boxplot showing Crinoidea, Ophiuroidea and Echinoidea Taxonomic Richness variations between absence or present of Scleractinaria (B, D, F).

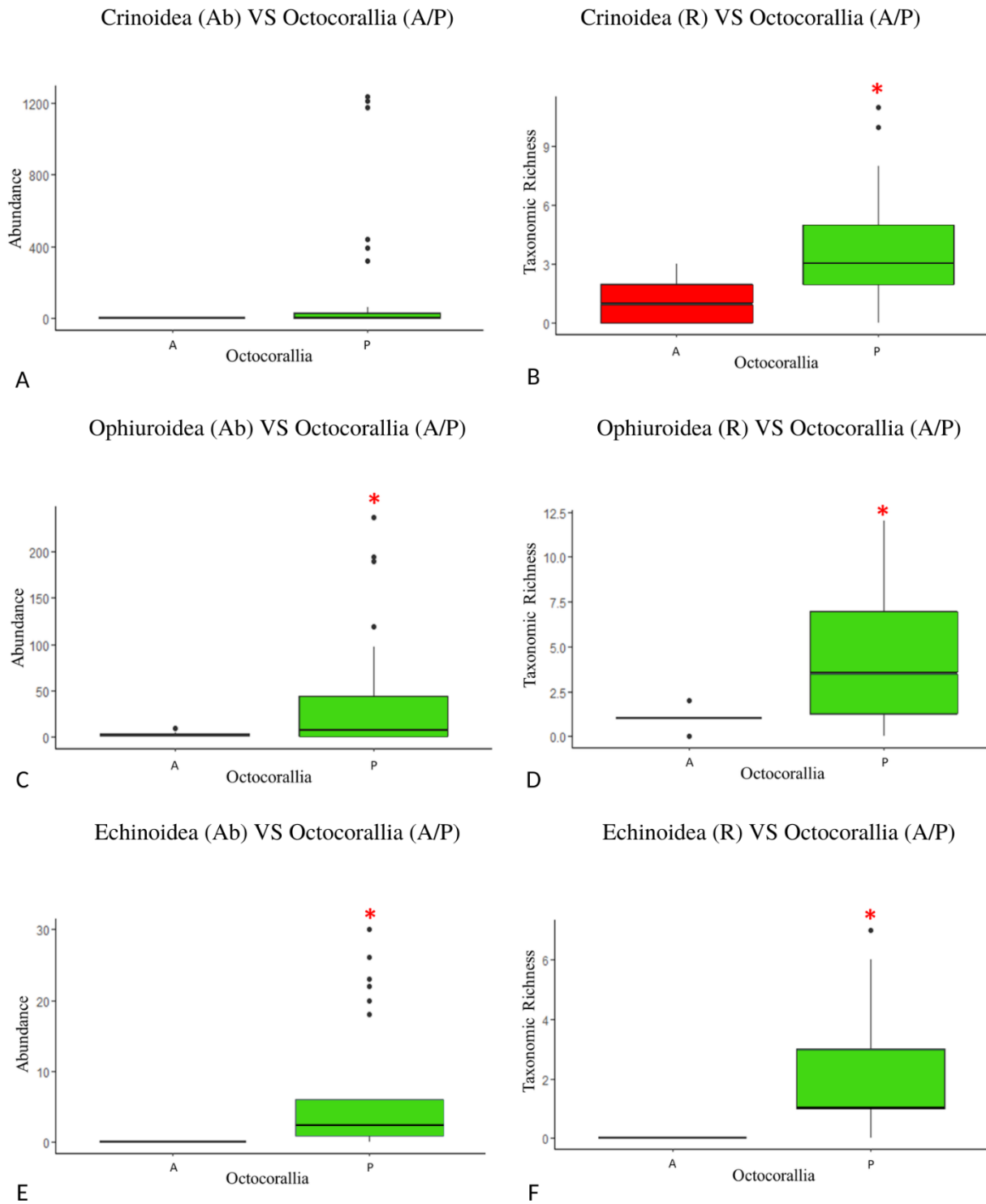


Fig.6e. Boxplot showing Crinoidea, Ophiuroidea and Echinoidea abundance variations between absence or presence of Octocorallia (A, C, E) on the right boxplot showing Crinoidea, Ophiuroidea and Echinoidea Taxonomic Richness variations between absence or present of Octocorallia (B, D, F).

4. Discussion

The Bremer Canyon System, located in correspondence of a marine protected area (Marine Bremer Park), is known to represent a biodiversity hotspot. Its canyons, with their steep and narrow walls, receive organic material from the near productive lands (Richardson et al. 2005) and contribute to creating suitable conditions for an incredibly rich and differentiated fauna (Trotter et al. 2022). Among them, Cold-Water Corals (CWC) are the conspicuous inhabitant of this deep-sea environment, playing a key role as habitat-former and providing different ecosystem services, such as carbon sink, food resources, and refuge (Fabri et al., 2017; Van de Beld et al., 2017). The peculiar currents and water masses in the BCS generate conditions suitable for the presence of CWC (Woo & Pattiaratchi 2008; Duran et al., 2020), with dissolved oxygen exceeding the minimum level required for the survival of CWC species even in the deepest sections of the explored canyons (Addamo et al., 2016).

Among the megafauna associated with CWC ecosystems, Echinodermata received comparatively less attention with a scarce number of studies reporting quantitative information on this Phylum. The analysis of about 8,000 frames extracted from high-resolution video allowed to provide the first quantitative assessment of the distribution and richness of echinoderms in the BCS.

It is well known that Echinoderms can easily adapt and occupied a wide range of environmental conditions (Stöhr et al., 2012; Mecho et al., 2019), from the shallowest depth of tide pools to the deepest depth of the abyss, without preferences (Mecho et al., 2014; Mironov et al., 2018). Previous studies have shown that they can colonize substrate exposed to a different amount of dissolved oxygen, from very low concentration to higher, when water is renewed by local currents (Chiang & Quiñones 2007; Cañete et al., 2012).

The analysis of ROV videos confirmed the cosmopolitan nature of the Phylum, being present in a wide depth range, varied from 200 m to 2000 m, of the Hood Canyon and Bremer Canyon. Indeed, abundance and richness of Echinodermata resulted as not being influenced by the depth, used also as a proxy of variation of depth-related variables (such as temperature, nutrients), and dissolved oxygen. Despite a set of different abiotic variables that may influence the distribution of benthic fauna, the results here reported

suggesting that the distribution of Echinodermata in the BCS might not be significantly influenced by physical-chemical conditions.

Contrarily, the typology of substrate seems to play a major role in shaping Echinodermata distribution in the BCS, with crinoids, ophiuroids and echinoids often occupied hard substrates (McClain et al., 2010).

Furthermore, the co-occurrence with cnidarians suggests that abundance and richness of echinoderms might be favoured by the presence of corals. The rocky steep walls of the canyons host various Orders of Cnidarian, specially Antipatharia, Scleractinia and Octocorallia, on which it was common to find echinoderms, where they seemed to find a shelter, food source, or a good substrate to live. For instance, branches of individuals of Primnoidea and Paragorgiidae branches were observed highly colonized by echinoderms. Corals belonging to the *Caliptrophora* genre often have been found forming spectacular forests, inhabited by a rich and abundant Echinodermata community, especially ophiuroids like basket stars and different species of crinoids.

Along the flatter margin of the head of the Hood Canyon, black corals hosted basket stars, big Brisingsidae individuals, little brittle stars, crinoids and Cidaridae sea urchins. Antipatharians, *Acesta excavata*, actinians and stylasterids have been found on the steep wall of the Bremer canyon forming aggregations with hundreds of crinoids, brittle stars and echinoids.

A species that has raised particular attention was *Dermechinus horridus*, which has been observed both numerous aligned on the hard and flat bottom of Hood Canyon and sparse grabbed on Antipatharia's branches. Despite the scarce literature on cactus urchins, however, prevents to understand the exact reason for this aggregative behaviour, this species might use corals as support to better reach the water column or as a source of organic particles during grazing (Rowden et al., 2010).

In the sheltered areas of the BCS, patches of Octocorals (e.g., *Narella* and *Corallium*) with *Solenosmillia variabilis* not only were observed in association with glass sponges, solitary corals in the Genus *Desmophyllum*, zoanthids, brachiopods and bivalves, but also provided refuge for crinoids and brittle stars.

A statistically strong correlation between Echinodermata and Cnidaria richness was found, confirming the contribution of cnidarians to create suitable conditions for

echinoderms' lives. Especially, the presence of coral specimens belonging to the Order Antipatharia (e.g. *Leiopathes* and *Sticopathes*) favoured higher values of abundance and taxonomic richness of Crinoidea and Echinoidea and taxonomic richness of Ophiuroidea, although they have often been observed in large numbers hidden between black corals branches (Stöhr et al., 2012; Ingrassia et al., 2016).

Despite Crinoidea abundance doesn't benefit from Octocorallia, their presence resulted as having a great influence on both abundance and taxonomic richness of Ophiuroidea and Echinoidea, also Crinoidea taxonomic richness reach and higher value in presence of this cnidarians. While Scleractinia's presence supported significant higher values of abundance and richness of Echinoidea and a higher taxonomic richness of Ophiuroidea. The results obtained, not only confirmed how CWC in the Bremer Canyon System are biodiversity hotspots, but also, about echinoderms, influencing their abundance and taxonomic richness.

Although the results of the thesis support the hypothesis that biotic factors may influence the abundance and richness of Echinodermata in the BCS, it must be acknowledged that visual analysis is not devoid of limitations that may affect the results. Abundance and taxonomic richness of echinoderms might be underestimated due to the behaviour of specimens, often hiding among sessile fauna. The quality of the images can also affect the quality of the identification.

Also, holothuroids and asteroids were poorly recorded in the analysed videos. However, individuals of these Classes are known to populate soft substrates that were scarcely imaged during the dives since the aim of the expedition was to explore CWC communities (Trotter et al., 2022). Echinoderms may, then, be abundant also on soft substrates in the BCS.

The present study, however, represents the first quantitative assessment of Echinodermata distribution in the BCS, providing baseline information for more in-depth future studies. To increase the knowledge on the deep-sea echinoderms populating the BCS, it would be necessary to integrate observations with the analysis of physical samples for more precise identification of echinoderms species.

5. Conclusion

The Bremer Canyon System host a great variety of species. Echinodermata, represents a consistent component of the associated fauna of BCS's Cold Water Coral ecosystem. The knowledge about the role and distribution patterns in deep-water habitats of this Phylum is still scarce.

The present study provides, for the first time, general and preliminary observations about the Echinodermata community of the Bremer Canyon System, especially in terms of abundance and taxonomic identification. A total of 6505 Echinodermata were counted in the BCS during the frames observations, divided into 62 different taxa, belonging to Crinoidea, Ophiuroidea, Echinoidea, Holothuroidea and Asteroidea Classes. Individuals, were counted and classified at the lowest possible taxonomic rank. The analysis of ROV videos confirmed the cosmopolitan nature of the Phylum, indeed, abundance and richness of Echinodermata resulted as not being influenced by the abiotic variables considered: depth and dissolved oxygen. Contrarily, the typology of substrate seems to play a major role in shaping distribution of crinoids, ophiuroids and echinoids which preferred to occupy hard substrates, like the canyon's steep walls and corals.

Furthermore, the presence of cnidarians, especially species belonging to orders Antipatharia, Scleractinia and Octocorallia, suggests that abundance and richness of echinoderms might be favoured. They play a key role in providing food, shelter and a good substrate. For example, Antipatharia, significantly contributed to higher abundances and richness for Crinoidea and Echinoidea and significantly higher taxonomic richness for Ophiuroidea. As well as, the taxonomic richness of the three Classes and Ophiuroidea and Echinoidea abundance are positively influenced by Octocorallia's presence.

This study represents a starting point to improve information about the distribution of Echinodermata in the Bremer Canyon Systems, ultimately providing further supporting information on the biodiversity associated with CWC ecosystems that may be included in the management and conservation of natural heritage of the Bremer Marine Park.

6. References

- Addamo AM, Vertino A, Stolarski J, García-Jiménez R, Taviani M & Machordom A (2016). Merging scleractinian genera: The overwhelming genetic similarity between solitary *Desmophyllum* and colonial *Lophelia*. *BMC Evolutionary Biology*, 16(1), 1–17. <https://doi.org/10.1186/s12862-016-0654-8>
- Amaro T, Huvenne VAI, Allcock AL, Aslam T, Davies JS, Danovaro R, De Stugter HC, Duineveld GCA, Gambi C, Gooday AJ, Gunton LM, Hall R, Howell KL, Ingels J, Kiriakoulakis K, Kershaw CE, Lavaleye MSS, Robert K, Stewart H, Van Rooij D D & Wilson AM (2016). The Whittard Canyon—A case study of submarine canyon processes. *Progress in Oceanography*, 146, 38-57. <https://doi.org/1j.pocean.2016.06.003>
- Angeletti L, Taviani M, Canese S, Foglini F, Mastrototaro F, Argnani A, Trincardi F, Bakran-petricioli T, Ceregato A, Chimienti G, Macic V, Polineso A (2014). New deep-water cnidarian sites in the southern Adriatic Sea. *Mediterranean Marine Science* 15, 263–273. <https://doi.org/10.12681/mms.558>
- Arnone MI, Byrne M, Martinez P (2015). Echinodermata. In *Evolutionary developmental biology of invertebrates 6* (pp. 1-58). Springer, Vienna.
- Bargain A, Foglini F, Pairaud I, Bonaldo D, Carniel S, Angeletti L, Taviani M, Rochette S, Fabri MC (2018). Predictive habitat modeling in two Mediterranean canyons including hydrodynamic variables. *Progress in Oceanography*. 169, 151–168. <https://doi.org/10.1016/j.pocean>.
- Bett BJ, Malzone MG, Narayanaswamy BE, Wigham BD (2001). Temporal variability in phytodetritus and megabenthic activity at the seabed in the deep Northeast Atlantic. *Progress in Oceanography* 50:349–368. [https://doi.org/10.1016/S0079-6611\(01\)00066-0](https://doi.org/10.1016/S0079-6611(01)00066-0)
- Bouchet PJ, Meeuwig J, Erbe C, Salgado Kent C, Wellard R, Pattiaratchi C (2018). Bremer Canyon Emerging Priorities Project EP2: Final Report. National Environmental Science 1101 Programme, Marine Biodiversity Hub., 1–32.
- Cairns SD (2007). Deep-water corals: An overview with special reference to diversity and distribution of deep-water scleractinian corals. *Bulletin of Marine Science*, 81(3), 311–322.
- Cañete JI, Häussermann V. (2012). Colonial life under the Humboldt Current System: deep-sea corals from O'Higgins I seamount. *Latin American Journal of Aquatic Research*, 40(2), 467-472. <https://doi.org/10.3856/vol40-issue2-fulltext-23>
- Chiang OE, Quiñones RA. 2007. Relationship between viral and prokaryotic abundance on the Bajo O'Higgins Seamount, Humboldt Current System off Chile. *Science Marine*, 71: 37-46. <https://doi.org/10.3989/scimar.2007.71n137>
- Cordes E, Arnaud-Haond S, Bergstad OA, da Costa Falcão AP, Freiwald A, Roberts JM et al. (2017). “Chapter 42 - cold-water corals,” in *The First Global Integrated Marine Assessment: World Ocean Assessment I*, ed. United Nations (New York,

- NY: Cambridge University Press), 803–816. <https://doi.org/10.1017/9781108186148.052>
- Currie DR, Sorokin SJ (2014). Megabenthic biodiversity in two contrasting submarine canyons on Australia's southern continental margin. *Marine Biology Research* 10, 97–110. <https://doi.org.ezproxy.unibo.it/10.1080/17451000.2013.797586>
- De Leo FC, Smith CR, Rowden AA, Bowden DA, Clark MR (2010). Submarine canyons: hotspots of benthic biomass and productivity in the deep sea. *Proceedings of the Royal Society B* 277, 2783–2792. <http://dx.doi.org/10.1098/rspb.2010.0462>.
- Duran ER, Phillips HE, Furue R, Spence P, Bindoff NL (2020). Southern Australia Current System based on a gridded hydrography and a high-resolution model. *Progress in Oceanography*. 181, 102254. <https://doi.org/10.1016/j.pocean.2019.102254>
- Fabri MC, Bargain A, Paireaud I, Pexdel L, Taupier-Letage I (2017). Cold-water coral ecosystems in Cassidaigne Canyon: an assessment of their environmental living conditions. *Deep Sea Res. II* 137, 436–453. <https://doi.org/10.1016/j.dsr2.2016.06.006>
- Fernandez-Arcaya U, Ramirez-Llodra E, Aguzzi J, Allcock AL, Davies JS, Dissanayake A, Harry P, Howell K, Huevenne VAI, Macmillan-Lawler M, Martín J, Menot L, Nizinski M, Puig P., Rowden AA, Sanchez F, Van den Beld IMJ (2017). Ecological role of submarine canyons and need for canyon conservation: a review. *Frontiers in Marine Science*, 4, 5. <https://doi.org/10.3389/frames.2017.00005>
- Freiwald A, Fosså JH, Grehan A, Koslow T, Roberts JM (2004). Cold-water coral reefs: out of sight-no longer out of mind. UNEP-WCMC. <https://doi.org/10.5962/bhl.title.45025>
- Harris PT, McMillan-Lawler M, Rupp J, Baker EK (2014). Geomorphology of the oceans. *Marine Geology*, 352, 4-24. <https://doi.org/10.1016/j.margeo.2014.07.007>
- Heap AD, Edwards J, Fountain L, Spinnocchia M, Hughes M, Mathews E, Griffin J, Borissova I, Blevin J, Mitchell C, Krassay A (2008). Geomorphology, Sedimentology, and Stratigraphy of Submarine Canyons on the SW Australian Slope. Geoscience Australia, Canberra, ACT.
- Heap AD, Harris PT (2008). Geomorphology of the Australian margin and adjacent seafloor. *Australian Journal of Earth Science* 55, 555–585. <https://doi.org.ezproxy.unibo.it/10.1080/08120090801888669>
- Henry LA, Roberts JM (2017). Global biodiversity in cold-water coral reef ecosystems. *Marine animal forests: the ecology of benthic biodiversity hotspots*, 235-256. https://doi.org/10.1007/978-3-319-21012-4_6
- Henry LA, Moreno N, Roberts M (2013a). Multi-scale interaction between local hydrography, seabed, topography and community assembly on cold-water coral reefs. *Deep-Sea Res I*. 10:2737-800. <https://doi.org/10.5194/bg-10-2737-2013>

- Hill PJ, De Deckker P, Exon NF (2005). Geomorphology and evolution of the gigantic Murray canyons on the Australian southern margin. *Australian Journal of Earth Sciences* 52: 11736. <https://doi.org.ezproxy.unibo.it/10.1080/08120090500100085>
- Huang Z, Nichol SL, Harris PT, Caley MJ (2014). Classification of submarine canyons of the Australian continental margin. *Marine Geology*, 357, 362-383. <https://doi.org/10.1016/j.margeo.2014.07.007>
- Huvenne VAI, Tyler PA, Masson DG, Fisher EH, Hauton C, Huhnerbach V, Le Bas TP, Wolff GA (2011) A picture on the wall: innovative mapping reveals cold-water coral refuge in submarine canyon. *PLoS ONE*, 6, e28755. <https://doi-org.ezproxy.unibo.it/10.1371/journal.pone.0028755>
- Ingrassia M, Macelloni L, Bosman A, Chiocci FL, Cerrano C, Martorelli E (2016). Black coral (Anthozoa, Antipatharia) forest near the western Pontine Islands (Tyrrhenian Sea). *Marine Biodiversity*, 46, 285-290. <https://doi.org/10.1007/s12526-015-0315-y>
- Krieger K, Wing B (2002). Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia* 471, 83–90.
- Leonard C, Evans J, Knittweis L, Aguilar R, Alvarez H, Borg JA, Garcia S, Schembri PJ (2020). Diversity, distribution, and habitat associations of deep-water echinoderms in the Central Mediterranean. *Marine Biodiversity*, 50, 1-15. <https://doi.org/10.1007/s12526-020-01095-3>
- McClain CR, Barry JP (2010). Habitat heterogeneity, disturbance, and productivity work in concert to regulate biodiversity in deep submarine canyons. *Ecology*, 91(4), 964-976. <https://doi-org.ezproxy.unibo.it/10.1890/09-0087.1>
- Mecho A, Billett DS, Ramírez-Llodra E, Aguzzi J, Tyler PA (2014). First records, rediscovery and compilation of deep-sea echinoderms in the middle and lower continental slope of the Mediterranean Sea. <https://doi.org/10.3989/scimar.03983.30C>
- Mecho A, Easton EE, Sellanes J, Gorny M, Mah C (2019). Unexplored diversity of the mesophotic echinoderm fauna of the Easter Island ecoregion. *Marine Biology*, 166, 1-17. <https://doi.org/10.1007/s00227-019-3537-x>
- Meeuwig J, Turner J (2017) Bremer Canyon Progress Report.
- Mironov AN, Minin KV, Dilman AB, Smirnov IS (2018). Deep-sea echinoderms of the Sea of Okhotsk. *Deep Sea Research Part II: Topical Studies in Oceanography*, 154, 342-357. <https://doi.org/10.3989/scimar.03983.30C>
- Morris KJ, Tyler PA, Masson DG, Huvenne VIA, Rogers AD (2013). Distribution of cold-water corals in the Whittard Canyon, NE Atlantic Ocean. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 92, 136–144. <https://doi.org/10.1016/j.dsr2.2013.03.036>
- Mortensen PB (2001). Aquarium observation on the deep water coral *Lophelia pertusa* (L., 1758) (Scleractinia) and selected associated invertebrates. *Ophelia* 54:83-104. <https://doi-org.ezproxy.unibo.it/10.1080/00785236.2001.10409457>

- Pattiaratchi C (2007). Understanding areas of high productivity within the south-west marine region Report prepared for the National Oceans Office.
- Porter-Smith R, Lyne VD, Kloser RJ, Lucieer VL (2012). Catchment-based classification of Australia's continental slope canyons. *Marine Geology* 303–306, 183–192. [Hattps://doi.org/10.1016/j.margeo.2012.01.008](https://doi.org/10.1016/j.margeo.2012.01.008)
- Puig P, Palanques A, Martín J (2014). Contemporary sediment-transport processes in Submarine Canyons. *Annual Review of Marine Science* 6, 53–77. [Hattps://doi.org.ezproxy.unibo.it/10.1146/annurev-marine-010213-135037](https://doi.org.ezproxy.unibo.it/10.1146/annurev-marine-010213-135037)
- Richardson L, Mathews E, Heap A (2005) Geomorphology and sedimentology of the South Western planning area of Australia: Review and synthesis of recent literature in support of regional marine planning.
- Robert K, Jones DO, Tyler PA, Van Rooij D, Huvenne VA (2015). Finding the hotspots within a biodiversity hotspot: fine-scale biological predictions within a submarine canyon using high-resolution acoustic mapping techniques. *Marine Ecology*, 36(4), 1256-1276. <https://doi-org.ezproxy.unibo.it/10.1111/maec.12228>
- Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312(5773): 543–54. <https://doi.org/10.1126/science.1119861>
- Roberts JM, Wheeler A, Freiwald A, Cairns S (2009). Cold-water corals: the biology and geology of deep-sea coral habitats. Cambridge University Press.
- Rowden AA, Schlacher TA, Williams A, Clark MR, Stewart R, Althaus F, Bowden, DA, Consalvey M, Robinson W, Dowdney J (2010). A test of the seamount oasis hypothesis: seamounts support higher epibenthic megafaunal biomass than adjacent slopes. *Marine Ecology*. 31, 95–106. <https://doi-org.ezproxy.unibo.it/10.1111/j.1439-0485.2010.00369>
- Ruhl HA, KL Smith (2004). Shifts in deep-sea community structure linked to climate and food supply. *Science* 305:513–515. SAS Institute. 1989–2007. <https://doi.org/10.1126/science.10997>
- Salgado KC, Bouchet P, Wellard R, Parnum I, Fouda L, Erbe C. (2021). Seasonal productivity drives aggregations of killer whales and other cetaceans over 43 submarine canyons of the Bremer Sub-Basin, south-western Australia. *Australian Mammalogy*, 43(2), 168–178. <https://doi.org/10.1071/AM19058>
- Schlacher TA, Schlacher-Hoenlinger MA, Williams A, Althaus F, Hooper JA, Kloser R (2007). Richness and distribution of sponge megabenthos in continental margin canyons off southeastern Australia. *Marine Ecology Progress Series* 340:73–78. <https://doi.org/10.3354/meps340073>
- Skliris N, Denidi S (2006). Plankton dynamics controlled by hydrodynamic processes near a submarine canyon off NW corsican coast: a numerical modelling study. *Continental Shelf Research* 26, 1336–1358. <https://doi.org/10.1016/j.csr.2006.05.004>
- Smith AB, Stockley B (2005). The geological history of deep-sea colonization by echinoids: roles of surface productivity and deep-water ventilation. *Proceedings of*

- the Royal Society B: Biological Sciences, 272(1565), 865-869. <https://doi-org-ezproxy.unibo.it/10.1098/rspb.2004.2996>
- Stevenson A, Rocha C (2013). Evidence for the bioerosion of deep-water corals by echinoids in the Northeast Atlantic. *Deep Sea research part I: Oceanographic research papers*, 71, 73-78. <https://doi.org/10.1016/j.dsr.2012.09.005>
- Stevenson A, Mitchell FJG, Davies JS (2014). Predation has no competition: factor influencing space and resource use by echinoids in deep-sea coral habitats, as evidenced by continuous video transects. *Mar Ecol*. Doi:10.1111/maec.12245
- Stöhr S, O'Hara TD, Thuy B (2012). Global diversity of brittle stars (Echinodermata: Ophiuroidea). *Plos one*, 7(3), e31940. <https://doi-org-ezproxy.unibo.it/10.1371/journal.pone.0031940>
- Taviani M, Angeletti L, Canese S, Cannas R, Cardone F, Cau A, et al. (2017). The “Sardinian Cold-Water Coral Province” in the context of the Mediterranean coral ecosystems. *Deep Sea Res. II* 145, 61–78. doi: 10.1016/j.dsr2.2015.12.008
- Taviani M, Foglini F, Castellan G, Montagna P, McCulloch MT, Trotter JA (2023). First assessment of anthropogenic impacts in submarine canyon systems off southwestern Australia. *Science of The Total Environment*, 857, 159243. <https://doi.org/10.1016/j.scitotenv.2022.159243>
- Trotter JA, Pattiaratchi C, Montagna P, Taviani M, Falter J, Thresher R, Hoise A, Haig D, Foglini F, Hua Q, McCulloch MT (2019). First ROV exploration of the Perth Canyon: Canyon setting, faunal observations, and anthropogenic impacts. *Frontiers in Marine Science*, 6, 173. <https://doi.org/10.3389/fmars.2019.00173>
- Trotter JA, Taviani M, Foglini F, Sadekov A, Skrzypek G, Mazzoli C, Remia A, Santodomingo N, Castellan G, McCulloch M, Pattiaractchi C, Mantagna (2022). Unveiling deep-sea habitats of the Southern Ocean-facing submarine canyons of southwestern Australia. *Progress in Oceanography*, 209, 102904. <https://doi.org/10.1016/j.pocean.2022.102904>
- Trotter J, Montagna P, Taviani M, Sadekov A, Skrzypek G, Foglini F, Mazzoli C, Remia A, Hosie A, Hara A, Pattiaratchi C, McCulloch M (2021). ROV exploration of deep-water coral habitats of southwest Australian submarine canyons. SOI Cruise FK200126 Final. Report. 61, pp. <https://doi.org/10.1016/j.scitotenv.2022.159243>
- Van den Beld IMJ, Bourillet JF, Arnaud-Haond S, de Chambure L, Davies JS, Guillaumont B, et al. (2017). Cold-water coral habitats in submarine canyons of the Bay of Biscay. *Front. Mar. Sci.* 4:118. doi: 10.3389/fmars.2017.00118. <https://doi.org/10.3389/fmars.2017.00025>
- Van Rooij D, De Mol L, Le Guilloux E, Wisshak M, Huvenne VAI, Moeremans R, Henriët JP (2010a) Environmental setting of deep-water oysters in the Bay of Biscay. *Deep Sea Research Part I: Oceanographic Research Papers*, 57, 1561–1572. <https://doi.org/10.1016/j.dsr.2010.09.002>

Wagner H, Purser A, Thomsen L, Jesus CC, Lundälv T (2011). Particulate organic matter fluxes and hydrodynamics at the Tisler cold-water coral reef. *Journal of Marine Systems* 85:19–29. <https://doi.org/10.1016/j.jmarsys.2010.11.003>

White M, Wolff GA, Lundälv T, Guihen D, Kiriakoulakis K, Lavaleye M, Duineveld G (2012). Cold-water coral ecosystem (Tisler Reef, Norwegian Shelf) may be a hotspot for carbon cycling. *Marine Ecology Progress Series*, 465, 11-23. Doi: <https://doi-org.ezproxy.unibo.it/10.335/meps09888>

Woo M, Pattiaratchi C (2008). Hydrography and water masses off the Western Australian coast. *Deep-Sea Res. I* 55, 1090–1104. <https://doi.org/10.1016/j.dsr.2008.05.005>.

- ROV SuBastian - Schmidt Ocean Institute:

<https://schmidtocean.org/technology/robotic-platforms/4500-m-operated-vehicle-rov/>

- Adélie Video 3:

<https://www.flotteoceanographique.fr/en/Facilities/Shipboard-software/Analyse-et-traitement-de-l-information/ADELIE>

7. Supplementary information

Tab.S1. Taxa identified during the frames analysis, showing the lowest rank possible division form all the individuals.

Phylum	Class	Order	Family	Genus	Species	N°
Echinodermata	Asteroidea				Sp.1	1
Echinodermata	Asteroidea				Sp.2	2
Echinodermata	Asteroidea				Sp.3	7
Echinodermata	Asteroidea				Sp.4	1
Echinodermata	Asteroidea				Sp.5	1
Echinodermata	Asteroidea	Brisingida	Brisingidae		Sp.1	11
Echinodermata	Asteroidea	Forcipulatida			Sp.1	1
Echinodermata	Asteroidea	Velatida	Pterasteridae	<i>Pteraster</i>	<i>Pteraster militaris</i>	1
Echinodermata	Asteroidea	Valvatida	Solasteridae	<i>Solastrer</i>	Sp.1	12
Echinodermata	Asteroidea	Spinulosidae			Sp.1	10
Echinodermata	Asteroidea	Spinulosidae			Sp.2	1
Echinodermata	Asteroidea	Valvatida			Sp.1	8
Echinodermata	Asteroidea	Valvatida			Sp.2	3
Echinodermata	Asteroidea	Valvatida			Sp.3	4
Echinodermata	Asteroidea	Valvatida			Sp.4	2
Echinodermata	Echinoidea	Cidaroida	Cidaridae		Sp.1	30
Echinodermata	Echinoidea	Cidaroida	Cidaridae		Sp.2	9
Echinodermata	Echinoidea	Cidaroida	Cidaridae		Sp.3	5
Echinodermata	Echinoidea	Camarodonta	Echinidae	<i>Dermechinus</i>	<i>Dermechinus horridus</i>	363
Echinodermata	Echinoidea	Echinothuroidea	Echinoturidae		Sp.1	68
Echinodermata	Echinoidea	Echinothuroidea	Echinoturidae		Sp.2	5
Echinodermata	Echinoidea	Echinothuroidea	Echinoturidae		Sp.3	12
Echinodermata	Echinoidea				Sp.1	1
Echinodermata	Crinoidea				Sp.1	2713
Echinodermata	Crinoidea				Sp.2	121
Echinodermata	Crinoidea				Sp.3	160
Echinodermata	Crinoidea				Sp.4	1348
Echinodermata	Crinoidea				Sp.5	7
Echinodermata	Crinoidea				Sp.6	59
Echinodermata	Crinoidea				Sp.7	15
Echinodermata	Crinoidea				Sp.8	538
Echinodermata	Crinoidea				Sp.9	21
Echinodermata	Crinoidea	Isocrinida			Sp.1	3
Echinodermata	Crinoidea	Isocrinida			Sp.2	7
Echinodermata	Crinoidea	Isocrinida			Sp.3	13
Echinodermata	Ophiuroidea	Phrynophiurida	Euryalina		Sp.1	22
Echinodermata	Ophiuroidea	Phrynophiurida	Euryalina		Sp.2	1
Echinodermata	Ophiuroidea	Phrynophiurida	Euryalina		Sp.3	1
Echinodermata	Holothuroidea				Sp.1	37
Echinodermata	Holothuroidea				Sp.2	15
Echinodermata	Holothuroidea				Sp.3	2
Echinodermata	Holothuroidea				Sp.4	2
Echinodermata	Holothuroidea				Sp.5	4
Echinodermata	Holothuroidea				Sp.6	1
Echinodermata	Holothuroidea				Sp.7	1
Echinodermata	Holothuroidea				Sp.8	1
Echinodermata	Holothuroidea				Sp.8	7
Echinodermata	Holothuroidea	Elasipodida	Elpidiidae	<i>Scotoplanes</i>	Sp.1	35
Echinodermata	Holothuroidea	Aspidochirotida	Stichopodidae		Sp.1	2
Echinodermata	Ophiuroidea	Ophiacanthida	Ophicanthidae	<i>Ophioplinthaca</i>	Sp.1	20
Echinodermata	Ophiuroidea				Sp.1	245
Echinodermata	Ophiuroidea				Sp.2	365
Echinodermata	Ophiuroidea				Sp.3	49
Echinodermata	Ophiuroidea				Sp.4	8
Echinodermata	Ophiuroidea				Sp.5	515
Echinodermata	Ophiuroidea				Sp.6	30
Echinodermata	Ophiuroidea				Sp.7	182
Echinodermata	Ophiuroidea				Sp.8	4
Echinodermata	Ophiuroidea				Sp.9	2
Echinodermata	Ophiuroidea				Sp.10	4
Echinodermata	Ophiuroidea				Sp.11	20
Echinodermata	Ophiuroidea				Sp.12	1
Cnidaria	Anthozoa	Scleractinia	Dendrophylliidae	<i>Balanophyllia</i>	Sp.1	
Cnidaria	Anthozoa	Scleractinia	Caryophyllidae		Sp.1	
Cnidaria	Anthozoa	Scleractinia	Caryophyllidae	Desmophyllum	Sp.1	

Cnidaria	Anthozoa	Scleractinia	Caryophyllidae	Desmophyllum	Sp.2	
Cnidaria	Anthozoa	Scleractinia	Caryophyllidae	<i>Solenosmilia</i>	<i>Solenosmilia variabilis</i>	
Cnidaria	Anthozoa	Antipatharia			Sp.1	
Cnidaria	Anthozoa	Antipatharia			Sp.2	
Cnidaria	Anthozoa	Antipatharia			Sp.3	
Cnidaria	Anthozoa	Antipatharia			Sp.4	
Cnidaria	Anthozoa	Antipatharia			Sp.5	
Cnidaria	Anthozoa	Antipatharia	Leiopathidae	<i>Leiopathes</i>	Sp.1	
Cnidaria	Anthozoa	Antipatharia	Leiopathidae	<i>Leiopathes</i>	Sp.2	
Cnidaria	Anthozoa	Antipatharia	Schizopathidae	<i>Stauropathes</i>	Sp.1	
Cnidaria	Anthozoa	Antipatharia	Schizopathidae	<i>Stauropathes</i>	Sp.2	
Cnidaria	Anthozoa	Antipatharia	Antipathidae	<i>Stichopathes</i>	Sp.1	
Cnidaria	Anthozoa	Antipatharia	Antipathidae	<i>Stichopathes</i>	Sp.2	
Cnidaria	Anthozoa	Alcyonacea			Sp.1	
Cnidaria	Anthozoa	Alcyonacea			Sp.2	
Cnidaria	Anthozoa	Alcyonacea			Sp.3	
Cnidaria	Anthozoa	Alcyonacea			Sp.4	
Cnidaria	Anthozoa	Alcyonacea			Sp.5	
Cnidaria	Anthozoa	Alcyonacea	Alcyoniidae	<i>Anthomastus</i>	Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	<i>Iridogorgia</i>	Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Isididae		Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Isididae		Sp.2	
Cnidaria	Anthozoa	Alcyonacea	Isididae		Sp.3	
Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	<i>Metallogorgia</i>	Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Chrysogorgiidae	<i>Metallogorgia</i>	Sp.2	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.2	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.3	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.4	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.5	
Cnidaria	Anthozoa	Alcyonacea	Primnoidae	Narella	Sp.6	
Cnidaria	Anthozoa	Alcyonacea	Paragorgiidae		Sp.1	
Cnidaria	Anthozoa	Alcyonacea	Paragorgiidae		Sp.2	
Cnidaria	Anthozoa	Alcyonacea	Plexauridae		Sp.1	
Cnidaria	Anthozoa	Scleralcyonacea	Primnoidae	<i>Calyptrophora</i>	Sp.1	
Cnidaria	Anthozoa	Scleralcyonacea	Primnoidae	<i>Calyptrophora</i>	Sp.2	
Cnidaria	Anthozoa	Scleralcyonacea	Primnoidae	<i>Calyptrophora</i>	Sp.3	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.1	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.2	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.3	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.4	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.5	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.6	
Cnidaria	Anthozoa	Scleralcyonacea	Coralliidae	Corallium	Sp.7	
Cnidaria	Anthozoa	Actinaria			Sp.1	
Cnidaria	Anthozoa	Actinaria			Sp.2	
Cnidaria	Anthozoa	Actinaria			Sp.3	
Cnidaria	Anthozoa	Actinaria			Sp.4	
Cnidaria	Anthozoa	Actinaria			Sp.5	
Cnidaria	Anthozoa	Actinaria			Sp.6	
Cnidaria	Anthozoa	Actinaria			Sp.7	
Cnidaria	Anthozoa	Actinaria			Sp.8	
Cnidaria	Anthozoa	Actinaria			Sp.9	
Cnidaria	Anthozoa	Actinaria			Sp.10	
Cnidaria	Anthozoa	Actinaria			Sp.11	
Cnidaria	Anthozoa	Actinaria	<i>Liponematidae</i>	<i>Liponema</i>	Sp.1	
Cnidaria	Anthozoa	Actinaria	<i>Liponematidae</i>	<i>Liponema</i>	Sp.2	
Cnidaria	Anthozoa	Zoantharia			Sp.1	
Cnidaria	Anthozoa	Zoantharia			Sp.2	
Cnidaria	Anthozoa	Zoantharia			Sp.3	
Cnidaria	Anthozoa	Zoantharia			Sp.4	
Cnidaria	Anthozoa	Anthoathecata	Stylasteridae		Sp.1	
Cnidaria	Anthozoa	Anthoathecata	Stylasteridae		Sp.2	
Cnidaria	Anthozoa	Anthoathecata	Stylasteridae		Sp.3	
Cnidaria	Anthozoa	Anthoathecata	Stylasteridae		Sp.4	
Cnidaria	Anthozoa	Anthoathecata	Stylasteridae		Sp.5	
Cnidaria	Anthozoa	Pennatulacea	Anthoptilidae	<i>Anthoptilum</i>	Sp.1	
Cnidaria	Anthozoa	Pennatulacea	Anthoptilidae	<i>Anthoptilum</i>	Sp.2	
Cnidaria	Anthozoa	Pennatulacea			Sp.1	
Cnidaria	Anthozoa	Pennatulacea			Sp.2	
Cnidaria	Ceriantharia	Spirularia	Cerianthidae	<i>Cerianthus</i>	Sp.1	
Cnidaria	Hydrozoa				Sp.1	

Cnidaria	Hydrozoa				Sp.2	
Anellida	Polychaeta	Echiuroidea	Bonelliidae	<i>Bonellia</i>	Sp.1	
Anellida	Polychaeta				Sp.1	
Porifera					Sp.1	
Poeifera					Sp.2	
Porifera					Sp.3	
Poirifera					Sp.4	
Porifera					Sp.5	
Porifera	Exhactinellida	Lyssacinosida	Euplectellidae	<i>Euplectella</i>	Sp.1	
Porifera	Hyalospongiae				Sp.1	
Porifera	Hyalospongiae				Sp.2	
Porifera	Hyalospongiae				Sp.3	
Porifera	Hyalospongiae				Sp.4	
Porifera	Demospogoniae	Suberitida	Stylocordylidae	<i>Stylocordila</i>	Sp.1	
Mollusca	Bivalvia	Limida	Limidae	<i>Acesta</i>	<i>Acesta excavata</i>	
Mollusca	Gastropoda	Littorinimorpha	Cymatiidae	<i>Fusitriton</i>	Sp.1	
Mollusca	Gastropoda	Nudibranchia	Doridoidei		Sp.1	
Arthropoda	Malacostraca	Decapoda	Aristidae		Sp.1	
Arthropoda	Malacostraca	Decapoda	Aristidae		Sp.2	
Arthropoda	Malacostraca	Decapoda			Sp.1	
Arthropoda	Malacostraca	Decapoda			Sp.2	
Arthropoda	Malacostraca	Decapoda	Munididae		Sp.1	
Arthropoda	Malacostraca	Decapoda	Munididae		Sp.2	
Arthropoda	Malacostraca	Decapoda	Paguroidea		Sp.3	
Arthropoda	Malacostraca	Decapoda	Paguroidea		Sp.4	
Arthropoda	Malacostraca	Decapoda	Palinuridae		Sp.5	
Arthropoda	Malacostraca	Decapoda	Parthenipidae		Sp.6	
Arthropoda	Pycnogonida				Sp.1	
Arthropoda	Pycnogonida				Sp.2	
Arthropoda	Maxillopoda	Pedunculata		<i>Smilium</i>	Sp.1	
Brachiopoda					Sp.1	
Chordata	Ascidiacea				Sp.1	
Chordata	Ascidiacea				Sp.2	
Chordata	Ascidiacea				Sp.3	
Chordata	Ascidiacea	Phlebobranchia			Sp.1	
Chordata	Actinopterygii				Sp.1	
Chordata	Actinopterygii				Sp.2	
Chordata	Actinopterygii				Sp.3	
Chordata	Actinopterygii				Sp.4	
Chordata	Actinopterygii				Sp.5	
Chordata	Actinopterygii				Sp.6	
Chordata	Actinopterygii	Anguilliformes			Sp.1	
Chordata	Actinopterygii	Anguilliformes			Sp.2	
Chordata	Actinopterygii	Godiformes			Sp.1	
Chordata	Actinopterygii	Godiformes			Sp.2	
Chordata	Actinopterygii	Godiformes			Sp.3	
Chordata	Actinopterygii	Scorpaeniformes			Sp.1	
Chordata	Actinopterygii	Scorpaeniformes			Sp.2	
Chordata	Actinopterygii	Baryciformes			Sp.1	
Chordata	Actinopterygii	Chimaeriformes			Sp.1	
Chordata	Actinopterygii	Rajiformes			Sp.1	

Tab.S2. Statistical analysis results.

	Depth	Oxygen	Substrate (Ab)	Substrate (R)	Richness (Tot)	Echinodermata (Ab)	Echinodermata (R)	Shannon
ANOVA	-	-	-	-	-	-	-	0.00102*
Turkey HSD	-	-	-	-	-	-	-	≠317
Kruscall-Wallis	-				-	-	-	-
Dunn-Test	-	≠322	≠hard	≠hard	-	-	-	-

	Echinodermata (Ab)-Antipatharia	Echinodermata (R)-Antipatharia	Echinodermata (Ab)-Scleractinaria	Echinodermata (R)-Scleractinaria	Echinodermata (R)-Octocorallia	Echinodermata (Ab)-Octocorallia
ANOVA	-	-	-	-	-	-
Turkey HSD	-	-	-	-	-	-
Kruscall-Wallis	0.0337***	0.005035***	0.04749**	0.03042**	0.0001167***	0.002784***
Dunn-Test	0.0133	0.0025	0.0237	0.0152	0.00006	0.0014

	Crinoidea (Ab)-Antipatharia	Crinoidea (R)-Antipatharia	Ophiuroidea (Ab)-Antipatharia	Ophiuroidea (R)-Antipatharia	Echinoidea (R)-Antipatharia	Echinoidea (Ab)-Antipatharia
ANOVA	-	-	-	-	-	-
Turkey HSD	-	-	-	-	-	-
Kruscall-Wallis	0.006635*	0.01016*	-	0.04905*	3.18e-06*	26e-06*
Dunn-Test	0.0033	0.0051	-	0.0245	0	0

	Crinoidea (Ab)-Octocorallia	Crinoidea (R)-Octocorallia	Ophiuroidea (Ab)-Octocorallia	Echinoidea (Ab)-Octocorallia	Echinoidea (R)-Octocorallia	Ophiuroidea (R)-Octocorallia
ANOVA	-	-	-	-	-	-
Turkey HSD	-	-	-	-	-	-
Kruscall-Wallis	-	0.004666**	0.0500	0.0002114***	0.0001818***	0.003655**
Dunn-Test	-	0.0023		0.0001	0.0001	0.0018

	Crinoidea (Ab)-Scleractinia	Crinoidea (R)-Scleractinia	Ophiuroidea (Ab)-Scleractinia	Echinoidea (Ab)-Scleractinia	Echinoidea (R)-Scleractinia	Ophiuroidea (R)-Scleractinia
ANOVA	-	-	-	-	-	-
Turkey HSD	-	-	-	-	-	-
Kruscall-Wallis	-	-	-	0.0009134***	0.0001128***	0.04509*
Dunn-Test	-	-	-	0.0005	0.0000	0.0225