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Spatio-temporal distribution of Isidella elongata, a vulnerable marine ecosystem indicator species, in the southern Adriatic Sea

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Spatio-temporal distribution of *Isidella elongata*, a vulnerable marine ecosystem indicator species, in the southern Adriatic Sea

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Abstract

The bamboo coral *Isidella elongata* is a forest-forming alcyonacean that dwells on deep-sea soft bottoms and is presently found in the Otranto Channel (Southern Adriatic Sea). In this study, we explored the spatial distribution and the demographic structure of the *I. elongata* facies (IF) over time, along with the diversity of IF-associated fauna in the southern Adriatic Sea, by using a time-series data of nine years (2012–2020) from the Mediterranean International Bottom Trawl Survey (MEDITS). The spatial distribution of *I. elongata* was confronted with the fishing effort in the study area over time. This facies showed a constant spatial extent but a decreasing biomass over time. Changes in the basal diameter distribution of the colonies were also observed, with a significant decrease in the sizes from 2014 to 2020. These results suggest an increasing fishery-related impact from a developing deep-sea fishery occurring in the study area. The bamboo coral in the study area represents a hotspot of biodiversity in the context of the bathyal environment. A fisheries-restricted area was recently proposed in the context of the General Fisheries Commission for the Mediterranean at the Otranto Channel to help the conservation of *I. elongata* in the southern Adriatic Sea.

Keywords: Vulnerable marine ecosystem; *Isidella elongata*; Spatial distribution; Time series; Colonies basal diameter; southern Adriatic Sea; Fisheries

Introduction

Vulnerable Marine Ecosystems (VMEs) are overall defined as a group of species, communities, or habitats characterised by hotspots of biodiversity and ecosystem functioning in the deep sea that may be exposed to the impacts of fishing activities (FAO, 2009). Moreover, VMEs are characterised by a high vulnerability to fishing disturbances (Ashford et al., 2019). This vulnerability is related to its weakness in terms of the renewal of population and/or habitat stability as a result of fishing impacts. The set of criteria to class an ecosystem as VME was detailed in FAO (2009) for fisheries management, following the discussion detailed in United Nations General Assembly (UNGA) Resolution 61/105 in 2006. Indeed, fishery activities performed in the deep sea can compromise the physical and functional stability of the ecosystem, triggering negative effects on both living marine resources and the ecosystem itself. Moreover, there is increasing concern linked with the overfishing of the target species associated with VMEs, where continuous removal may impact the overall functionality of the ecosystem (Maynou & Cartes, 2012; FAO, 2018). This is of primary interest, since VMEs are considered hotspots of biodiversity that provide healthy ecosystem functioning and several ecosystem services in the deep sea (FAO, 2009; Ashford et al., 2019; Chimienti et al., 2019b; Carbonara et al., 2020; Maiorano et al., 2022).

The *Isidella elongata* facies (IF) was added to the list of VMEs by the General Fisheries Commission for the Mediterranean Sea (GFCM) (GFCM, 2017), and several international actions have been implemented for their protection. This facies has been included in the “Deep Water Engineering benthic invertebrate assemblages” in the “Dark Habitats Action Plan” of the Barcelona Convention (UNEP-MAP-RAC-SPA, 2015). This inclusion has also been supported by the previous addition of the species to the International Union for Conservation of Nature (IUCN) red list for the Mediterranean, with *Isidella elongata* being the only Mediterranean anthozoan species classified as critically endangered (http://www.iucn.it/scheda.php?id=789649086). Recently, *Isidella elongata* has been also recognised as a deep-water VME representative taxon of the VME habitat type "Soft bottom coral garden: Soft bottom gorgonian and black coral gardens" by the International Council for the Exploration of the Sea (ICES, 2020). In the context of the Marine Strategy Framework Directive, only recently has it been recognised that the IF needs protection as a habitat (coral garden) (Palialexis et al., 2018; Danovaro et al., 2020).

The Mediterranean Sea is considered a major biodiversity hotspot due to its high species richness coupled with a considerable proportion of endemic species (Coll et al., 2010; Granger et al., 2015). The bamboo coral *I. elongata* is an alcyonacean species (family Keratoisididae), near-endemic to the Mediterranean Sea (Grasshoff, 1989), that dwells on soft bottoms at depths between 100 m and 1500 m (Bellan-Santini, 1985; Laubier & Emig, 1993; Bo et al., 2015a), where it can form very dense aggregations (Mastrototaro et al., 2017) called coral gardens or coral forests (FAO, 2009; Rossi et al., 2017; Chimienti et al., 2019b). The coral forests of *I. elongata* represent the true facies of the bathyal mud in the Mediterranean Sea (*sensu* Pérès and Picard 1964).

I. elongata has a candelabrum-like shape and can reach 80 cm in height (Bo et al., 2015a; Carbonara et al., 2020), acting as a structuring organism that is able to generate a complex and three-dimensional heterogeneity on otherwise flat muddy bottoms where the species dwells. The IF can consist of dense bamboo coral colonies constituting a habitat that hosts several fishes and crustacean species (Mastrototaro et al., 2017; D'Onghia, 2019; Carbonara et al., 2020), as in the Balearic Sea where up to 2300–2683 colonies/ha and 50 taxa have been identified (Mastrototaro et al., 2017). Several studies have demonstrated that the presence of bamboo coral influences both the biodiversity and the abundance of several species (Buhl-Mortensen et al., 2010; Maynou & Cartes, 2012; Mytilineou et al., 2014; Carbonara et al., 2020; Cartes et al., 2022). These studies have been mainly focused on megafauna (fish and large invertebrates), and much less on macrofauna associated with the IF (Cartes et al., 2017, 2022; Carbonara et al., 2020). Predator species take advantage of the presence of IF, as they find a higher density of prey within bamboo coral (D'Onghia, 2019; Carbonara et al., 2020). Moreover, the arborescent complexity of *I. elongata* colonies' could further provide a shelter effect against predators (Mastrototaro et al., 2017). Some of the typical species associated with the bamboo coral, such as the red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* and the Norway lobster *Nephrops norvegicus* (Maynou & Cartes, 2012; Mastrototaro et al., 2017; D'Onghia, 2019), are of high commercial value and targeted by professional fisheries (Spedicato et al., 1998; Maynou & Cartes, 2012; Cartes et al., 2013; Lauria et al., 2017; D'Onghia, 2019; EUMOFA, 2019).

In the last decades, trawling activities in the Mediterranean have enlarged their operational bathymetric range, causing a greater impact on deep-sea bottoms (FAO, 2009, 2018) and consequently on deep-sea VMEs such as IF. In this context, determining the presence and understanding the spatial distribution of VMEs, including bamboo coral facies, are crucial to implementing actions of management or protection (Lauria et al., 2017; FAO, 2018; Chimienti et al., 2019a; Otero & Marin, 2019). IF occurrences have been studied in the western Mediterranean (Fabri et al., 2014; Mastrototaro et al., 2017; Chimienti et al., 2019a), in the central-eastern (D'Onghia et al., 2003; Vafidis et al., 2006; Mytilineou et al., 2014; Pierdomenico et al., 2016, 2018, 2019; Lauria et al., 2017; D'Onghia, 2019; Carbonara et al., 2020) and in the eastern part of the basin (Gerovasileiou et al., 2019). More recently, Carbonara et al. (2020) reported the occurrence of IF in the southern Adriatic Sea, where the IF was the least impacted by fishery among the study areas (i.e., Sardinian Sea, south-central Tyrrhenian, southern Adriatic, and north-western Ionian). It is to note that some populations are also in good condition in other areas, such as those around the Balearic Islands (Mastrototaro et al., 2017). While acknowledging how bottom trawl surveys are not the optimum way of sampling for benthic biocoenosis, opportunistic data collected during the Mediterranean International Bottom Trawl Survey (MEDITS) (Spedicato et al., 2019) could, nevertheless, be useful for setting up spatial-temporal analysis of IF and associated communities on trawled soft bottoms (Farriols et al., 2015; Granger et al., 2015; Petović et al., 2016; Chimienti et al., 2018; Gerovasileiou et al., 2019).

Thus, the aim of this study was to detect over a time-series data of nine years (2012–2020) the potential changes of: i) occurrence, spatial distribution and abundance of the *I. elongata* facies in the southern Adriatic Sea (GSA 18; *sensu* FAO GFCM); ii) biodiversity of the fauna associated with the IF; iii) the bamboo coral colonies demography; and iv) the overlap of IF with trawler fishing effort in the study area from 2015 to 2020.

Materials and Method

Sampling method

The data analysed in this work were collected in the context of the MEDITS trawl surveys in the years from 2012 to 2020 in the geographical subarea GSA 18: southern Adriatic Sea (**Fig. 1**). The primary objective of the MEDITS trawl survey is to estimate the abundance, distribution, and population structure of commercial fish and invertebrate species in the Mediterranean Sea. The MEDITS survey is carried out annually between late spring and midsummer, and it covers the depth range from 10 to 800 m (AAVV, 2017). Trawl stations were allocated in five bathymetrical strata (10–50, 50–100, 100–200, 200–500 and 500–800 m) on the trawlable bottom (i.e. flat and soft-bottom) and consistently carried out in the same position according to a random-stratified sampling design (AAVV, 2017). The survey design, as well as the details of the sampling methodology, are reported by Spedicato et al. (2019). The standard sampling gear used was the bottom trawl GOC 73 (Bertrand et al., 2002) designed for experimental fishing. Briefly, it has a vertical opening slightly larger than that of the most common professional gear used in the area and the stretched mesh size of 20 mm at the codend. The haul duration was 30 minutes on the continental shelf (10–200 m depth) and 60 minutes on the slope (201–800 m depth), and hauls were allowed only during daytime. The standard fishing speed was 3 knots on the ground. Other specific details can be found in the study of Spedicato et al. (2019).

Analysis of the occurrence, distribution, and biomass of **I. elongata** *in GSA 18 and the associated biodiversity*

The occurrence of *I. elongata* was computed as the percentage of hauls with the presence of IF over the total number of hauls carried out by year. For each haul in which *I. elongata* was observed, its total weight was measured (kg; at gram resolution) and standardized to the swept surface unit (km^2). As the trawling activity caused mechanical damage to the colonies of bamboo coral, its biomass caught in each haul consisted of various parts of fragmented colonies, including the basal part and/or the arms. Thus, the biomass of *I. elongata* was proportional to the number of colonies and their size. The biomass ($kg\ km^{-2}$) index was computed according to Souplet (1996) by weighting the mean index by depth stratum or macro stratum (e.g. 200-800).

The spatial distribution analysis of *I. elongata* biomass was conducted using a spatial modelling approach based on a generalised additive model (GAM). In particular, biomass data were modelled using the Gaussian family distribution and link function identity, with longitude (Lon) and latitude (Lat) as explanatory variables. Three different GAM models were estimated to display *I. elongata* biomass distribution in two bathymetric strata from the MEDITS protocol (AAVV, 2017) where the species was present (200–500 m and 500–800 m), for three periods (2012–2014, 2015–2017 and 2018–2020), as reported in the following formula:

$$\text{Biomass} \sim s(Lon_{ij}, Lat_{ij}) + \varepsilon_{ij}$$

where i is the observation in the j time period, and ε is the error term.

The prediction maps were generated by using a regular grid with a point resolution of 0.01°. The data used to resize the grid to the selected depth range were derived from the EMODnet-Bathymetry portal (grid resolution of 1/16 * 1/16 arc minutes, circa 115 × 115 metres). All the GAM analyses were performed using the R software (R Development Core Team, 2021) and the *mgcv* package, while distribution maps were generated with QGIS software (QGIS Development Team, 2017).

For the analysis of the biodiversity of associated assemblages, we considered only those hauls performed on substrates (fine muddy bottom), where *I. elongata* was typically found (Mytilineou et al., 2014; Pierdomenico et al., 2016, 2018; Mastrototaro et al., 2017; Chimienti et al., 2019a; Gerovasileiou et al., 2019; Carbonara et al., 2020; Cartes et al., 2022) for which the presence or the absence of the species was recorded (Carbonara et al., 2020). In this way, it is possible to minimise in the analysis the influence of the hauls where IF generally does not occur (e.g., gravel, coarse sand) (Lauria et al., 2017). From each haul, all the faunal specimens larger than 1 cm (Spedicato et al., 2019) were classified at the lowest possible taxonomic level, and for each Operational Taxonomic Unit (OTU) data on weight and number of specimens were collected according to the MEDITS protocol (AAVV, 2017). The Margalef richness index (D) (Margalef, 1958) and Shannon-Wiener index (H') (Shannon, 1948) were computed for each sampling station carried out deeper than 200 m, which represents the area where the probability of IF occurrence was higher (Carbonara et al., 2020). These indexes were used to detect the potential effects of the presence of *I. elongata* on the associated assemblages. The hauls performed on suitable substrate types (fine muddy) were pooled into two categories: "presence," if the bamboo coral was caught in the haul, and "absence" for all remaining hauls on the muddy bottom. The analysis was carried out separately by year for the benthic and demersal species, and the differences in biodiversity between the two assemblages with (associated) and without (not associated) *I. elongata* for each year were evaluated using the non-parametric Wilcoxon–Mann–Whitney test. Moreover, the presence of a temporal trend in the biomass index (kg/km^2) of *I. elongata* was tested by Spearman's rho correlation test.

Spatial distribution of fishing efforts

Fishing effort in the study area was estimated by means of the aggregated Automatic Identification System (AIS) data provided by Global Fishing Watch (https://globalfishingwatch.org/). Annual fishing activities referred to those from 2015 to 2020 (expressed in hours) and were aggregated in the same temporal frame of the MEDITS *I. elongata* spatial analysis (three years): 2015–2017 and 2018–2020. The first years (2012–2014) were not considered in the analysis because of the limited coverage of the active fishery by the AIS system (Global Fishing Watch; https://globalfishingwatch.org/data-download/datasets/public-fishing-effort) that came into effect progressively from May 2012 to May 2014 (2002/59/CE) in Italy. Moreover, the data were averaged over a grid with a resolution of 0.01° x 0.01°. The hotspot of fishing activities was calculated as the 75th percentile of effort data distribution. The resulting fishing polygon bordering the effort hotspot was superimposed with the polygon bordering the 75th percentile of the estimated coral bamboo distribution, in order to assess the percentage of *I. elongata* hotspot surface area overlapping the main fishing ground in the southern Adriatic Sea (GSA18). The analysis was conducted using R software (R Core Team, 2021) by means of the raster library (Hijmans, 2021).

Morphological parameter measurements and analyses

During the survey, the morphological parameters of *I. elongata* colonies were collected in terms of basal diameter (BD, in millimetres) to infer information on the population demographic structure in the southern Adriatic Sea from 2014 to 2020. The trawl survey caused mechanical damage to the colonies and it did not allow us to collect specific data, such as maximum height, branching patterns (colony width), and/or colony vitality (Carbonara et al., 2020). However, the basal diameter is often used to infer the size of the colonies (Andrews et al., 2009; Carbonara et al., 2020; Cartes et al., 2022), as it is correlated to the height (Carbonara et al., 2020). Basal diameter was measured only when the base of the colony was present, established by the presence of at least part of the root-shaped bases (Carbonara et al., 2020). In all the hauls where the presence of bamboo coral specimens was detected, the bases of the colonies were collected and subsequently measured. On each base colony, as close as possible to the root, at least three measurements of the diameter were taken by caliper (resolution of 0.1 mm), and the final diameter was the average of these measurements (Coefficient of Variation between 0 and 9.75). The annual average values of colony BD were used to test the trend of the colony sizes over seven years (2014–2020) using Spearman's correlation. In addition, the eventual differences during the study period were tested using a Kruskal–Wallis one-way analysis of variance by ranks. The Nemenyi *post hoc* test was used to evaluate the significance of such median differences between years. In order to analyse the change in the basal diameter distribution (BDD), the years were grouped into three periods as follows: 2014, 2015–2017 and 2018–2020. The years were grouped according to the time periods selected for the GAM analysis. The different BDDs were compared by Kolmogorov–Smirnov (K–S) test.

The skewness index (SK) of BD distribution was calculated to measure the distributions' deviation from symmetry. The skewness describes three scenarios: (i) distribution dominated by smaller colonies (SK > 0.5), (ii) distribution dominated by larger colonies (SK < 0), and (iii) no size dominance (0 ≤ SK ≤ 0.5).

Results

Occurrence, distribution, and abundance of **I. elongata** *in GSA 18*

The percentage and depth range of occurrence of *I. elongata* per haul in GSA 18 is reported in **Table 1**. The percentage of occurrence (number of hauls positive with the presence of IF out of the total number of hauls carried out) showed from a maximum of 9.41% in 2017 to a minimum value of 4.44% in 2019. The depth range of occurrence was between 410 m (2017) and 625 m (2016).

Table 1. Percentage (%) (number of positive hauls to the presence of bamboo coral) and depth range (m) of occurrence of *Isidella elongata* in each year, total number of hauls carried out in the survey, and their depth range.

Year	Percentage of occurrence (%)	Depth range of *I. elongata* occurrence (m)	Total number hauls carried out in the survey	Depth range of hauls carried out in the survey (m)
2012	6.67	520–618	90	12–678
2013	7.78	517–617	90	11–713
2014	6.67	447–617	90	11–715
2015	6.67	515–619	90	10–693
2016	6.67	429–625	90	10–739
2017	9.41	410–601	85	10–733
2018	6.74	518–596	89	10–701
2019	4.44	569–621	90	10–749
2020	7.14	551–600	70	10–759

In all the three models tested to describe the effect of the spatial displacement on the biomass of *I. elongata* (kg km^{-2}), the bidimensional splines of the geographic coordinates included in the Gaussian GAM model were significant for the three monitored periods ($p < 0.05$ for all), explaining the following amount of deviance: 86.2% in 2012–2014, 72.4% in 2015–2017 and 59.7% in 2018–2020. These splines (**Fig. 2**) indicate the combined effects of northing and easting on the biomass, locating the hotspot bamboo coral biomass in the Otranto Channel (**Fig. 3**). The extension of the area, in which the hotspots (75th percentile of the estimated biomass distribution) of IF were estimated to be located, is similar for the three periods considered (1436.7 km^2 for 2012–2014, 1520.4 km^2 for 2015–2017 and 1421.6 km^2 for 2018–2020). Similarities were seen in its spatial distribution pattern as well, although with a clear decreasing biomass of the bamboo coral over the three groups of study periods (**Fig. 3**). A significant decreasing trend ($p < 0.05$) in the biomass index of *I. elongata* was also detected over the time series considered (2012–2020). The biomass index of *I. elongata* was around 25 kg/m^2 in both 2012 and 2013, with a peak in 2014 (65.7 ± 47.1 kg/m^2), while very low biomass indexes below 1.3 kg/m^2 were observed from 2018 to 2020 (**Fig. 4**).

The list of the OTUs found in the different years in the study area and their relative biomass were provided in the supplementary material. In **Figures 5 and 6**, the analyses of the Margalef and Shannon-Wiener biodiversity indexes for the hauls associated or not associated with the presence of *I. elongata* are reported. The results of the diversity indexes for the assemblages "associated" and "not associated" were compared within each year. For the benthic species, no significant difference between the assemblages with and without the bamboo coral was observed, except in 2016 for the Shannon diversity index. In contrast, for the demersal species the assemblage associated with *I. elongata* showed significantly higher values for both indices in most of the years analysed ($p < 0.05$), excepted in 2016 for the Shannon diversity index and from 2018 to 2020 for the Margalef one ($p < 0.05$; **Fig. 5**). A significant decreasing trend ($p < 0.05$) of the Margalef index was detected for the demersal "associated" assemblage over the study period (**Fig. 6**). No significant trend over time was observed in both indices of both benthic assemblages nor in the Margalef index of "not associated" demersal assemblages and in the Shannon diversity index of both demersal assemblages (**Fig. 5, 6**).

Spatial distribution of fishing efforts

Figure 7 reports the hotspot of fishing activities (75th percentile) for the two-time frames analysed (2015–2017 and 2018–2020). Moreover, the overlap between the area hotspot of fishing activities and the hotspot (75th percentile) of bamboo coral distribution is indicated and quantified in terms of percentage. The percentage of overlapping between the area hotspot of fishing activities and bamboo coral was found to be 8.84% between 2015-2017 while it reached 12.27 between 2018-2020, with a resulting increase of 38.8 % between the two periods considered.

Morphological parameters

Significant differences were detected between BDD distributions in the three considered periods ($p < 0.05$; **Fig. 8**). In 2014, the BDD skewed towards larger-sized colonies (basal diameters > 4 mm; SK = -0.275) than in the 2015–2017 period when no dominance of any size was observed (SK = 0.26) and two small peaks (1.5–2 mm and 3.5–4 mm) were observed. In 2018–2020, the BDDs skewed towards smaller-size colonies (peak at 1.5–2 mm; SK = 846).

This pattern is more evident while analysing the yearly distribution (**Fig. 9**), where the Spearman's rho test revealed a significant decreasing trend in BD over the years ($p < 0.05$) (**Fig. 9**). Indeed, in 2014, BD was significantly larger (mean ± SE, 4.02 ± 0.096 mm) than in other years ($p < 0.05$). Between 2016 and 2019, the BD values were overall similar over the years (from 0.58 mm to 6.0 mm), while the BD measured in 2020 was found significantly smaller than all other years (1.86 ± 0.095 mm) ($p < 0.05$) (**Fig. 9**).

Discussion

The present study investigated the spatial and temporal distributions of *I. elongata* in the southern Adriatic Sea (GSA 18) through time-series data of nine years (2012–2020) collected during MEDITS surveys. The biodiversity of the assemblages associated with *I. elongata* was also investigated. In the study area, the depth range of species occurrence in the present study was from 410 m to 625 m, which is in line with data already published for the southern Adriatic Sea (Carbonara et al., 2020) as well as with other areas of the western and central Mediterranean (Cartes et al., 2009; Lauria et al., 2017; Mastrototaro et al., 2017; Pierdomenico et al., 2018; Ingrassia et al., 2019). However, it is difficult to define the maximum depth of the species distribution in the study area due to both the depth range of sampling of the MEDITS protocol (i.e., down to maximum 800 m in depth) and the bottom morphology of the study area around the IF presence, that are unsuitable to trawling at depths greater than 650 m. Despite the overall depth range of the investigated area was larger than the bamboo coral occurrence (**Table 1**) in the GSA 18 (north part of the GSA18), some deeper areas around the *I. elongata* presence are not trawlable and thus not explored during the MEDITS surveys. Consequently, it is not excluded that the IF in the southern Adriatic Sea could extend even deeper than that already observed (625 m depth) (Rueda et al., 2016; González-García et al., 2020) in a more pristine area unexplored by trawl-survey, as shown by the results of the GAM model (**Fig. 3**) (Carbonara et al., 2020). The spatial analysis performed in this study confirms that the Otranto Channel represents a suitable area with a consistent presence of IF (Carbonara et al., 2020), probably due to a combination of all required environmental factors (i.e. compact/semi consolidated mud with a low slope angle, low seasonal variation in term of salinity and temperature and high concentration of near bottom zooplankton) (Cartes et al., 2013; Bo et al., 2015a; Lauria et al., 2017; Ingrassia et al., 2019). In addition, the presence of IF can be enhanced by the upwelling of nutrient-rich deep waters, which has been documented in the area (Vilibic & Orlic, 2002). Moreover, the fishing activity of the southern Adriatic trawlers fleet is more concentrated on the continental shelf and on the upper slope (Spedicato & Lembo, 2011), resulting in a lesser impact on the deeper bottoms where IF can be found. Although modelling *I. elongata* quantitative data was affected by the limitations of the MEDITS trawl net which is not the best sampler for exploring the benthic communities (González-García et al., 2020), the systematic collection of data on the macrobenthic species caught during the MEDITS trawl survey could represent a valuable source of information, particularly for understanding their distribution patterns and potential significant changes over time (Fernandez-arcaya et al., 2019), as well as the impact of human-related activities, such as trawling (Mangano et al., 2013). Mechanical damage from trawling rarely allows the collection of unbroken complete individual colonies, limiting morphological study; however, the biomass data of the bamboo coral collected during the MEDITS trawl survey are proportional to the number of colonies and their size (Carbonara et al., 2020). Moreover, in the absence of other systematic sources of information, these opportunistic data have proven to be useful sources of information for benthic communities in general and, in particular, for the IF (Lauria et al., 2017; Carbonara et al., 2020).

The temporal analysis performed through the spatial distribution of biomass within the IF shows a clear decreasing trend of abundance (biomass index) over the study period, but no difference in distribution extent. The decreasing trend of the IF in the southern Adriatic Sea in the last nine years (2012–2020) could be related to the cumulative impact of trawlers on the bamboo coral, produced by the increasing fishing effort detected at least in the area over time (**Fig. 7**) at least on the area monitored by the MEDITS survey (until about 630 m of depth; see **Table 1**). Despite the traditional fishing habits of the trawler fleet in southern Adriatic Sea, that mostly exploited the continental shelf and the upper slope (Spedicato & Lembo, 2011), in recent years, there has been an increase in trawler numbers capable of fishing even at great depths in the eastern part of the southern Adriatic Sea (Albania) (STECF, 2019), with an increasing impact on the IF. *Isidella elongata* is often associated with the main targets species of deep fishery trawlers, such as the red shrimps (*Aristaeomorpha foliacea* and *Aristeus antennatus*) and the Norway lobster (*Nephrops norvegicus*) (Maynou & Cartes, 2012) in areas where a high overlap with the Essential Fish Habitat (EFH) was recently documented for both shrimps, particularly in the Otranto Channel (Carbonara et al., 2020). Pulcinella et al. (2021) analysed the AIS data and the fishing ground in the central-east Mediterranean and revealed how the number of fishing vessels dedicated to deep fishing in the GSA 18 increased from 23 in 2017 to 29 in 2018. Furthermore, the area of the Otranto Channel seems to be the most frequented area by deep sea fishing vessels with a monthly trawling haul frequency at depths greater than 400 m (deep water fishery) ranging from 12 to 24 over three years (2015–2018) and a mean number of fishing hours per km^2 ranging from 6 to 16 in the east and from 44 to 118 in the west part of the Otranto channel in the same time series. The combined analysis with spatial distribution of the fishing effort and the distribution of IF, showed an increase in the fishing effort on the hotspot of bamboo coral presence over time. Indeed, the overlap between the IF presence and the hotspot (75th percentile) deep (depth > 200 m) fishing ground increased from 8.84% to 12.27% over time, resulting in an increase of 38.8% between the two periods considered (2015-2017 *vs* 2018-2020; **Fig. 7**). Consequently, the increasing fishing effort for commercial fishery activity registered in recent years in the southern Adriatic Sea (IUCN, 2019) could deeply affect the distribution of the IF with fishing being considered one of the most impactful human activities on the VME, including the IF (Cartes et al., 2013; FAO, 2018; Fanelli et al., 2021).

The biodiversity associated with the colonies of the bamboo coral is significantly higher for both diversity indices used (i.e., Margalef and Shannon-Wiener) considering all time series (2012–2020) for the demersal OTU whereas no difference in the benthic OTU was found between the two assemblages considered (i.e., with and without bamboo coral). Based on these results, *I. elongata* seems to generate an important effect on the associated assemblage, more evident on the demersal than benthic fauna. Indeed, due to its candelabrum-like shape, the bamboo coral is one of the soft-bottom cold-water corals (CWCs) with a distinct frame-building ability to construct coral forests (Chimienti et al., 2019b) that also act as trophic areas where many species, such as the sharks *G. melastomus* and *E. spinax*, the teleost fishes *M. merluccius*, *M. poutassou*, *P. blennoides*, *H. dactylopterus*, *H. mediterraneus* and *Lepidorhombus boscii*, find preys swimming among the colonies or climbing on them (Mastrototaro et al., 2017; Carbonara et al., 2020; Cartes et al., 2022). Several studies on CWCs reveal a link between habitat complexity formed by corals and species diversity, particularly in bathyal zones (D'Onghia, 2019; Rueda et al., 2019; Cartes et al., 2022) where habitat-forming species variety is generally limited (Gage and Tyler, 1992). The presence of the bamboo coral, as a passive feeder, is often associated with the high abundance of zooplankton (Cartes et al., 2013). This biological feature, in turn, qualitatively and quantitatively influences IF-associated fauna in terms of demersal species within and around the colonies (Mastrototaro et al., 2017; Rueda et al., 2019; Carbonara et al., 2020). The large amount of zooplankton can produce a positive effect on several species in various food web positions, from the lower trophic levels to the higher of top predators (Rueda et al., 2019; Carbonara et al., 2020). For example, the presence of red shrimps in the IF (Cartes et al., 2013; Carbonara et al., 2020) seems to be linked with the presence of the Pandalidae species, which probably shares the same prey as bamboo coral (zooplankton), and, in turn, they are the favourite prey of both *A. foliacea* and *A. antennatus* (Kapiris, 2012). Moreover, the high concentration of pandalids and other crustaceans, including Aristeidae, attracts several bony fishes and ommastrephid cephalopods, producing a cascade of effects that could modify the fauna in the areas characterized by the presence of *I. elongata* and the energy flow through the food web (Eddy et al., 2021). Fishing is known to remove individuals at various trophic levels from natural habitats, thus affecting the overall energy flow through the food web (Watling & Norse, 1998; Pauly & Palomares, 2005; Sieben et al., 2011; Carbonara et al., 2022), making the environment less efficient in supporting a certain level of biodiversity (Hooper et al., 2005; Thompson et al., 2012; Ullah et al., 2018). Finally, the typical candelabrum-like shape of *I. elongata* also plays a role in terms of refuge from predators (Mastrototaro et al., 2017) and spawning area for several elasmobranch species (e.g., *Galeus melastomus* and *Scyliorhinus canicula*) (Carbonara et al., 2020). This effect was already observed in other CWC habitats in both the Ionian and southern Adriatic Seas (D'Onghia et al., 2010, 2012, 2016; Sion et al., 2019).

In this study, the time-series analysis also highlighted a temporal effect on biodiversity of assemblages with *I. elongata*, but with different results for the two indices. The richness index shows a significant negative trend over time in the assemblages with *I. elongata* whereas the Shannon-Wiener index exhibits no clear trend. The Margalef index has a good discriminatory ability towards species richness (Yeom & Kim, 2011; Magurran, 2013) that probably presents a faster response to the impact whereas the Shannon index is influenced by both species richness and species abundance distribution (evenness) that can exhibit a slower change in deep-sea communities. Moreover, the significant negative trend for the Margalef index could be linked to a decrease of the IF consistency over time (see **Fig. 2,3**). Indeed, the IF can play its role as a biodiversity hotspot (Cartes et al., 2013; Mytilineou et al., 2014; Mastrototaro et al., 2017) when it shows a certain level of integrity (Carbonara et al., 2020). When the IF is strongly impacted by fishery activity and consists of a few young and isolated colonies (Mastrototaro et al., 2017; Pierdomenico et al., 2018), it cannot fulfil its role as an attractive three-dimensional habitat (e.g., food riches, refuges) (Rueda et al., 2016).

Furthermore, the analyses carried out on the assemblages (with and without *I. elongata*) in the Otranto Channel showed significant differences in their specific compositions. The complete list of the OTUs found in the different years of the study is available in the supplementary material. In particular, among the most abundant species in the areas associated with IF, key species determine these differences more than others (Carbonara et al., 2020). Included in these key species are the osteoichthyes *Hoplostethus mediterraneus mediterraneus* Cuvier, 1829, *Phycis blennoides* (Brünnich, 1768) *Helicolenus dactylopterus* (Delaroche, 1809), and *Coelorinchus caelorhincus* (Risso, 1810); the elasmobranchs *Etmopterus spinax* (Linnaeus, 1758), *Dalatias licha* (Bonnaterre, 1788), and *Chimaera monstrosa* (Linnaeus, 1758); the crustaceans *Aristaeomorpha foliacea* (Risso, 1827), *Aristeus antennatus (*Risso, 1816), and *Paromola cuvieri* (Risso, 1816); and the cephalopod *Todarodes sagittatus* (Lamarck, 1798). Several of these species are commercial (see supplementary material), in particular the red shrimps (*A. foliacea* and *A. antennatus*) that are the target of the trawlers fishing on the slope (deeper than 200 m) (Maiorano et al., 2010; Russo et al., 2017).

Mature colonies (i.e., larger colonies with higher density) of *I. elongata* exhibit a higher macrofaunal community diversity (Cartes et al., 2022), also highlighting the importance of the colony size in the species diversity. Basal diameter is correlated with the height and width of the colonies in *I. elongata* (Carbonara et al., 2020) and with the age of colonies in congeneric species (Roark et al., 2005; Andrews et al., 2009). In this study, we observed that the BDD was different among the three periods considered (2014, 2015–2017 and 2018–2020). In the first period (2014), the BDDs are dominated by larger and older colonies (basal diameters > 4 mm), while in the 2015–2017 period, the BDDs are characterized by two similar peaks (1.5–2 mm and 3.5–4 mm) with a lower peak at 5 mm. In the last period considered (2018–2020), the BDD is quite monomodal with a peak at 1.5–2 mm. Thus, in the time series considered, the colony dimension/age seems to shift from a non- or little-impacted population (2012–2014) to a highly impacted population (2018–2020). The records from the last period considered (2018–2020) are similar to those found by Carbonara et al. (2020) in a population that was highly impacted by fishing (Tyrrhenian Sea). The population dominated by colonies with BD greater than 4 mm, found in 2014, could be considered quite pristine or minimally impacted by fishing (Bo et al., 2015a, 2015b; Carbonara et al., 2020). Colonies with BD greater than 4 mm correspond to the overall size of colonies (Carbonara et al., 2020) in pristine areas (Bo et al., 2015a, 2015b) with a capacity for reproduction and the renewal of the population still untouched (Bo et al., 2015a, 2015b). These changes over time are also confirmed by the significant trend of a decrease in yearly average BD. In this case, as well as for the spatial analysis, the reason for this decrease (average BD) could be the increased pressure of deep-sea fishing (FAO, 2018; IUCN, 2019). Although the age and growth for the *I. elongata* data are missing, congeneric species have been found to have a slow growth rate (Roark et al., 2005; Andrews et al., 2009). In the Gulf of Alaska, it was estimated that the lifespan for *Isidella spp.* was 75 to 126 years, with a slow growth rate ranged between about 0.1-0.05 mm of radial basal diameter per year (Roark et al., 2005; Andrews et al., 2009). From the perspective of *I. elongata* VME conservation, such fast decreasing trend detected in few years together with the low growth of *Isidella* sp. (Andrews et al., 2009) could be a dangerous warning sign of a severe progressive impact on IF. This biological characteristic of *Isidella* sp. coral indicates that the recovery of areas impacted by fishing (Mastrototaro et al., 2017; Pierdomenico et al., 2018) can take a very long time, ranging from a few decades to a century (Roark et al., 2005). Furthermore, it should be emphasised that studies on the growth and age of *I. elongata* have not yet been carried out and should be implemented as soon as possible not only for the purpose of biological and ecological knowledge but also for the conservation of this species (Carbonara et al., 2020).

Concluding remarks

In conclusion, the consistent presence of an *I. elongata* VME was confirmed in the Otranto Channel in the southern Adriatic Sea (Carbonara et al., 2020). Over a period of nine years, this VME seems to have a constant extension, but with a significant decrease in biomass and changes in demographic structure. The overlap between the spatial distribution of the bamboo coral and that of the fishing effort, indicates a severe impact clearly highlighted by the results of this study. Furthermore, other signs of the increasing impact of anthropogenic activities, such as fishing, are the changes in BDD (skewed towards smaller colonies in the last period from 2018 to 2020, unlike in 2014, where it skewed more towards large sizes) and the significant decrease in BD over time (from 2014–2020). It is also important to emphasise that IF represents biodiversity hotspots for deep environments in the study area (Cartes et al., 2009; Chimienti et al., 2019a, 2019b) that could be compromised by fisheries (Cartes et al., 2013). Until now, no fishing restrictions have been implemented in the area where the presence of IF (Otranto Channel) has been detected; indeed, as shown by our analysis, this area is a fishing ground for deep trawlers. Thus, it was recently proposed, in the context of the GFCM Subregional Committee for the Adriatic Sea, that the process to establish a fisheries restricted area (FRA) at the Otranto Channel (GFCM, 2021) must be started in order to help the conservation of *I. elongata* in the southern Adriatic Sea, achieving the goal of protecting VMEs set by various international organizations/conventions (FAO, 2009; UNEP-MAP-RAC-SPA, 2015).

Statements and Declarations

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Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files, further inquiries can be directed to the corresponding author.

Competing of Interest: The authors declare that they have no conflicts of interest.

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References

AAVV, 2017. MEDITS-Handbook. Version n. 9. , http://www.sibm.it/MEDITS.

Andrews, A. H., R. P. Stone, C. C. Lundstrom, & A. P. Devogelaere, 2009. Growth rate and age determination of bamboo corals from the northeastern Pacific Ocean using refined 210Pb dating. Marine Ecology Progress Series 397: 173–185, http://dx.doi.org/10.3354/meps08193.

Ashford, O. S., A. J. Kenny, C. R. S. B. Froján, A. L. Downie, T. Horton, & A. D. Rogers, 2019. On the influence of vulnerable marine ecosystem habitats on peracarid crustacean assemblages in the Northwest Atlantic Fisheries Organisation regulatory area. Frontiers in Marine Science 6: 401, https://doi.org/10.3389/fmars.2019.00401.

Bellan-Santini, D., 1985. The Mediterranean benthos: reflections and problems raised by a classification of the benthic assemblages In Moraitou-Apostolopoulou, M., & V. Kiortsis (eds), Mediterranean Marine Ecosystems. New York,: 19–48.

Bertrand, J. A., I. Leonori, P. Y. Dremière, & G. Cosimi, 2002. Depth trajectory and performance of a trawl used for an international bottom trawl survey in the Mediterranean. Scientia Marina 66: 169–182, https://doi.org/10.3989/scimar.2002.66s2169.

Bo, M., G. Bavestrello, M. Angiolillo, L. Calcagnile, S. Canese, R. Cannas, A. Cau, M. D’Elia, F. D’Oriano, M. C. Follesa, G. Quarta, & A. Cau, 2015a. Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). PLoS ONE 10(3): e0119393, https://doi.org/10.1371/journal.pone.0119393.

Bo, M., C. Ceranno, C. Antoniadou, S. Garcia, & C. Orejas, 2015b. *Isidella elongata* The IUCN Red List of Threatened Species e.T50012256A50605973. http://www.iucnredlist.org/details/50012256/3.

Buhl-Mortensen, L., A. Vanreusel, A. J. Gooday, L. A. Levin, I. G. Priede, P. Buhl-Mortensen, H. Gheerardyn, N. J. King, & M. Raes, 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Marine Ecology 31: 21–50, https://doi.org/10.1111/j.1439-0485.2010.00359.x.

Carbonara, P., A. Ciccolella, F. De Franco, M. Palmisano, A. Bellodi, G. Lembo, C. Neglia, M. T. Spedicato, W. Zupa, & P. Guidetti, 2022. Does fish growth respond to fishing restrictions within Marine Protected Areas? A case study of the striped red mullet in the south-west Adriatic Sea (central Mediterranean). Aquatic Conservation: Marine and Freshwater Ecosystems 32: 417–429, https://doi.org/10.1002/aqc.3776.

Carbonara, P., W. Zupa, M. C. Follesa, A. Cau, F. Capezzuto, G. Chimienti, G. D’Onghia, G. Lembo, P. Pesci, C.

Porcu, I. Bitetto, M. T. Spedicato, & P. Maiorano, 2020. Exploring a deep-sea vulnerable marine ecosystem: *Isidella elongata* (Esper, 1788) species assemblages in the Western and Central Mediterranean. Deep-Sea Research Part I: Oceanographic Research Papers 166: 103406, https://doi.org/10.1016/j.dsr.2020.103406.

Cartes, J. E., D. Díaz-Viñolas, J. M. González-Irusta, A. Serrano, S. Mohamed, & A. Lombarte, 2022. The macrofauna associated to the bamboo coral I*sidella elongata*: to what extent the impact on isideidae affects diversification of deep-sea fauna. Coral Reefs 41: 1273-1284, https://doi.org/10.1007/s00338-022-02243-w.

Cartes, J. E., C. LoIacono, V. Mamouridis, C. López-Pérez, & P. Rodríguez, 2013. Geomorphological, trophic and human influences on the bamboo coral *Isidella elongata* assemblages in the deep Mediterranean: To what extent does *Isidella* form habitat for fish and invertebrates?. Deep-Sea Research Part I: Oceanographic Research Papers 76: 52–65, https://doi.org/10.1016/j.dsr.2013.01.006.

Cartes, J. E., F. Maynou, E. Fanelli, C. Romano, V. Mamouridis, & V. Papiol, 2009. The distribution of megabenthic, invertebrate epifauna in the Balearic Basin (western Mediterranean) between 400 and 2300 m: Environmental gradients influencing assemblages composition and biomass trends. Journal of Sea Research 61: 244–257, http://dx.doi.org/10.1016/j.seares.2009.01.005.

Cartes, J. E., A. Schirone, M. Barsanti, I. Delbono, A. Martínez-Aliaga, & A. Lombarte, 2017. Recent reconstruction of deep-water macrofaunal communities recorded in Continental Margin sediments in the Balearic Basin. Deep-Sea Research Part I: Oceanographic Research Papers 125: 52–64, http://dx.doi.org/10.1016/j.dsr.2017.04.016.

Chimienti, G., L. Angeletti, L. Rizzo, A. Tursi, & F. Mastrototaro, 2018. ROV vs trawling approaches in the study of benthic communities: The case of *Pennatula rubra* (Cnidaria: Pennatulacea). Journal of the Marine Biological Association of the United Kingdom 98: 1859–1869, http://dx.doi.org/10.1017/S0025315418000851.

Chimienti, G., M. Bo, M. Taviani, & F. Mastrototaro, 2019a. 19 Occurrence and Biogeography of Mediterranean Cold-Water Corals In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_19.

Chimienti, G., F. Mastrototaro, & G. D'Onghia, 2019b. Mesophotic and Deep-Sea Vulnerable Coral Habitats of the Mediterranean Sea: Overview and Conservation Perspectives The Benthos Zone. In Advances in the Studies of the Benthic Zone, edited by Luis Soto. London: IntechOpen. IntechOpen: 1–20, https://doi.org/10.5772/intechopen.90024.

Coll, M., C. Piroddi, J. Steenbeek, K. Kaschner, F. B. R. Lasram, J. Aguzzi, E. Ballesteros, C. N. Bianchi, J. Corbera, T. Dailianis, R. Danovaro, M. Estrada, C. Froglia, B. S. Galil, J. M. Gasol, R. Gertwage, J. Gil, F. Guilhaumon, K. Kesner-

Reyes, M. S. Kitsos, A. Koukouras, N. Lampadariou, E. Laxamana, C. M. L. F. de la Cuadra, H. K. Lotze, D. Martin, D. Mouillot, D. Oro, S. Raicevich, J. Rius-Barile, J. I. Saiz-Salinas, C. S. Vicente, S. Somot, J. Templado, X. Turon, D. Vafidis, R. Villanueva, & E. Voultsiadou, 2010. The biodiversity of the Mediterranean Sea: Estimates, patterns, and threats. PLoS ONE 5(8): e11842, https://doi.org/10.1371/journal.pone.0011842.

D'Onghia, G., 2019. 30 Cold-Water Corals as Shelter, Feeding and Life-History Critical Habitats for Fish Species: Ecological Interactions and Fishing Impact In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_30.

D'Onghia, G., C. Calculli, F. Capezzuto, R. Carlucci, A. Carluccio, P. Maiorano, A. Pollice, P. Ricci, L. Sion, & A. Tursi, 2016. New records of cold-water coral sites and fish fauna characterization of a potential network existing in the Mediterranean Sea. Marine Ecology 37: 1398–1422, https://doi.org/10.1111/maec.12356.

D'Onghia, G., P. Maiorano, R. Carlucci, F. Capezzuto, A. Carluccio, A. Tursi, & L. Sion, 2012. Comparing Deep-Sea Fish Fauna between Coral and Non-Coral "Megahabitats" in the Santa Maria di Leuca Cold-Water Coral Province (Mediterranean Sea). PLoS ONE 7 (9): e44509, https://doi.org/10.1371/journal.pone.0044509.

D'Onghia, G., P. Maiorano, L. Sion, A. Giove, F. Capezzuto, R. Carlucci, & A. Tursi, 2010. Effects of deep-water coral banks on the abundance and size structure of the megafauna in the Mediterranean Sea. Deep-Sea Research Part II: Topical Studies in Oceanography 57: 397–411, http://dx.doi.org/10.1016/j.dsr2.2009.08.022.

D'Onghia, G., F. Mastrototaro, A. Matarrese, C. Y. Politou, & C. Mytilineou, 2003. Biodiversity of the upper slope demersal community in the Eastern Mediterranean: Preliminary comparison between two areas with and without trawl fishing. Journal of Northwest Atlantic Fishery Science 31: 263–273, http://dx.doi.org/10.2960/J.v31.a20.

Danovaro, R., E. Fanelli, M. Canals, T. Ciuffardi, M. C. Fabri, M. Taviani, M. Argyrou, E. Azzurro, S. Bianchelli, A. Cantafaro, L. Carugati, C. Corinaldesi, W. P. de Haan, A. Dell'Anno, J. Evans, F. Foglini, B. Galil, M. Gianni, M. Goren, S. Greco, J. Grimalt, Q. Güell-Bujons, A. Jadaud, L. Knittweis, J. L. Lopez, A. Sanchez-Vidal, P. J. Schembri, P. Snelgrove, S. Vaz, & T. I. Consortium, 2020. Towards a marine strategy for the deep Mediterranean Sea: Analysis of current ecological status. Marine Policy 112: 103781, https://doi.org/10.1016/j.marpol.2019.103781.

Eddy, T. D., J. R. Bernhardt, J. L. Blanchard, W. W. L. Cheung, M. Colléter, H. du Pontavice, E. A. Fulton, D. Gascuel, K. A. Kearney, C. M. Petrik, T. Roy, R. R. Rykaczewski, R. Selden, C. A. Stock, C. C. C. Wabnitz, & R. A. Watson, 2021. Energy Flow Through Marine Ecosystems: Confronting Transfer Efficiency. Trends in Ecology and Evolution 36: 76–86, https://doi.org/10.1016/j.tree.2020.09.006.

EUMOFA, 2019. The EU fish market-2019 edition. Publications Office of the European Union, Luxembourg (LU). https://doi.org/10.2771/168390.

Fabri, M. C., L. Pedel, L. Beuck, F. Galgani, D. Hebbeln, & A. Freiwald, 2014. Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. Deep-Sea Research Part II: Topical Studies in Oceanography 104: 184–207, http://dx.doi.org/10.1016/j.dsr2.2013.06.016.

Fanelli, E., S. Bianchelli, F. Foglini, M. Canals, G. Castellan, Q. Güell-Bujons, B. Galil, M. Goren, J. Evans, M. C. Fabri, S. Vaz, T. Ciuffardi, P. J. Schembri, L. Angeletti, M. Taviani, & R. Danovaro, 2021. Identifying Priorities for the Protection of Deep Mediterranean Sea Ecosystems Through an Integrated Approach. Frontiers in Marine Science 8: 698890, https://doi.org/10.3389/fmars.2021.698890.

FAO, 2009. International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. Rome, Italy, https://www.fao.org/3/i0816t/i0816t00.htm.

FAO, 2018. Report of the Second Meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). Rome, Italy.

Farriols, M. T., F. Ordines, M. Hidalgo, B. Guijarro, & E. Massutí, 2015. N90 index: A new approach to biodiversity based on similarity and sensitive to direct and indirect fishing impact. Ecological Indicators 52: 245–255, http://dx.doi.org/10.1016/j.ecolind.2014.12.009.

Fernandez-arcaya, U., Bitetto, I., Esteban, A., Farriols, M. T., García-ruiz, C., De Sola, L. G., Guijarro, B., Jadaud, A., Kavadas, S., Lembo, G., Milisenda, G., Maina, I., Petovic, S., Sion, L., Vaz, S., Massutí, E., 2019. Large-scale distribution of a deep-sea megafauna community along Mediterranean trawlable grounds. Scientia Marina 83S1: 175–187, https://doi.org/10.3989/scimar.04852.14A.

Gerovasileiou, V., C. J. Smith, S. Kiparissis, C. Stamouli, C. Dounas, & C. Mytilineou, 2019. Updating the distribution status of the critically endangered bamboo coral *Isidella elongata* (Esper, 1788) in the deep Eastern Mediterranean Sea. Regional Studies in Marine Science 28: 100610, https://doi.org/10.1016/j.rsma.2019.100610.

GFCM, 2017. Report of the first meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). Malaga, Spain.

GFCM, 2021. Report of the fifth meeting of the Subregional Committee for the Adriatic Sea (SRC-AS). Online, https://www.fao.org/gfcm/technical-meetings/detail/en/c/1410712/.

González-García, E., Á. Mateo-Ramírez, J. Urra, C. Farias, P. Marina, P. Lozano, P. J. López-González, C. Megina, J. E. García Raso, S. Gofas, E. López, J. Moreira, N. López-González, R. F. Sánchez-Leal, L. M. Fernández-Salas, & J. L. Rueda, 2020. Composition, structure and distribution of epibenthic communities within a mud volcano field of the northern Gulf of Cádiz in relation to environmental variables and trawling activity. Journal of Sea Research 160–161: 101892, https://doi.org/10.1016/j.seares.2020.101892.

Granger, V., J. M. Fromentin, N. Bez, G. Relini, C. N. Meynard, J. C. Gaertner, P. Maiorano, C. Garcia Ruiz, C. Follesa, M. Gristina, P. Peristeraki, A. Brind'Amour, P. Carbonara, C. Charilaou, A. Esteban, A. Jadaud, A. Joksimovic, A. Kallianiotis, J. Kolitari, C. Manfredi, E. Massuti, R. Mifsud, A. Quetglas, W. Refes, M. Sbrana, N. Vrgoc, M. T. Spedicato, & B. Mérigot, 2015. Large-scale spatio-temporal monitoring highlights hotspots of demersal fish diversity in the Mediterranean Sea. Progress in Oceanography 130: 65–74, http://dx.doi.org/10.1016/j.pocean.2014.10.002.

Grasshoff, M., 1989. Die Meerenge von Gibraltar als Faunen- Barriere: Die Gorgonaria, Pennatularia und Antipatharia der Balgim-Expedition (Cnidaria: Anthozoa). Senckenbergiana Maritima 20: 201–223.

Hijmans, R. J., 2021. raster: Geographic Data Analysis and Modeling. R package version 3.5-2. , https://cran.r-project.org/package=raster.

Hooper, D. ., F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A. J. Symstad, J. Vandermeer, & D. A. Wardle, 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Eclogical Monographs 75: 3–35, https://doi.org/10.1890/04-0922.

ICES, 2020. ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC). ICES Scientific Reports 2: 188 pp.

Ingrassia, M., E. Martorelli, A. Bosman, & F. L. Chiocci, 2019. *Isidella elongata* (Cnidaria: Alcyonacea): First report in the Ventotene Basin (Pontine Islands, western Mediterranean Sea). Regional Studies in Marine Science 25: 100494, https://doi.org/10.1016/j.rsma.2018.100494.

IUCN, 2019. Thematic Report – Conservation Overview of Mediterranean Deep-Sea Biodiversity: A Strategic Assessment. 122 pages. IUCN Gland, Switzerland and Malaga, Spain, https://uicnmed.org/docs/mediterraneandeepsea.pdf..

Kapiris, K., 2012. Feeding Habits of Both Deep-Water Red Shrimps, *Aristaeomorpha foliacea* and *Aristeus antennatus* (Decapoda, Aristeidae) in the Ionian Sea (E. Mediterranean) In Kapiris, K. (ed), Food Quality. IntechOpen: 112–134.

Laubier, L., & C. C. Emig, 1993. La faune benthique profonde de Mediterranee Symposium Mediterranen Seas 2000. S. Margherita Ligure: Istituto di Scienze Ambientali Marine. : pp 397–428.

Lauria, V., G. Garofalo, F. Fiorentino, D. Massi, G. Milisenda, S. Piraino, T. Russo, & M. Gristina, 2017. Species distribution models of two critically endangered deep-sea octocorals reveal fishing impacts on vulnerable marine ecosystems in central Mediterranean Sea. Scientific Reports 7: 1–14, http://dx.doi.org/10.1038/s41598-017-08386-z.

Magurran, A. E., 2013. Measuring biological diversity. Wiley-Blackwell.

Maiorano, P., F. Capezzuto, A. Carluccio, C. Calculli, G. Cipriano, R. Carlucci, P. Ricci, L. Sion, A. Tursi, & G. D'Onghia, 2022. Food from the Depths of the Mediterranean: The Role of Habitats, Changes in the Sea-Bottom Temperature and Fishing Pressure. Foods 11: 1420, https://doi.org/10.3390/foods11101420.

Maiorano, P., L. Sion, R. Carlucci, F. Capezzuto, A. Giove, G. Costantino, M. Panza, G. D'Onghia, & A. Tursi, 2010. The demersal faunal assemblage of the north-western Ionian Sea (central Mediterranean): Current knowledge and perspectives. Chemistry and Ecology 26: 219–240, https://doi.org/10.1080/02757541003693987.

Mangano, M., E. Porporato, E. Russo, G. I. Lambert, M. J. Kaiser, N. Spanò, P. Carbonara, & M. T. Spedicato, 2013. Effects of trawling impacts on mega-epibenthic communities from heavy exploited to undisturbed areas in a Mediterranean fishing ground (Central Mediterranean Sea). ICES CM I: 46.

Margalef, R., 1958. Information theory in ecology. International Journal of General Systems 3: 36–71.

Mastrototaro, F., G. Chimienti, J. Acosta, J. Blanco, S. Garcia, J. Rivera, & R. Aguilar, 2017. *Isidella elongata* (Cnidaria: Alcyonacea) facies in the western Mediterranean Sea: Visual surveys and descriptions of its ecological role. European Zoological Journal Taylor & Francis 84: 209–225, http://dx.doi.org/10.1080/24750263.2017.1315745.

Maynou, F., & J. E. Cartes, 2012. Effects of trawling on fish and invertebrates from deep-sea coral facies of *Isidella elongata* in the western Mediterranean. Journal of the Marine Biological Association of the United Kingdom 92: 1501–1507, https://doi.org/10.1017/S0025315411001603.

Mytilineou, C., C. J. Smith, A. Anastasopoulou, K. N. Papadopoulou, G. Christidis, P. Bekas, S. Kavadas, & J. Dokos, 2014. New cold-water coral occurrences in the Eastern Ionian Sea: Results from experimental long line fishing. Deep-Sea Research Part II: Topical Studies in Oceanography 99: 146–157, http://dx.doi.org/10.1016/j.dsr2.2013.07.007.

Otero, M. del M., & P. Marin, 2019. 46 Conservation of Cold-Water Corals in the Mediterranean: Current Status and Future Prospects for Improvement In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future.Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_46.

Palialexis, A., A. C. Cardoso, & F. Somma, 2018. JRC’s reference lists of MSFD species and habitats : MSFD reporting for descriptors 1 and 6. JRC’s reference lists of MSFD species and habitats : MSFD reporting for descriptors 1 and 6. Publications Office, Luxembourg.

Pauly, D., & M. L. Palomares, 2005. Fishing down marine food web: It is far more pervasive than we thought. Bulletin of Marine Science 76(2): 197–211.

Pérès, J. M., & J. Picard, 1964. Nouveau manuel de bionomie benthique de la Méditerranée. Recueil des Travaux de la Station Marine d’Endoume 31: 1–37.

Petović, S., O. Marković, Z. Ikica, M. Đurović, & A. Joksimović, 2016. Effects of bottom trawling on the benthic assemblages in the south Adriatic Sea (Montenegro). Acta Adriatica 57: 79–90.

Pierdomenico, M., F. Cardone, A. Carluccio, D. Casalbore, F. Chiocci, P. Maiorano, & G. D’Onghia, 2019. Megafauna distribution along active submarine canyons of the central Mediterranean: Relationships with environmental variables. Progress in Oceanography 171: 49–69, https://doi.org/10.1016/j.pocean.2018.12.015.

Pierdomenico, M., E. Martorelli, C. Dominguez-Carrió, J. M. Gili, & F. L. Chiocci, 2016. Seafloor characterization and benthic megafaunal distribution of an active submarine canyon and surrounding sectors: The case of Gioia Canyon (Southern Tyrrhenian Sea). Journal of Marine Systems 157: 101–117, http://dx.doi.org/10.1016/j.jmarsys.2016.01.005.

Pierdomenico, M., T. Russo, S. Ambroso, A. Gori, E. Martorelli, L. D’Andrea, J. M. Gili, & F. L. Chiocci, 2018. Effects of trawling activity on the bamboo-coral *Isidella elongata* and the sea pen *Funiculina quadrangularis* along the Gioia Canyon (Western Mediterranean, southern Tyrrhenian Sea). Progress in Oceanography 169: 214–226, http://dx.doi.org/10.1016/j.pocean.2018.02.019.

Pulcinella, J., E. N. Armelloni, C. Ferrà, G. Scarcella, & A. N. Tassetti, 2021. Identification and mapping of bottom trawl fishing grounds for deep-water red shrimp in the Eastern. FAO-GFCM. Report submitted .

QGIS Development Team, 2017. Geographic Information System. Open Source Geospatial Foundation Project. Qgis. http://www.qgis.org/.

R Development Core Team, 2021. R Software. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. .

Roark, E. B., T. P. Guilderson, S. Flood-Page, R. B. Dunbar, B. L. Ingram, S. J. Fallon, & M. McCulloch, 2005.

Radiocarbon-based ages and growth rates of bamboo corals from the Gulf of Alaska. Geophysical Research Letters 32: 1–5, http://dx.doi.org/10.1029/2004GL021919.

Rossi, S., L. Bramanti, A. Gori, & C. Orejas, 2017. An overview of the animal forests of the world In Rossi, S., L. Bramanti, A. Gori, & C. Orejas (eds), Marine Animal Forests. Springer, Cham, https://doi.org/10.1007/978-3-319-17001-5_1-1

Rueda, J. L., E. González-García, C. Krutzky, F. J. López-Rodriguez, G. Bruque, N. López-González, D. Palomino, R. F. Sánchez, J. T. Vázquez, L. M. Fernández-Salas, & V. Díaz-del-Río, 2016. From chemosynthesis-based communities to cold-water corals: Vulnerable deep-sea habitats of the Gulf of Cádiz. Marine Biodiversity 46: 473–482, https://doi.org/10.1007/s12526-015-0366-0.

Rueda, J. L., J. Urra, R. Aguilar, L. Angeletti, M. Bo, C. García-Ruiz, M. M. González-Duarte, E. López, T. Madurell, M. Maldonado, Á. Mateo-Ramírez, C. Megina, J. Moreira, F. Moya, L. V. Ramalho, A. Rosso, C. Sitjà, & M. Taviani, 2019. 29 Cold-Water Coral Associated Fauna in the Mediterranean Sea and Adjacent Areas In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future.. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_29.

Russo, T., I. Bitetto, P. Carbonara, R. Carlucci, L. D’Andrea, M. T. Facchini, G. Lembo, P. Maiorano, L. Sion, M. T. Spedicato, A. Tursi, & S. Cataudella, 2017. A holistic approach to fishery management: Evidence and insights from a central mediterranean case study (Western Ionian Sea). Frontiers in Marine Science 4: 1–18, https://doi.org/10.3389/fmars.2017.00193.

Shannon, C. E., 1948. A mathematical theory of communication. Bell System Technical Journal 27: 379–423.

Sieben, K., A. D. Rippen, & B. K. Eriksson, 2011. Cascading effects from predator removal depend on resource availability in a benthic food web. Marine Biology 158: 391–400, https://doi.org/10.1007/s00227-010-1567-5.

Sion, L., C. Calculli, F. Capezzuto, R. Carlucci, A. Carluccio, L. Cornacchia, P. Maiorano, A. Pollice, P. Ricci, A. Tursi, & G. D’Onghia, 2019. Does the Bari Canyon (Central Mediterranean) influence the fish distribution and abundance?. Progress in Oceanography 170: 81–92, https://doi.org/10.1016/j.pocean.2018.10.015.

Souplet, A., 1996. Calculation of abundance indices and length frequencies in the MEDITS survey In Bertrand, J. A., L. Gil de Sola, C. Papaconstantinou, G. Relini, & A. Souplet (eds), Campagne internationale du chalutage démersal en Méditerranée. Campagne 1995, vol. III. EU Final Report. .

Spedicato, M. T., & G. Lembo, 2011. Caratterizzazione ambientale delle aree di pesca: GSA 10 – tirreno Centro-

Meridionale In Cataudella, S., & M. Spagnolo (eds), The state of Italian marine fisheries and aquaculture. Rome: 52–59, https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina%0A/6412.

Spedicato, M. T., G. Lembo, P. Carbonara, & T. Silecchia, 1998. Valutazione delle risorse demersali dal fiume gariglianoa capo suvero. Biologia Marina Mediterranea 5: 64–73.

Spedicato, M. T., E. Massutí, B. Mérigot, G. Tserpes, A. Jadaud, & G. Relini, 2019. The MEDITS trawl survey specifications in an ecosystem approach to fishery management. Scientia Marina 83S1: 9–20, https://doi.org/10.3989/scimar.04915.11X.

STECF, 2019. Multiannual Plan for the fisheries exploiting demersal stocks in the Adriatic Sea (STECF-19-02). Luxembourg.

Thompson, R. M., U. Brose, J. A. Dunne, R. O. Hall, S. Hladyz, R. L. Kitching, N. D. Martinez, H. Rantala, T. N. Romanuk, D. B. Stouffer, & J. M. Tylianakis, 2012. Food webs: Reconciling the structure and function of biodiversity. Trends in Ecology and Evolution 27: 689–697, http://dx.doi.org/10.1016/j.tree.2012.08.005.

Ullah, H., I. Nagelkerken, S. U. Goldenberg, & D. A. Fordham, 2018. Climate change could drive marine food web collapse through altered trophic flows and cyanobacterial proliferation. PLoS Biology 16(1): e2003446, https://doi.org/10.1371/journal.pbio.2003446.

UNEP-MAP-RAC-SPA, 2015. A guide on environmental monitoring of rocky seabeds in Mediterranean Marine Protected Areas and surrounding zones. By José Carlos GARCÍA-GÓMEZ. Tunis.

Vafidis, D., C. H. Mytilineous, F. Mastrototaro, & G. D'Onghia, 2006. First records of Leiopathes glaberrima (Esper, 1792) and *Isidella elongata* (Esper, 1788) (Cnidaria: anthozoa) in the ionian. Proceedings of the 10th ICZEGAR. Patra, Greece: 220.

Vilibic, I., & M. Orlic, 2002. Adriatic water masses, their rates of formation and transport through the Otranto Strait. Deep-Sea Research Part I: Oceanographic Research Papers 49: 1321–1340, https://doi.org/10.1016/S0967-0637(02)00028-6.

Watling, L., & E. A. Norse, 1998. Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. Conservation Biology 12: 1180–1197, https://www.jstor.org/stable/2989836.

Yeom, D. J., & J. H. Kim, 2011. Comparative evaluation of species diversity indices in the natural deciduous forest of Mt. Jeombong. Forest Science and Technology 7: 68–74, https://doi.org/10.1080/21580103.2011.573940.

Captions for figures

Figure 1. The study area is the southern Adriatic Sea (Geographical sub–area GSA 18 *sensu* GFCM-FAO). The geographic allocation of the hauls explored during the MEDITS trawl surveys in GSA 18 are indicated by black points.

Figure 2. The bidimensional splines of the Gaussian GAM models used to describe the spatial distribution of *Isidella elongata* biomass (kg/km^2) in **(a)** 2012–2014, **(b)** 2015–2017, and **(c)** 2018–2020. X: Longitude, Y: Latitude.

Figure 3. The spatial distribution of *Isidella elongata* biomass (kg/km^2) in the three considered periods: **(a)** 2012–2014, **(b)** 2015–2017, and **(c)** 2018–2020. The green line borders the 75th percentile of the estimated biomass distribution.

Figure 4. *Isidella elongata* biomass index (kg/km^2) (blue trend in macrostratum at depths of 200–800 m). The Spearman's rho correlation test showed a significant decrease ($p < 0.05$). The solid line represents the biomass index, while the dashed lines represent the standard deviation.

Figure 5. Benthos OTU box plots of the **(a)** Margalef (D) and **(b)** Shannon (H') indexes of assemblages with (associated) and without (not associated) *Isidella elongata* per year. The solid line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Statistics reported in the figure are based on Wilcoxon–Mann–Whitney tests carried out within each period (*: $p < 0.05$; **: $p < 0.01$; NS = not significant). The Spearman's rho correlation test was not significant ($p > 0.05$) for both assemblages (associated and not associated) and both indices (Margalef and Shannon).

Figure 6. Demersal OTU box plots of the **(a)** Margalef (D) and **(b)** Shannon (H') indexes of assemblages with (associated) and without (not associated) *Isidella elongata* per year. The solid line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Statistics reported in the figure are based on Wilcoxon–Mann–Whitney tests carried out within each period (*: $p < 0.05$; **: $p < 0.01$; NS (not significant): $p > 0.05$). The Spearman's rho correlation test was not significant ($p > 0.05$) for both assemblages (associated and not associated) for Shannon's index. For the Margalef's index the "associated" assemblage shows a significant decreasing trend (Spearman's rho correlation test $p < 0.05$), while that of the "not associated" assemblage was not significant ($p > 0.05$).

Figure 7. Fishing effort in the southern Adriatic Sea in (A) 2015–2017 and (B) 2018–2020, estimated using the aggregated AIS data provided by Global Fishing Watch (https://globalfishingwatch.org/). The hotspot of fishing activities was calculated as the 75th percentile of effort data distribution. Moreover, the spatial and percentage overlap between the hotspot of *Isidella elongata* presence and fishing efforts is also shown.

Figure 8. Basal diameter (mm) distribution of *Isidella elongata* colonies in **(a)** 2014, **(b)** 2015–2017, and **(c)** 2018–2020.

Figure 9. Box plots of the colony basal diameter (mm) measured from 2014 to 2020 in the GSA 18. For boxplot representation, the central line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Different letters indicate significant differences among groups between the years (Kruskal–Wallis and Nemenyi post-hoc tests, $p < 0.05$).

Spatio-temporal distribution of *Isidella elongata*, a vulnerable marine ecosystem indicator species, in the southern Adriatic Sea

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Abstract

The bamboo coral *Isidella elongata* is a forest-forming alcyonacean that dwells on deep-sea soft bottoms and is presently found in the Otranto Channel (Southern Adriatic Sea). In this study, we explored the spatial distribution and the demographic structure of the *I. elongata* facies (IF) over time, along with the diversity of IF-associated fauna in the southern Adriatic Sea, by using a time-series data of nine years (2012–2020) from the Mediterranean International Bottom Trawl Survey (MEDITS). The spatial distribution of *I. elongata* was confronted with the fishing effort in the study area over time. This facies showed a constant spatial extent but a decreasing biomass over time. Changes in the basal diameter distribution of the colonies were also observed, with a significant decrease in the sizes from 2014 to 2020. These results suggest an increasing fishery-related impact from a developing deep-sea fishery occurring in the study area. The bamboo coral in the study area represents a hotspot of biodiversity in the context of the bathyal environment. A fisheries-restricted area was recently proposed in the context of the General Fisheries Commission for the Mediterranean at the Otranto Channel to help the conservation of *I. elongata* in the southern Adriatic Sea.

Keywords: Vulnerable marine ecosystem; *Isidella elongata*; Spatial distribution; Time series; Colonies basal diameter; southern Adriatic Sea; Fisheries

Introduction

Vulnerable Marine Ecosystems (VMEs) are overall defined as a group of species, communities, or habitats characterised by hotspots of biodiversity and ecosystem functioning in the deep sea that may be exposed to the impacts of fishing activities (FAO, 2009). Moreover, VMEs are characterised by a high vulnerability to fishing disturbances (Ashford et al., 2019). This vulnerability is related to its weakness in terms of the renewal of population and/or habitat stability as a result of fishing impacts. The set of criteria to class an ecosystem as VME was detailed in FAO (2009) for fisheries management, following the discussion detailed in United Nations General Assembly (UNGA) Resolution 61/105 in 2006. Indeed, fishery activities performed in the deep sea can compromise the physical and functional stability of the ecosystem, triggering negative effects on both living marine resources and the ecosystem itself. Moreover, there is increasing concern linked with the overfishing of the target species associated with VMEs, where continuous removal may impact the overall functionality of the ecosystem (Maynou & Cartes, 2012; FAO, 2018). This is of primary interest, since VMEs are considered hotspots of biodiversity that provide healthy ecosystem functioning and several ecosystem services in the deep sea (FAO, 2009; Ashford et al., 2019; Chimienti et al., 2019b; Carbonara et al., 2020; Maiorano et al., 2022).

The *Isidella elongata* facies (IF) was added to the list of VMEs by the General Fisheries Commission for the Mediterranean Sea (GFCM) (GFCM, 2017), and several international actions have been implemented for their protection. This facies has been included in the “Deep Water Engineering benthic invertebrate assemblages” in the “Dark Habitats Action Plan” of the Barcelona Convention (UNEP-MAP-RAC-SPA, 2015). This inclusion has also been supported by the previous addition of the species to the International Union for Conservation of Nature (IUCN) red list for the Mediterranean, with *Isidella elongata* being the only Mediterranean anthozoan species classified as critically endangered (http://www.iucn.it/scheda.php?id=789649086). Recently, *Isidella elongata* has been also recognised as a deep-water VME representative taxon of the VME habitat type "Soft bottom coral garden: Soft bottom gorgonian and black coral gardens" by the International Council for the Exploration of the Sea (ICES, 2020). In the context of the Marine Strategy Framework Directive, only recently has it been recognised that the IF needs protection as a habitat (coral garden) (Palialexis et al., 2018; Danovaro et al., 2020).

The Mediterranean Sea is considered a major biodiversity hotspot due to its high species richness coupled with a considerable proportion of endemic species (Coll et al., 2010; Granger et al., 2015). The bamboo coral *I. elongata* is an alcyonacean species (family Keratoisididae), near-endemic to the Mediterranean Sea (Grasshoff, 1989), that dwells on soft bottoms at depths between 100 m and 1500 m (Bellan-Santini, 1985; Laubier & Emig, 1993; Bo et al., 2015a), where it can form very dense aggregations (Mastrototaro et al., 2017) called coral gardens or coral forests (FAO, 2009; Rossi et al., 2017; Chimienti et al., 2019b). The coral forests of *I. elongata* represent the true facies of the bathyal mud in the Mediterranean Sea (*sensu* Pérès and Picard 1964).

I. elongata has a candelabrum-like shape and can reach 80 cm in height (Bo et al., 2015a; Carbonara et al., 2020), acting as a structuring organism that is able to generate a complex and three-dimensional heterogeneity on otherwise flat muddy bottoms where the species dwells. The IF can consist of dense bamboo coral colonies constituting a habitat that hosts several fishes and crustacean species (Mastrototaro et al., 2017; D'Onghia, 2019; Carbonara et al., 2020), as in the Balearic Sea where up to 2300–2683 colonies/ha and 50 taxa have been identified (Mastrototaro et al., 2017). Several studies have demonstrated that the presence of bamboo coral influences both the biodiversity and the abundance of several species (Buhl-Mortensen et al., 2010; Maynou & Cartes, 2012; Mytilineou et al., 2014; Carbonara et al., 2020; Cartes et al., 2022). These studies have been mainly focused on megafauna (fish and large invertebrates), and much less on macrofauna associated with the IF (Cartes et al., 2017, 2022; Carbonara et al., 2020). Predator species take advantage of the presence of IF, as they find a higher density of prey within bamboo coral (D'Onghia, 2019; Carbonara et al., 2020). Moreover, the arborescent complexity of *I. elongata* colonies' could further provide a shelter effect against predators (Mastrototaro et al., 2017). Some of the typical species associated with the bamboo coral, such as the red shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus* and the Norway lobster *Nephrops norvegicus* (Maynou & Cartes, 2012; Mastrototaro et al., 2017; D'Onghia, 2019), are of high commercial value and targeted by professional fisheries (Spedicato et al., 1998; Maynou & Cartes, 2012; Cartes et al., 2013; Lauria et al., 2017; D'Onghia, 2019; EUMOFA, 2019).

In the last decades, trawling activities in the Mediterranean have enlarged their operational bathymetric range, causing a greater impact on deep-sea bottoms (FAO, 2009, 2018) and consequently on deep-sea VMEs such as IF. In this context, determining the presence and understanding the spatial distribution of VMEs, including bamboo coral facies, are crucial to implementing actions of management or protection (Lauria et al., 2017; FAO, 2018; Chimienti et al., 2019a; Otero & Marin, 2019). IF occurrences have been studied in the western Mediterranean (Fabri et al., 2014; Mastrototaro et al., 2017; Chimienti et al., 2019a), in the central-eastern (D'Onghia et al., 2003; Vafidis et al., 2006; Mytilineou et al., 2014; Pierdomenico et al., 2016, 2018, 2019; Lauria et al., 2017; D'Onghia, 2019; Carbonara et al., 2020) and in the eastern part of the basin (Gerovasileiou et al., 2019). More recently, Carbonara et al. (2020) reported the occurrence of IF in the southern Adriatic Sea, where the IF was the least impacted by fishery among the study areas (i.e., Sardinian Sea, south-central Tyrrhenian, southern Adriatic, and north-western Ionian). It is to note that some populations are also in good condition in other areas, such as those around the Balearic Islands (Mastrototaro et al., 2017). While acknowledging how bottom trawl surveys are not the optimum way of sampling for benthic biocoenosis, opportunistic data collected during the Mediterranean International Bottom Trawl Survey (MEDITS) (Spedicato et al., 2019) could, nevertheless, be useful for setting up spatial-temporal analysis of IF and associated communities on trawled soft bottoms (Farriols et al., 2015; Granger et al., 2015; Petović et al., 2016; Chimienti et al., 2018; Gerovasileiou et al., 2019).

Thus, the aim of this study was to detect over a time-series data of nine years (2012–2020) the potential changes of: i) occurrence, spatial distribution and abundance of the *I. elongata* facies in the southern Adriatic Sea (GSA 18; *sensu* FAO GFCM); ii) biodiversity of the fauna associated with the IF; iii) the bamboo coral colonies demography; and iv) the overlap of IF with trawler fishing effort in the study area from 2015 to 2020.

Materials and Method

Sampling method

The data analysed in this work were collected in the context of the MEDITS trawl surveys in the years from 2012 to 2020 in the geographical subarea GSA 18: southern Adriatic Sea (**Fig. 1**). The primary objective of the MEDITS trawl survey is to estimate the abundance, distribution, and population structure of commercial fish and invertebrate species in the Mediterranean Sea. The MEDITS survey is carried out annually between late spring and midsummer, and it covers the depth range from 10 to 800 m (AAVV, 2017). Trawl stations were allocated in five bathymetrical strata (10–50, 50–100, 100–200, 200–500 and 500–800 m) on the trawlable bottom (i.e. flat and soft-bottom) and consistently carried out in the same position according to a random-stratified sampling design (AAVV, 2017). The survey design, as well as the details of the sampling methodology, are reported by Spedicato et al. (2019). The standard sampling gear used was the bottom trawl GOC 73 (Bertrand et al., 2002) designed for experimental fishing. Briefly, it has a vertical opening slightly larger than that of the most common professional gear used in the area and the stretched mesh size of 20 mm at the codend. The haul duration was 30 minutes on the continental shelf (10–200 m depth) and 60 minutes on the slope (201–800 m depth), and hauls were allowed only during daytime. The standard fishing speed was 3 knots on the ground. Other specific details can be found in the study of Spedicato et al. (2019).

Analysis of the occurrence, distribution, and biomass of **I. elongata** *in GSA 18 and the associated biodiversity*

The occurrence of *I. elongata* was computed as the percentage of hauls with the presence of IF over the total number of hauls carried out by year. For each haul in which *I. elongata* was observed, its total weight was measured (kg; at gram resolution) and standardized to the swept surface unit (km^2). As the trawling activity caused mechanical damage to the colonies of bamboo coral, its biomass caught in each haul consisted of various parts of fragmented colonies, including the basal part and/or the arms. Thus, the biomass of *I. elongata* was proportional to the number of colonies and their size. The biomass (kg km^{-2}) index was computed according to Souplet (1996) by weighting the mean index by depth stratum or macro stratum (e.g. 200-800).

The spatial distribution analysis of *I. elongata* biomass was conducted using a spatial modelling approach based on a generalised additive model (GAM). In particular, biomass data were modelled using the Gaussian family distribution and link function identity, with longitude (Lon) and latitude (Lat) as explanatory variables. Three different GAM models were estimated to display *I. elongata* biomass distribution in two bathymetric strata from the MEDITS protocol (AAVV, 2017) where the species was present (200–500 m and 500–800 m), for three periods (2012–2014, 2015–2017 and 2018–2020), as reported in the following formula:

$$\text{Biomass} \sim s(Lon_{ij}, Lat_{ij}) + \varepsilon_{ij}$$

where i is the observation in the j time period, and ε is the error term.

The prediction maps were generated by using a regular grid with a point resolution of 0.01°. The data used to resize the grid to the selected depth range were derived from the EMODnet-Bathymetry portal (grid resolution of 1/16 * 1/16 arc minutes, circa 115 × 115 metres). All the GAM analyses were performed using the R software (R Development Core Team, 2021) and the *mgcv* package, while distribution maps were generated with QGIS software (QGIS Development Team, 2017).

For the analysis of the biodiversity of associated assemblages, we considered only those hauls performed on substrates (fine muddy bottom), where *I. elongata* was typically found (Mytilineou et al., 2014; Pierdomenico et al., 2016, 2018; Mastrototaro et al., 2017; Chimienti et al., 2019a; Gerovasileiou et al., 2019; Carbonara et al., 2020; Cartes et al., 2022) for which the presence or the absence of the species was recorded (Carbonara et al., 2020). In this way, it is possible to minimise in the analysis the influence of the hauls where IF generally does not occur (e.g., gravel, coarse sand) (Lauria et al., 2017). From each haul, all the faunal specimens larger than 1 cm (Spedicato et al., 2019) were classified at the lowest possible taxonomic level, and for each Operational Taxonomic Unit (OTU) data on weight and number of specimens were collected according to the MEDITS protocol (AAVV, 2017). The Margalef richness index (D) (Margalef, 1958) and Shannon-Wiener index (H’) (Shannon, 1948) were computed for each sampling station carried out deeper than 200 m, which represents the area where the probability of IF occurrence was higher (Carbonara et al., 2020). These indexes were used to detect the potential effects of the presence of *I. elongata* on the associated assemblages. The hauls performed on suitable substrate types (fine muddy) were pooled into two categories: “presence,” if the bamboo coral was caught in the haul, and “absence” for all remaining hauls on the muddy bottom. The analysis was carried out separately by year for the benthic and demersal species, and the differences in biodiversity between the two assemblages with (associated) and without (not associated) *I. elongata* for each year were evaluated using the non-parametric Wilcoxon–Mann–Whitney test. Moreover, the presence of a temporal trend in the biomass index (kg/km^2) of *I. elongata* was tested by Spearman's rho correlation test.

Spatial distribution of fishing efforts

Fishing effort in the study area was estimated by means of the aggregated Automatic Identification System (AIS) data provided by Global Fishing Watch (https://globalfishingwatch.org/). Annual fishing activities referred to those from 2015 to 2020 (expressed in hours) and were aggregated in the same temporal frame of the MEDITS *I. elongata* spatial analysis (three years): 2015–2017 and 2018–2020. The first years (2012–2014) were not considered in the analysis because of the limited coverage of the active fishery by the AIS system (Global Fishing Watch; https://globalfishingwatch.org/data-download/datasets/public-fishing-effort) that came into effect progressively from May 2012 to May 2014 (2002/59/CE) in Italy. Moreover, the data were averaged over a grid with a resolution of 0.01° x 0.01°. The hotspot of fishing activities was calculated as the 75th percentile of effort data distribution. The resulting fishing polygon bordering the effort hotspot was superimposed with the polygon bordering the 75th percentile of the estimated coral bamboo distribution, in order to assess the percentage of *I. elongata* hotspot surface area overlapping the main fishing ground in the southern Adriatic Sea (GSA18). The analysis was conducted using R software (R Core Team, 2021) by means of the raster library (Hijmans, 2021).

Morphological parameter measurements and analyses

During the survey, the morphological parameters of *I. elongata* colonies were collected in terms of basal diameter (BD, in millimetres) to infer information on the population demographic structure in the southern Adriatic Sea from 2014 to 2020. The trawl survey caused mechanical damage to the colonies and it did not allow us to collect specific data, such as maximum height, branching patterns (colony width), and/or colony vitality (Carbonara et al., 2020). However, the basal diameter is often used to infer the size of the colonies (Andrews et al., 2009; Carbonara et al., 2020; Cartes et al., 2022), as it is correlated to the height (Carbonara et al., 2020). Basal diameter was measured only when the base of the colony was present, established by the presence of at least part of the root-shaped bases (Carbonara et al., 2020). In all the hauls where the presence of bamboo coral specimens was detected, the bases of the colonies were collected and subsequently measured. On each base colony, as close as possible to the root, at least three measurements of the diameter were taken by caliper (resolution of 0.1 mm), and the final diameter was the average of these measurements (Coefficient of Variation between 0 and 9.75). The annual average values of colony BD were used to test the trend of the colony sizes over seven years (2014–2020) using Spearman’s correlation. In addition, the eventual differences during the study period were tested using a Kruskal–Wallis one-way analysis of variance by ranks. The Nemenyi *post hoc* test was used to evaluate the significance of such median differences between years. In order to analyse the change in the basal diameter distribution (BDD), the years were grouped into three periods as follows: 2014, 2015–2017 and 2018–2020. The years were grouped according to the time periods selected for the GAM analysis. The different BDDs were compared by Kolmogorov–Smirnov (K–S) test.

The skewness index (SK) of BD distribution was calculated to measure the distributions' deviation from symmetry. The skewness describes three scenarios: (i) distribution dominated by smaller colonies ($SK > 0.5$), (ii) distribution dominated by larger colonies ($SK < 0$), and (iii) no size dominance ($0 \leq SK \leq 0.5$).

Results

Occurrence, distribution, and abundance of* I. elongata *in GSA 18

The percentage and depth range of occurrence of *I. elongata* per haul in GSA 18 is reported in **Table 1**. The percentage of occurrence (number of hauls positive with the presence of IF out of the total number of hauls carried out) showed from a maximum of 9.41% in 2017 to a minimum value of 4.44% in 2019. The depth range of occurrence was between 410 m (2017) and 625 m (2016).

Table 1. Percentage (%) (number of positive hauls to the presence of bamboo coral) and depth range (m) of occurrence of *Isidella elongata* in each year, total number of hauls carried out in the survey, and their depth range.

Year	Percentage of occurrence (%)	Depth range of *I. elongata* occurrence (m)	Total number hauls carried out in the survey	Depth range of hauls carried out in the survey (m)
2012	6.67	520–618	90	12–678
2013	7.78	517–617	90	11–713
2014	6.67	447–617	90	11–715
2015	6.67	515–619	90	10–693
2016	6.67	429–625	90	10–739
2017	9.41	410–601	85	10–733
2018	6.74	518–596	89	10–701
2019	4.44	569–621	90	10–749
2020	7.14	551–600	70	10–759

In all the three models tested to describe the effect of the spatial displacement on the biomass of *I. elongata* (kg km^{-2}), the bidimensional splines of the geographic coordinates included in the Gaussian GAM model were significant for the three monitored periods ($p < 0.05$ for all), explaining the following amount of deviance: 86.2% in 2012–2014, 72.4% in 2015–2017 and 59.7% in 2018–2020. These splines (**Fig. 2**) indicate the combined effects of northing and easting on the biomass, locating the hotspot bamboo coral biomass in the Otranto Channel (**Fig. 3**). The extension of the area, in which the hotspots (75th percentile of the estimated biomass distribution) of IF were estimated to be located, is similar for the three periods considered (1436.7 km^2 for 2012–2014, 1520.4 km^2 for 2015–2017 and 1421.6 km^2 for 2018–2020). Similarities were seen in its spatial distribution pattern as well, although with a clear decreasing biomass of the bamboo coral over the three groups of study periods (**Fig. 3**). A significant decreasing trend ($p < 0.05$) in the biomass index of *I. elongata* was also detected over the time series considered (2012–2020). The biomass index of *I. elongata* was around 25 kg/m^2 in both 2012 and 2013, with a peak in 2014 (65.7 ± 47.1 kg/m^2), while very low biomass indexes below 1.3 kg/m^2 were observed from 2018 to 2020 (**Fig. 4**).

The list of the OTUs found in the different years in the study area and their relative biomass were provided in the supplementary material. In **Figures 5 and 6**, the analyses of the Margalef and Shannon-Wiener biodiversity indexes for the hauls associated or not associated with the presence of *I. elongata* are reported. The results of the diversity indexes for the assemblages “associated” and “not associated” were compared within each year. For the benthic species, no significant difference between the assemblages with and without the bamboo coral was observed, except in 2016 for the Shannon diversity index. In contrast, for the demersal species the assemblage associated with *I. elongata* showed significantly higher values for both indices in most of the years analysed ($p < 0.05$), excepted in 2016 for the Shannon diversity index and from 2018 to 2020 for the Margalef one ($p < 0.05$; **Fig. 5**). A significant decreasing trend ($p < 0.05$) of the Margalef index was detected for the demersal “associated” assemblage over the study period (**Fig. 6**). No significant trend over time was observed in both indices of both benthic assemblages nor in the Margalef index of “not associated” demersal assemblages and in the Shannon diversity index of both demersal assemblages (**Fig. 5, 6**).

Spatial distribution of fishing efforts

Figure 7 reports the hotspot of fishing activities (75th percentile) for the two-time frames analysed (2015–2017 and 2018–2020). Moreover, the overlap between the area hotspot of fishing activities and the hotspot (75th percentile) of bamboo coral distribution is indicated and quantified in terms of percentage. The percentage of overlapping between the area hotspot of fishing activities and bamboo coral was found to be 8.84% between 2015-2017 while it reached 12.27 between 2018-2020, with a resulting increase of 38.8 % between the two periods considered.

Morphological parameters

Significant differences were detected between BDD distributions in the three considered periods ($p < 0.05$; **Fig. 8**). In 2014, the BDD skewed towards larger-sized colonies (basal diameters > 4 mm; SK = -0.275) than in the 2015–2017 period when no dominance of any size was observed (SK = 0.26) and two small peaks (1.5–2 mm and 3.5–4 mm) were observed. In 2018–2020, the BDDs skewed towards smaller-size colonies (peak at 1.5–2 mm; SK = 846).

This pattern is more evident while analysing the yearly distribution (**Fig. 9**), where the Spearman's rho test revealed a significant decreasing trend in BD over the years ($p < 0.05$) (**Fig. 9**). Indeed, in 2014, BD was significantly larger (mean ± SE, 4.02 ± 0.096 mm) than in other years ($p < 0.05$). Between 2016 and 2019, the BD values were overall similar over the years (from 0.58 mm to 6.0 mm), while the BD measured in 2020 was found significantly smaller than all other years (1.86 ± 0.095 mm) ($p < 0.05$) (**Fig. 9**).

Discussion

The present study investigated the spatial and temporal distributions of *I. elongata* in the southern Adriatic Sea (GSA 18) through time-series data of nine years (2012–2020) collected during MEDITS surveys. The biodiversity of the assemblages associated with *I. elongata* was also investigated. In the study area, the depth range of species occurrence in the present study was from 410 m to 625 m, which is in line with data already published for the southern Adriatic Sea (Carbonara et al., 2020) as well as with other areas of the western and central Mediterranean (Cartes et al., 2009; Lauria et al., 2017; Mastrototaro et al., 2017; Pierdomenico et al., 2018; Ingrassia et al., 2019). However, it is difficult to define the maximum depth of the species distribution in the study area due to both the depth range of sampling of the MEDITS protocol (i.e., down to maximum 800 m in depth) and the bottom morphology of the study area around the IF presence, that are unsuitable to trawling at depths greater than 650 m. Despite the overall depth range of the investigated area was larger than the bamboo coral occurrence (**Table 1**) in the GSA 18 (north part of the GSA18), some deeper areas around the *I. elongata* presence are not trawlable and thus not explored during the MEDITS surveys. Consequently, it is not excluded that the IF in the southern Adriatic Sea could extend even deeper than that already observed (625 m depth) (Rueda et al., 2016; González-García et al., 2020) in a more pristine area unexplored by trawl-survey, as shown by the results of the GAM model (**Fig. 3**) (Carbonara et al., 2020). The spatial analysis performed in this study confirms that the Otranto Channel represents a suitable area with a consistent presence of IF (Carbonara et al., 2020), probably due to a combination of all required environmental factors (i.e. compact/semi consolidated mud with a low slope angle, low seasonal variation in term of salinity and temperature and high concentration of near bottom zooplankton) (Cartes et al., 2013; Bo et al., 2015a; Lauria et al., 2017; Ingrassia et al., 2019). In addition, the presence of IF can be enhanced by the upwelling of nutrient-rich deep waters, which has been documented in the area (Vilibic & Orlic, 2002). Moreover, the fishing activity of the southern Adriatic trawlers fleet is more concentrated on the continental shelf and on the upper slope (Spedicato & Lembo, 2011), resulting in a lesser impact on the deeper bottoms where IF can be found. Although modelling *I. elongata* quantitative data was affected by the limitations of the MEDITS trawl net which is not the best sampler for exploring the benthic communities (González-García et al., 2020), the systematic collection of data on the macrobenthic species caught during the MEDITS trawl survey could represent a valuable source of information, particularly for understanding their distribution patterns and potential significant changes over time (Fernandez-arcaya et al., 2019), as well as the impact of human-related activities, such as trawling (Mangano et al., 2013). Mechanical damage from trawling rarely allows the collection of unbroken complete individual colonies, limiting morphological study; however, the biomass data of the bamboo coral collected during the MEDITS trawl survey are proportional to the number of colonies and their size (Carbonara et al., 2020). Moreover, in the absence of other systematic sources of information, these opportunistic data have proven to be useful sources of information for benthic communities in general and, in particular, for the IF (Lauria et al., 2017; Carbonara et al., 2020).

The temporal analysis performed through the spatial distribution of biomass within the IF shows a clear decreasing trend of abundance (biomass index) over the study period, but no difference in distribution extent. The decreasing trend of the IF in the southern Adriatic Sea in the last nine years (2012–2020) could be related to the cumulative impact of trawlers on the bamboo coral, produced by the increasing fishing effort detected at least in the area over time (**Fig. 7**) at least on the area monitored by the MEDITS survey (until about 630 m of depth; see **Table 1**). Despite the traditional fishing habits of the trawler fleet in southern Adriatic Sea, that mostly exploited the continental shelf and the upper slope (Spedicato & Lembo, 2011), in recent years, there has been an increase in trawler numbers capable of fishing even at great depths in the eastern part of the southern Adriatic Sea (Albania) (STECF, 2019), with an increasing impact on the IF. *Isidella elongata* is often associated with the main targets species of deep fishery trawlers, such as the red shrimps (*Aristaeomorpha foliacea* and *Aristeus antennatus*) and the Norway lobster (*Nephrops norvegicus*) (Maynou & Cartes, 2012) in areas where a high overlap with the Essential Fish Habitat (EFH) was recently documented for both shrimps, particularly in the Otranto Channel (Carbonara et al., 2020). Pulcinella et al. (2021) analysed the AIS data and the fishing ground in the central-east Mediterranean and revealed how the number of fishing vessels dedicated to deep fishing in the GSA 18 increased from 23 in 2017 to 29 in 2018. Furthermore, the area of the Otranto Channel seems to be the most frequented area by deep sea fishing vessels with a monthly trawling haul frequency at depths greater than 400 m (deep water fishery) ranging from 12 to 24 over three years (2015–2018) and a mean number of fishing hours per km^2 ranging from 6 to 16 in the east and from 44 to 118 in the west part of the Otranto channel in the same time series. The combined analysis with spatial distribution of the fishing effort and the distribution of IF, showed an increase in the fishing effort on the hotspot of bamboo coral presence over time. Indeed, the overlap between the IF presence and the hotspot (75th percentile) deep (depth > 200 m) fishing ground increased from 8.84% to 12.27% over time, resulting in an increase of 38.8% between the two periods considered (2015-2017 *vs* 2018-2020; **Fig. 7**). Consequently, the increasing fishing effort for commercial fishery activity registered in recent years in the southern Adriatic Sea (IUCN, 2019) could deeply affect the distribution of the IF with fishing being considered one of the most impactful human activities on the VME, including the IF (Cartes et al., 2013; FAO, 2018; Fanelli et al., 2021).

The biodiversity associated with the colonies of the bamboo coral is significantly higher for both diversity indices used (i.e., Margalef and Shannon-Wiener) considering all time series (2012–2020) for the demersal OTU whereas no difference in the benthic OTU was found between the two assemblages considered (i.e., with and without bamboo coral). Based on these results, *I. elongata* seems to generate an important effect on the associated assemblage, more evident on the demersal than benthic fauna. Indeed, due to its candelabrum-like shape, the bamboo coral is one of the soft-bottom cold-water corals (CWCs) with a distinct frame-building ability to construct coral forests (Chimienti et al., 2019b) that also act as trophic areas where many species, such as the sharks *G. melastomus* and *E. spinax*, the teleost fishes *M. merluccius*, *M. poutassou*, *P. blennoides*, *H. dactylopterus*, *H. mediterraneus* and *Lepidorhombus boscii*, find preys swimming among the colonies or climbing on them (Mastrototaro et al., 2017; Carbonara et al., 2020; Cartes et al., 2022). Several studies on CWCs reveal a link between habitat complexity formed by corals and species diversity, particularly in bathyal zones (D'Onghia, 2019; Rueda et al., 2019; Cartes et al., 2022) where habitat-forming species variety is generally limited (Gage and Tyler, 1992). The presence of the bamboo coral, as a passive feeder, is often associated with the high abundance of zooplankton (Cartes et al., 2013). This biological feature, in turn, qualitatively and quantitatively influences IF-associated fauna in terms of demersal species within and around the colonies (Mastrototaro et al., 2017; Rueda et al., 2019; Carbonara et al., 2020). The large amount of zooplankton can produce a positive effect on several species in various food web positions, from the lower trophic levels to the higher of top predators (Rueda et al., 2019; Carbonara et al., 2020). For example, the presence of red shrimps in the IF (Cartes et al., 2013; Carbonara et al., 2020) seems to be linked with the presence of the Pandalidae species, which probably shares the same prey as bamboo coral (zooplankton), and, in turn, they are the favourite prey of both *A. foliacea* and *A. antennatus* (Kapiris, 2012). Moreover, the high concentration of pandalids and other crustaceans, including Aristeidae, attracts several bony fishes and ommastrephid cephalopods, producing a cascade of effects that could modify the fauna in the areas characterized by the presence of *I. elongata* and the energy flow through the food web (Eddy et al., 2021). Fishing is known to remove individuals at various trophic levels from natural habitats, thus affecting the overall energy flow through the food web (Watling & Norse, 1998; Pauly & Palomares, 2005; Sieben et al., 2011; Carbonara et al., 2022), making the environment less efficient in supporting a certain level of biodiversity (Hooper et al., 2005; Thompson et al., 2012; Ullah et al., 2018). Finally, the typical candelabrum-like shape of *I. elongata* also plays a role in terms of refuge from predators (Mastrototaro et al., 2017) and spawning area for several elasmobranch species (e.g., *Galeus melastomus* and *Scyliorhinus canicula*) (Carbonara et al., 2020). This effect was already observed in other CWC habitats in both the Ionian and southern Adriatic Seas (D'Onghia et al., 2010, 2012, 2016; Sion et al., 2019).

In this study, the time-series analysis also highlighted a temporal effect on biodiversity of assemblages with *I. elongata*, but with different results for the two indices. The richness index shows a significant negative trend over time in the assemblages with *I. elongata* whereas the Shannon-Wiener index exhibits no clear trend. The Margalef index has a good discriminatory ability towards species richness (Yeom & Kim, 2011; Magurran, 2013) that probably presents a faster response to the impact whereas the Shannon index is influenced by both species richness and species abundance distribution (evenness) that can exhibit a slower change in deep-sea communities. Moreover, the significant negative trend for the Margalef index could be linked to a decrease of the IF consistency over time (see **Fig. 2,3**). Indeed, the IF can play its role as a biodiversity hotspot (Cartes et al., 2013; Mytilineou et al., 2014; Mastrototaro et al., 2017) when it shows a certain level of integrity (Carbonara et al., 2020). When the IF is strongly impacted by fishery activity and consists of a few young and isolated colonies (Mastrototaro et al., 2017; Pierdomenico et al., 2018), it cannot fulfil its role as an attractive three-dimensional habitat (e.g., food riches, refuges) (Rueda et al., 2016).

Furthermore, the analyses carried out on the assemblages (with and without *I. elongata*) in the Otranto Channel showed significant differences in their specific compositions. The complete list of the OTUs found in the different years of the study is available in the supplementary material. In particular, among the most abundant species in the areas associated with IF, key species determine these differences more than others (Carbonara et al., 2020). Included in these key species are the osteoichthyes *Hoplostethus mediterraneus mediterraneus* Cuvier, 1829, *Phycis blennoides* (Brünnich, 1768) *Helicolenus dactylopterus* (Delaroche, 1809), and *Coelorinchus caelorhincus* (Risso, 1810); the elasmobranchs *Etmopterus spinax* (Linnaeus, 1758), *Dalatias licha* (Bonnaterre, 1788), and *Chimaera monstrosa* (Linnaeus, 1758); the crustaceans *Aristaeomorpha foliacea* (Risso, 1827), *Aristeus antennatus (*Risso, 1816), and *Paromola cuvieri* (Risso, 1816); and the cephalopod *Todarodes sagittatus* (Lamarck, 1798). Several of these species are commercial (see supplementary material), in particular the red shrimps (*A. foliacea* and *A. antennatus*) that are the target of the trawlers fishing on the slope (deeper than 200 m) (Maiorano et al., 2010; Russo et al., 2017).

Mature colonies (i.e., larger colonies with higher density) of *I. elongata* exhibit a higher macrofaunal community diversity (Cartes et al., 2022), also highlighting the importance of the colony size in the species diversity. Basal diameter is correlated with the height and width of the colonies in *I. elongata* (Carbonara et al., 2020) and with the age of colonies in congeneric species (Roark et al., 2005; Andrews et al., 2009). In this study, we observed that the BDD was different among the three periods considered (2014, 2015–2017 and 2018–2020). In the first period (2014), the BDDs are dominated by larger and older colonies (basal diameters > 4 mm), while in the 2015–2017 period, the BDDs are characterized by two similar peaks (1.5–2 mm and 3.5–4 mm) with a lower peak at 5 mm. In the last period considered (2018–2020), the BDD is quite monomodal with a peak at 1.5–2 mm. Thus, in the time series considered, the colony dimension/age seems to shift from a non- or little-impacted population (2012–2014) to a highly impacted population (2018–2020). The records from the last period considered (2018–2020) are similar to those found by Carbonara et al. (2020) in a population that was highly impacted by fishing (Tyrrhenian Sea). The population dominated by colonies with BD greater than 4 mm, found in 2014, could be considered quite pristine or minimally impacted by fishing (Bo et al., 2015a, 2015b; Carbonara et al., 2020). Colonies with BD greater than 4 mm correspond to the overall size of colonies (Carbonara et al., 2020) in pristine areas (Bo et al., 2015a, 2015b) with a capacity for reproduction and the renewal of the population still untouched (Bo et al., 2015a, 2015b). These changes over time are also confirmed by the significant trend of a decrease in yearly average BD. In this case, as well as for the spatial analysis, the reason for this decrease (average BD) could be the increased pressure of deep-sea fishing (FAO, 2018; IUCN, 2019). Although the age and growth for the *I. elongata* data are missing, congeneric species have been found to have a slow growth rate (Roark et al., 2005; Andrews et al., 2009). In the Gulf of Alaska, it was estimated that the lifespan for *Isidella spp.* was 75 to 126 years, with a slow growth rate ranged between about 0.1-0.05 mm of radial basal diameter per year (Roark et al., 2005; Andrews et al., 2009). From the perspective of *I. elongata* VME conservation, such fast decreasing trend detected in few years together with the low growth of *Isidella* sp. (Andrews et al., 2009) could be a dangerous warning sign of a severe progressive impact on IF. This biological characteristic of *Isidella* sp. coral indicates that the recovery of areas impacted by fishing (Mastrototaro et al., 2017; Pierdomenico et al., 2018) can take a very long time, ranging from a few decades to a century (Roark et al., 2005). Furthermore, it should be emphasised that studies on the growth and age of *I. elongata* have not yet been carried out and should be implemented as soon as possible not only for the purpose of biological and ecological knowledge but also for the conservation of this species (Carbonara et al., 2020).

Concluding remarks

In conclusion, the consistent presence of an *I. elongata* VME was confirmed in the Otranto Channel in the southern Adriatic Sea (Carbonara et al., 2020). Over a period of nine years, this VME seems to have a constant extension, but with a significant decrease in biomass and changes in demographic structure. The overlap between the spatial distribution of the bamboo coral and that of the fishing effort, indicates a severe impact clearly highlighted by the results of this study. Furthermore, other signs of the increasing impact of anthropogenic activities, such as fishing, are the changes in BDD (skewed towards smaller colonies in the last period from 2018 to 2020, unlike in 2014, where it skewed more towards large sizes) and the significant decrease in BD over time (from 2014–2020). It is also important to emphasise that IF represents biodiversity hotspots for deep environments in the study area (Cartes et al., 2009; Chimienti et al., 2019a, 2019b) that could be compromised by fisheries (Cartes et al., 2013). Until now, no fishing restrictions have been implemented in the area where the presence of IF (Otranto Channel) has been detected; indeed, as shown by our analysis, this area is a fishing ground for deep trawlers. Thus, it was recently proposed, in the context of the GFCM Subregional Committee for the Adriatic Sea, that the process to establish a fisheries restricted area (FRA) at the Otranto Channel (GFCM, 2021) must be started in order to help the conservation of *I. elongata* in the southern Adriatic Sea, achieving the goal of protecting VMEs set by various international organizations/conventions (FAO, 2009; UNEP-MAP-RAC-SPA, 2015).

Statements and Declarations

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Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files, further inquiries can be directed to the corresponding author.

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References

AAVV, 2017. MEDITS-Handbook. Version n. 9. , http://www.sibm.it/MEDITS.

Andrews, A. H., R. P. Stone, C. C. Lundstrom, & A. P. Devogelaere, 2009. Growth rate and age determination of bamboo corals from the northeastern Pacific Ocean using refined 210Pb dating. Marine Ecology Progress Series 397: 173–185, http://dx.doi.org/10.3354/meps08193.

Ashford, O. S., A. J. Kenny, C. R. S. B. Froján, A. L. Downie, T. Horton, & A. D. Rogers, 2019. On the influence of vulnerable marine ecosystem habitats on peracarid crustacean assemblages in the Northwest Atlantic Fisheries Organisation regulatory area. Frontiers in Marine Science 6: 401, https://doi.org/10.3389/fmars.2019.00401.

Bellan-Santini, D., 1985. The Mediterranean benthos: reflections and problems raised by a classification of the benthic assemblages In Moraitou-Apostolopoulou, M., & V. Kiortsis (eds), Mediterranean Marine Ecosystems. New York,: 19–48.

Bertrand, J. A., I. Leonori, P. Y. Dremière, & G. Cosimi, 2002. Depth trajectory and performance of a trawl used for an international bottom trawl survey in the Mediterranean. Scientia Marina 66: 169–182, https://doi.org/10.3989/scimar.2002.66s2169.

Bo, M., G. Bavestrello, M. Angiolillo, L. Calcagnile, S. Canese, R. Cannas, A. Cau, M. D'Elia, F. D'Oriano, M. C. Follesa, G. Quarta, & A. Cau, 2015a. Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). PLoS ONE 10(3): e0119393, https://doi.org/10.1371/journal.pone.0119393.

Bo, M., C. Ceranno, C. Antoniadou, S. Garcia, & C. Orejas, 2015b. *Isidella elongata* The IUCN Red List of Threatened Species e.T50012256A50605973. http://www.iucnredlist.org/details/50012256/3.

Buhl-Mortensen, L., A. Vanreusel, A. J. Gooday, L. A. Levin, I. G. Priede, P. Buhl-Mortensen, H. Gheerardyn, N. J. King, & M. Raes, 2010. Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. Marine Ecology 31: 21–50, https://doi.org/10.1111/j.1439-0485.2010.00359.x.

Carbonara, P., A. Ciccolella, F. De Franco, M. Palmisano, A. Bellodi, G. Lembo, C. Neglia, M. T. Spedicato, W. Zupa, & P. Guidetti, 2022. Does fish growth respond to fishing restrictions within Marine Protected Areas? A case study of the striped red mullet in the south-west Adriatic Sea (central Mediterranean). Aquatic Conservation: Marine and Freshwater Ecosystems 32: 417–429, https://doi.org/10.1002/aqc.3776.

Carbonara, P., W. Zupa, M. C. Follesa, A. Cau, F. Capezzuto, G. Chimienti, G. D'Onghia, G. Lembo, P. Pesci, C.

Porcu, I. Bitetto, M. T. Spedicato, & P. Maiorano, 2020. Exploring a deep-sea vulnerable marine ecosystem: *Isidella elongata* (Esper, 1788) species assemblages in the Western and Central Mediterranean. Deep-Sea Research Part I: Oceanographic Research Papers 166: 103406, https://doi.org/10.1016/j.dsr.2020.103406.

Cartes, J. E., D. Díaz-Viñolas, J. M. González-Irusta, A. Serrano, S. Mohamed, & A. Lombarte, 2022. The macrofauna associated to the bamboo coral I*sidella elongata*: to what extent the impact on isideidae affects diversification of deep-sea fauna. Coral Reefs 41: 1273-1284, https://doi.org/10.1007/s00338-022-02243-w.

Cartes, J. E., C. LoIacono, V. Mamouridis, C. López-Pérez, & P. Rodríguez, 2013. Geomorphological, trophic and human influences on the bamboo coral *Isidella elongata* assemblages in the deep Mediterranean: To what extent does *Isidella* form habitat for fish and invertebrates?. Deep-Sea Research Part I: Oceanographic Research Papers 76: 52–65, https://doi.org/10.1016/j.dsr.2013.01.006.

Cartes, J. E., F. Maynou, E. Fanelli, C. Romano, V. Mamouridis, & V. Papiol, 2009. The distribution of megabenthic, invertebrate epifauna in the Balearic Basin (western Mediterranean) between 400 and 2300 m: Environmental gradients influencing assemblages composition and biomass trends. Journal of Sea Research 61: 244–257, http://dx.doi.org/10.1016/j.seares.2009.01.005.

Cartes, J. E., A. Schirone, M. Barsanti, I. Delbono, A. Martínez-Aliaga, & A. Lombarte, 2017. Recent reconstruction of deep-water macrofaunal communities recorded in Continental Margin sediments in the Balearic Basin. Deep-Sea Research Part I: Oceanographic Research Papers 125: 52–64, http://dx.doi.org/10.1016/j.dsr.2017.04.016.

Chimienti, G., L. Angeletti, L. Rizzo, A. Tursi, & F. Mastrototaro, 2018. ROV vs trawling approaches in the study of benthic communities: The case of *Pennatula rubra* (Cnidaria: Pennatulacea). Journal of the Marine Biological Association of the United Kingdom 98: 1859–1869, http://dx.doi.org/10.1017/S0025315418000851.

Chimienti, G., M. Bo, M. Taviani, & F. Mastrototaro, 2019a. 19 Occurrence and Biogeography of Mediterranean Cold-Water Corals In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_19.

Chimienti, G., F. Mastrototaro, & G. D'Onghia, 2019b. Mesophotic and Deep-Sea Vulnerable Coral Habitats of the Mediterranean Sea: Overview and Conservation Perspectives The Benthos Zone. In Advances in the Studies of the Benthic Zone, edited by Luis Soto. London: IntechOpen. IntechOpen: 1–20, https://doi.org/10.5772/intechopen.90024.

Coll, M., C. Piroddi, J. Steenbeek, K. Kaschner, F. B. R. Lasram, J. Aguzzi, E. Ballesteros, C. N. Bianchi, J. Corbera, T. Dailianis, R. Danovaro, M. Estrada, C. Froglia, B. S. Galil, J. M. Gasol, R. Gertwage, J. Gil, F. Guilhaumon, K. Kesner-

Reyes, M. S. Kitsos, A. Koukouras, N. Lampadariou, E. Laxamana, C. M. L. F. de la Cuadra, H. K. Lotze, D. Martin, D. Mouillot, D. Oro, S. Raicevich, J. Rius-Barile, J. I. Saiz-Salinas, C. S. Vicente, S. Somot, J. Templado, X. Turon, D. Vafidis, R. Villanueva, & E. Voultsiadou, 2010. The biodiversity of the Mediterranean Sea: Estimates, patterns, and threats. PLoS ONE 5(8): e11842, https://doi.org/10.1371/journal.pone.0011842.

D'Onghia, G., 2019. 30 Cold-Water Corals as Shelter, Feeding and Life-History Critical Habitats for Fish Species: Ecological Interactions and Fishing Impact In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_30.

D'Onghia, G., C. Calculli, F. Capezzuto, R. Carlucci, A. Carluccio, P. Maiorano, A. Pollice, P. Ricci, L. Sion, & A. Tursi, 2016. New records of cold-water coral sites and fish fauna characterization of a potential network existing in the Mediterranean Sea. Marine Ecology 37: 1398–1422, https://doi.org/10.1111/maec.12356.

D'Onghia, G., P. Maiorano, R. Carlucci, F. Capezzuto, A. Carluccio, A. Tursi, & L. Sion, 2012. Comparing Deep-Sea Fish Fauna between Coral and Non-Coral "Megahabitats" in the Santa Maria di Leuca Cold-Water Coral Province (Mediterranean Sea). PLoS ONE 7 (9): e44509, https://doi.org/10.1371/journal.pone.0044509.

D'Onghia, G., P. Maiorano, L. Sion, A. Giove, F. Capezzuto, R. Carlucci, & A. Tursi, 2010. Effects of deep-water coral banks on the abundance and size structure of the megafauna in the Mediterranean Sea. Deep-Sea Research Part II: Topical Studies in Oceanography 57: 397–411, http://dx.doi.org/10.1016/j.dsr2.2009.08.022.

D'Onghia, G., F. Mastrototaro, A. Matarrese, C. Y. Politou, & C. Mytilineou, 2003. Biodiversity of the upper slope demersal community in the Eastern Mediterranean: Preliminary comparison between two areas with and without trawl fishing. Journal of Northwest Atlantic Fishery Science 31: 263–273, http://dx.doi.org/10.2960/J.v31.a20.

Danovaro, R., E. Fanelli, M. Canals, T. Ciuffardi, M. C. Fabri, M. Taviani, M. Argyrou, E. Azzurro, S. Bianchelli, A. Cantafaro, L. Carugati, C. Corinaldesi, W. P. de Haan, A. Dell'Anno, J. Evans, F. Foglini, B. Galil, M. Gianni, M. Goren, S. Greco, J. Grimalt, Q. Güell-Bujons, A. Jadaud, L. Knittweis, J. L. Lopez, A. Sanchez-Vidal, P. J. Schembri, P. Snelgrove, S. Vaz, & T. I. Consortium, 2020. Towards a marine strategy for the deep Mediterranean Sea: Analysis of current ecological status. Marine Policy 112: 103781, https://doi.org/10.1016/j.marpol.2019.103781.

Eddy, T. D., J. R. Bernhardt, J. L. Blanchard, W. W. L. Cheung, M. Colléter, H. du Pontavice, E. A. Fulton, D. Gascuel, K. A. Kearney, C. M. Petrik, T. Roy, R. R. Rykaczewski, R. Selden, C. A. Stock, C. C. C. Wabnitz, & R. A. Watson, 2021. Energy Flow Through Marine Ecosystems: Confronting Transfer Efficiency. Trends in Ecology and Evolution 36: 76–86, https://doi.org/10.1016/j.tree.2020.09.006.

EUMOFA, 2019. The EU fish market-2019 edition. Publications Office of the European Union, Luxembourg (LU). https://doi.org/10.2771/168390.

Fabri, M. C., L. Pedel, L. Beuck, F. Galgani, D. Hebbeln, & A. Freiwald, 2014. Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. Deep-Sea Research Part II: Topical Studies in Oceanography 104: 184–207, http://dx.doi.org/10.1016/j.dsr2.2013.06.016.

Fanelli, E., S. Bianchelli, F. Foglini, M. Canals, G. Castellan, Q. Güell-Bujons, B. Galil, M. Goren, J. Evans, M. C. Fabri, S. Vaz, T. Ciuffardi, P. J. Schembri, L. Angeletti, M. Taviani, & R. Danovaro, 2021. Identifying Priorities for the Protection of Deep Mediterranean Sea Ecosystems Through an Integrated Approach. Frontiers in Marine Science 8: 698890, https://doi.org/10.3389/fmars.2021.698890.

FAO, 2009. International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. Rome, Italy, https://www.fao.org/3/i0816t/i0816t00.htm.

FAO, 2018. Report of the Second Meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). Rome, Italy.

Farriols, M. T., F. Ordines, M. Hidalgo, B. Guijarro, & E. Massutí, 2015. N90 index: A new approach to biodiversity based on similarity and sensitive to direct and indirect fishing impact. Ecological Indicators 52: 245–255, http://dx.doi.org/10.1016/j.ecolind.2014.12.009.

Fernandez-arcaya, U., Bitetto, I., Esteban, A., Farriols, M. T., García-ruiz, C., De Sola, L. G., Guijarro, B., Jadaud, A., Kavadas, S., Lembo, G., Milisenda, G., Maina, I., Petovic, S., Sion, L., Vaz, S., Massutí, E., 2019. Large-scale distribution of a deep-sea megafauna community along Mediterranean trawlable grounds. Scientia Marina 83S1: 175–187, https://doi.org/10.3989/scimar.04852.14A.

Gerovasileiou, V., C. J. Smith, S. Kiparissis, C. Stamouli, C. Dounas, & C. Mytilineou, 2019. Updating the distribution status of the critically endangered bamboo coral *Isidella elongata* (Esper, 1788) in the deep Eastern Mediterranean Sea. Regional Studies in Marine Science 28: 100610, https://doi.org/10.1016/j.rsma.2019.100610.

GFCM, 2017. Report of the first meeting of the Working Group on Vulnerable Marine Ecosystems (WGVME). Malaga, Spain.

GFCM, 2021. Report of the fifth meeting of the Subregional Committee for the Adriatic Sea (SRC-AS). Online, https://www.fao.org/gfcm/technical-meetings/detail/en/c/1410712/.

González-García, E., Á. Mateo-Ramírez, J. Urra, C. Farias, P. Marina, P. Lozano, P. J. López-González, C. Megina, J. E. García Raso, S. Gofas, E. López, J. Moreira, N. López-González, R. F. Sánchez-Leal, L. M. Fernández-Salas, & J. L. Rueda, 2020. Composition, structure and distribution of epibenthic communities within a mud volcano field of the northern Gulf of Cádiz in relation to environmental variables and trawling activity. Journal of Sea Research 160–161: 101892, https://doi.org/10.1016/j.seares.2020.101892.

Granger, V., J. M. Fromentin, N. Bez, G. Relini, C. N. Meynard, J. C. Gaertner, P. Maiorano, C. Garcia Ruiz, C. Follesa, M. Gristina, P. Peristeraki, A. Brind'Amour, P. Carbonara, C. Charilaou, A. Esteban, A. Jadaud, A. Joksimovic, A. Kallianiotis, J. Kolitari, C. Manfredi, E. Massuti, R. Mifsud, A. Quetglas, W. Refes, M. Sbrana, N. Vrgoc, M. T. Spedicato, & B. Mérigot, 2015. Large-scale spatio-temporal monitoring highlights hotspots of demersal fish diversity in the Mediterranean Sea. Progress in Oceanography 130: 65–74, http://dx.doi.org/10.1016/j.pocean.2014.10.002.

Grasshoff, M., 1989. Die Meerenge von Gibraltar als Faunen- Barriere: Die Gorgonaria, Pennatularia und Antipatharia der Balgim-Expedition (Cnidaria: Anthozoa). Senckenbergiana Maritima 20: 201–223.

Hijmans, R. J., 2021. raster: Geographic Data Analysis and Modeling. R package version 3.5-2. , https://cran.r-project.org/package=raster.

Hooper, D. ., F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A. J. Symstad, J. Vandermeer, & D. A. Wardle, 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Eclogical Monographs 75: 3–35, https://doi.org/10.1890/04-0922.

ICES, 2020. ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC). ICES Scientific Reports 2: 188 pp.

Ingrassia, M., E. Martorelli, A. Bosman, & F. L. Chiocci, 2019. *Isidella elongata* (Cnidaria: Alcyonacea): First report in the Ventotene Basin (Pontine Islands, western Mediterranean Sea). Regional Studies in Marine Science 25: 100494, https://doi.org/10.1016/j.rsma.2018.100494.

IUCN, 2019. Thematic Report – Conservation Overview of Mediterranean Deep-Sea Biodiversity: A Strategic Assessment. 122 pages. IUCN Gland, Switzerland and Malaga, Spain, https://uicnmed.org/docs/mediterraneandeepsea.pdf..

Kapiris, K., 2012. Feeding Habits of Both Deep-Water Red Shrimps, *Aristaeomorpha foliacea* and *Aristeus antennatus* (Decapoda, Aristeidae) in the Ionian Sea (E. Mediterranean) In Kapiris, K. (ed), Food Quality. IntechOpen: 112–134.

Laubier, L., & C. C. Emig, 1993. La faune benthique profonde de Mediterranee Symposium Mediterranen Seas 2000. S. Margherita Ligure: Istituto di Scienze Ambientali Marine. : pp 397–428.

Lauria, V., G. Garofalo, F. Fiorentino, D. Massi, G. Milisenda, S. Piraino, T. Russo, & M. Gristina, 2017. Species distribution models of two critically endangered deep-sea octocorals reveal fishing impacts on vulnerable marine ecosystems in central Mediterranean Sea. Scientific Reports 7: 1–14, http://dx.doi.org/10.1038/s41598-017-08386-z.

Magurran, A. E., 2013. Measuring biological diversity. Wiley-Blackwell.

Maiorano, P., F. Capezzuto, A. Carluccio, C. Calculli, G. Cipriano, R. Carlucci, P. Ricci, L. Sion, A. Tursi, & G. D’Onghia, 2022. Food from the Depths of the Mediterranean: The Role of Habitats, Changes in the Sea-Bottom Temperature and Fishing Pressure. Foods 11: 1420, https://doi.org/10.3390/foods11101420.

Maiorano, P., L. Sion, R. Carlucci, F. Capezzuto, A. Giove, G. Costantino, M. Panza, G. D’Onghia, & A. Tursi, 2010. The demersal faunal assemblage of the north-western Ionian Sea (central Mediterranean): Current knowledge and perspectives. Chemistry and Ecology 26: 219–240, https://doi.org/10.1080/02757541003693987.

Mangano, M., E. Porporato, E. Russo, G. I. Lambert, M. J. Kaiser, N. Spanò, P. Carbonara, & M. T. Spedicato, 2013. Effects of trawling impacts on mega-epibenthic communities from heavy exploited to undisturbed areas in a Mediterranean fishing ground (Central Mediterranean Sea). ICES CM I: 46.

Margalef, R., 1958. Information theory in ecology. International Journal of General Systems 3: 36–71.

Mastrototaro, F., G. Chimienti, J. Acosta, J. Blanco, S. Garcia, J. Rivera, & R. Aguilar, 2017. *Isidella elongata* (Cnidaria: Alcyonacea) facies in the western Mediterranean Sea: Visual surveys and descriptions of its ecological role. European Zoological Journal Taylor & Francis 84: 209–225, http://dx.doi.org/10.1080/24750263.2017.1315745.

Maynou, F., & J. E. Cartes, 2012. Effects of trawling on fish and invertebrates from deep-sea coral facies of *Isidella elongata* in the western Mediterranean. Journal of the Marine Biological Association of the United Kingdom 92: 1501–1507, https://doi.org/10.1017/S0025315411001603.

Mytilineou, C., C. J. Smith, A. Anastasopoulou, K. N. Papadopoulou, G. Christidis, P. Bekas, S. Kavadas, & J. Dokos, 2014. New cold-water coral occurrences in the Eastern Ionian Sea: Results from experimental long line fishing. Deep-Sea Research Part II: Topical Studies in Oceanography 99: 146–157, http://dx.doi.org/10.1016/j.dsr2.2013.07.007.

Otero, M. del M., & P. Marin, 2019. 46 Conservation of Cold-Water Corals in the Mediterranean: Current Status and Future Prospects for Improvement In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future.Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_46.

Palialexis, A., A. C. Cardoso, & F. Somma, 2018. JRC's reference lists of MSFD species and habitats : MSFD reporting for descriptors 1 and 6. JRC's reference lists of MSFD species and habitats : MSFD reporting for descriptors 1 and 6. Publications Office, Luxembourg.

Pauly, D., & M. L. Palomares, 2005. Fishing down marine food web: It is far more pervasive than we thought. Bulletin of Marine Science 76(2): 197–211.

Pérès, J. M., & J. Picard, 1964. Nouveau manuel de bionomie benthique de la Méditerranée. Recueil des Travaux de la Station Marine d'Endoume 31: 1–37.

Petović, S., O. Marković, Z. Ikica, M. Đurović, & A. Joksimović, 2016. Effects of bottom trawling on the benthic assemblages in the south Adriatic Sea (Montenegro). Acta Adriatica 57: 79–90.

Pierdomenico, M., F. Cardone, A. Carluccio, D. Casalbore, F. Chiocci, P. Maiorano, & G. D'Onghia, 2019. Megafauna distribution along active submarine canyons of the central Mediterranean: Relationships with environmental variables. Progress in Oceanography 171: 49–69, https://doi.org/10.1016/j.pocean.2018.12.015.

Pierdomenico, M., E. Martorelli, C. Dominguez-Carrió, J. M. Gili, & F. L. Chiocci, 2016. Seafloor characterization and benthic megafaunal distribution of an active submarine canyon and surrounding sectors: The case of Gioia Canyon (Southern Tyrrhenian Sea). Journal of Marine Systems 157: 101–117, http://dx.doi.org/10.1016/j.jmarsys.2016.01.005.

Pierdomenico, M., T. Russo, S. Ambroso, A. Gori, E. Martorelli, L. D'Andrea, J. M. Gili, & F. L. Chiocci, 2018. Effects of trawling activity on the bamboo-coral *Isidella elongata* and the sea pen *Funiculina quadrangularis* along the Gioia Canyon (Western Mediterranean, southern Tyrrhenian Sea). Progress in Oceanography 169: 214–226, http://dx.doi.org/10.1016/j.pocean.2018.02.019.

Pulcinella, J., E. N. Armelloni, C. Ferrà, G. Scarcella, & A. N. Tassetti, 2021. Identification and mapping of bottom trawl fishing grounds for deep-water red shrimp in the Eastern. FAO-GFCM. Report submitted .

QGIS Development Team, 2017. Geographic Information System. Open Source Geospatial Foundation Project. Qgis. http://www.qgis.org/.

R Development Core Team, 2021. R Software. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. .

Roark, E. B., T. P. Guilderson, S. Flood-Page, R. B. Dunbar, B. L. Ingram, S. J. Fallon, & M. McCulloch, 2005.

Radiocarbon-based ages and growth rates of bamboo corals from the Gulf of Alaska. Geophysical Research Letters 32: 1–5, http://dx.doi.org/10.1029/2004GL021919.

Rossi, S., L. Bramanti, A. Gori, & C. Orejas, 2017. An overview of the animal forests of the world In Rossi, S., L. Bramanti, A. Gori, & C. Orejas (eds), Marine Animal Forests. Springer, Cham, https://doi.org/10.1007/978-3-319-17001-5_1-1

Rueda, J. L., E. González-García, C. Krutzky, F. J. López-Rodriguez, G. Bruque, N. López-González, D. Palomino, R. F. Sánchez, J. T. Vázquez, L. M. Fernández-Salas, & V. Díaz-del-Río, 2016. From chemosynthesis-based communities to cold-water corals: Vulnerable deep-sea habitats of the Gulf of Cádiz. Marine Biodiversity 46: 473–482, https://doi.org/10.1007/s12526-015-0366-0.

Rueda, J. L., J. Urra, R. Aguilar, L. Angeletti, M. Bo, C. García-Ruiz, M. M. González-Duarte, E. López, T. Madurell, M. Maldonado, Á. Mateo-Ramírez, C. Megina, J. Moreira, F. Moya, L. V. Ramalho, A. Rosso, C. Sitjà, & M. Taviani, 2019. 29 Cold-Water Coral Associated Fauna in the Mediterranean Sea and Adjacent Areas In Orejas, C., & C. Jimenez (eds), Mediterranean Cold-Water Corals: Past, Present and Future.. Coral Reefs of the World, vol 9. Springer, Cham, https://doi.org/10.1007/978-3-319-91608-8_29.

Russo, T., I. Bitetto, P. Carbonara, R. Carlucci, L. D’Andrea, M. T. Facchini, G. Lembo, P. Maiorano, L. Sion, M. T. Spedicato, A. Tursi, & S. Cataudella, 2017. A holistic approach to fishery management: Evidence and insights from a central mediterranean case study (Western Ionian Sea). Frontiers in Marine Science 4: 1–18, https://doi.org/10.3389/fmars.2017.00193.

Shannon, C. E., 1948. A mathematical theory of communication. Bell System Technical Journal 27: 379–423.

Sieben, K., A. D. Rippen, & B. K. Eriksson, 2011. Cascading effects from predator removal depend on resource availability in a benthic food web. Marine Biology 158: 391–400, https://doi.org/10.1007/s00227-010-1567-5.

Sion, L., C. Calculli, F. Capezzuto, R. Carlucci, A. Carluccio, L. Cornacchia, P. Maiorano, A. Pollice, P. Ricci, A. Tursi, & G. D’Onghia, 2019. Does the Bari Canyon (Central Mediterranean) influence the fish distribution and abundance?. Progress in Oceanography 170: 81–92, https://doi.org/10.1016/j.pocean.2018.10.015.

Souplet, A., 1996. Calculation of abundance indices and length frequencies in the MEDITS survey In Bertrand, J. A., L. Gil de Sola, C. Papaconstantinou, G. Relini, & A. Souplet (eds), Campagne internationale du chalutage démersal en Méditerranée. Campagne 1995, vol. III. EU Final Report. .

Spedicato, M. T., & G. Lembo, 2011. Caratterizzazione ambientale delle aree di pesca: GSA 10 – tirreno Centro-

Meridionale In Cataudella, S., & M. Spagnolo (eds), The state of Italian marine fisheries and aquaculture. Rome: 52–59, https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina%0A/6412.

Spedicato, M. T., G. Lembo, P. Carbonara, & T. Silecchia, 1998. Valutazione delle risorse demersali dal fiume gariglianoa capo suvero. Biologia Marina Mediterranea 5: 64–73.

Spedicato, M. T., E. Massutí, B. Mérigot, G. Tserpes, A. Jadaud, & G. Relini, 2019. The MEDITS trawl survey specifications in an ecosystem approach to fishery management. Scientia Marina 83S1: 9–20, https://doi.org/10.3989/scimar.04915.11X.

STECF, 2019. Multiannual Plan for the fisheries exploiting demersal stocks in the Adriatic Sea (STECF-19-02). Luxembourg.

Thompson, R. M., U. Brose, J. A. Dunne, R. O. Hall, S. Hladyz, R. L. Kitching, N. D. Martinez, H. Rantala, T. N. Romanuk, D. B. Stouffer, & J. M. Tylianakis, 2012. Food webs: Reconciling the structure and function of biodiversity. Trends in Ecology and Evolution 27: 689–697, http://dx.doi.org/10.1016/j.tree.2012.08.005.

Ullah, H., I. Nagelkerken, S. U. Goldenberg, & D. A. Fordham, 2018. Climate change could drive marine food web collapse through altered trophic flows and cyanobacterial proliferation. PLoS Biology 16(1): e2003446, https://doi.org/10.1371/journal.pbio.2003446.

UNEP-MAP-RAC-SPA, 2015. A guide on environmental monitoring of rocky seabeds in Mediterranean Marine Protected Areas and surrounding zones. By José Carlos GARCÍA-GÓMEZ. Tunis.

Vafidis, D., C. H. Mytilineous, F. Mastrototaro, & G. D'Onghia, 2006. First records of Leiopathes glaberrima (Esper, 1792) and *Isidella elongata* (Esper, 1788) (Cnidaria: anthozoa) in the ionian. Proceedings of the 10th ICZEGAR. Patra, Greece: 220.

Vilibic, I., & M. Orlic, 2002. Adriatic water masses, their rates of formation and transport through the Otranto Strait. Deep-Sea Research Part I: Oceanographic Research Papers 49: 1321–1340, https://doi.org/10.1016/S0967-0637(02)00028-6.

Watling, L., & E. A. Norse, 1998. Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. Conservation Biology 12: 1180–1197, https://www.jstor.org/stable/2989836.

Yeom, D. J., & J. H. Kim, 2011. Comparative evaluation of species diversity indices in the natural deciduous forest of Mt. Jeombong. Forest Science and Technology 7: 68–74, https://doi.org/10.1080/21580103.2011.573940.

Captions for figures

Figure 1. The study area is the southern Adriatic Sea (Geographical sub–area GSA 18 *sensu* GFCM-FAO). The geographic allocation of the hauls explored during the MEDITS trawl surveys in GSA 18 are indicated by black points.

Figure 2. The bidimensional splines of the Gaussian GAM models used to describe the spatial distribution of *Isidella elongata* biomass (kg/km^2) in **(a)** 2012–2014, **(b)** 2015–2017, and **(c)** 2018–2020. X: Longitude, Y: Latitude.

Figure 3. The spatial distribution of *Isidella elongata* biomass (kg/km^2) in the three considered periods: **(a)** 2012–2014, **(b)** 2015–2017, and **(c)** 2018–2020. The green line borders the 75th percentile of the estimated biomass distribution.

Figure 4. *Isidella elongata* biomass index (kg/km^2) (blue trend in macrostratum at depths of 200–800 m). The Spearman's rho correlation test showed a significant decrease ($p < 0.05$). The solid line represents the biomass index, while the dashed lines represent the standard deviation.

Figure 5. Benthos OTU box plots of the **(a)** Margalef (D) and **(b)** Shannon (H') indexes of assemblages with (associated) and without (not associated) *Isidella elongata* per year. The solid line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Statistics reported in the figure are based on Wilcoxon–Mann–Whitney tests carried out within each period (*: $p < 0.05$; **: $p < 0.01$; NS = not significant). The Spearman's rho correlation test was not significant ($p > 0.05$) for both assemblages (associated and not associated) and both indices (Margalef and Shannon).

Figure 6. Demersal OTU box plots of the **(a)** Margalef (D) and **(b)** Shannon (H') indexes of assemblages with (associated) and without (not associated) *Isidella elongata* per year. The solid line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Statistics reported in the figure are based on Wilcoxon–Mann–Whitney tests carried out within each period (*: $p < 0.05$; **: $p < 0.01$; NS (not significant): $p > 0.05$). The Spearman's rho correlation test was not significant ($p > 0.05$) for both assemblages (associated and not associated) for Shannon's index. For the Margalef's index the "associated" assemblage shows a significant decreasing trend (Spearman's rho correlation test $p < 0.05$), while that of the "not associated" assemblage was not significant ($p > 0.05$).

Figure 7. Fishing effort in the southern Adriatic Sea in (A) 2015–2017 and (B) 2018–2020, estimated using the aggregated AIS data provided by Global Fishing Watch (https://globalfishingwatch.org/). The hotspot of fishing activities was calculated as the 75th percentile of effort data distribution. Moreover, the spatial and percentage overlap between the hotspot of *Isidella elongata* presence and fishing efforts is also shown.

Figure 8. Basal diameter (mm) distribution of *Isidella elongata* colonies in **(a)** 2014, **(b)** 2015–2017, and **(c)** 2018–2020.

Figure 9. Box plots of the colony basal diameter (mm) measured from 2014 to 2020 in the GSA 18. For boxplot representation, the central line of each boxplot indicates the median, and the boxes on either side represent the quartiles, with the whiskers covering 95% of the values. Outlier values are represented by black dots. Different letters indicate significant differences among groups between the years (Kruskal–Wallis and Nemenyi post-hoc tests, $p < 0.05$).

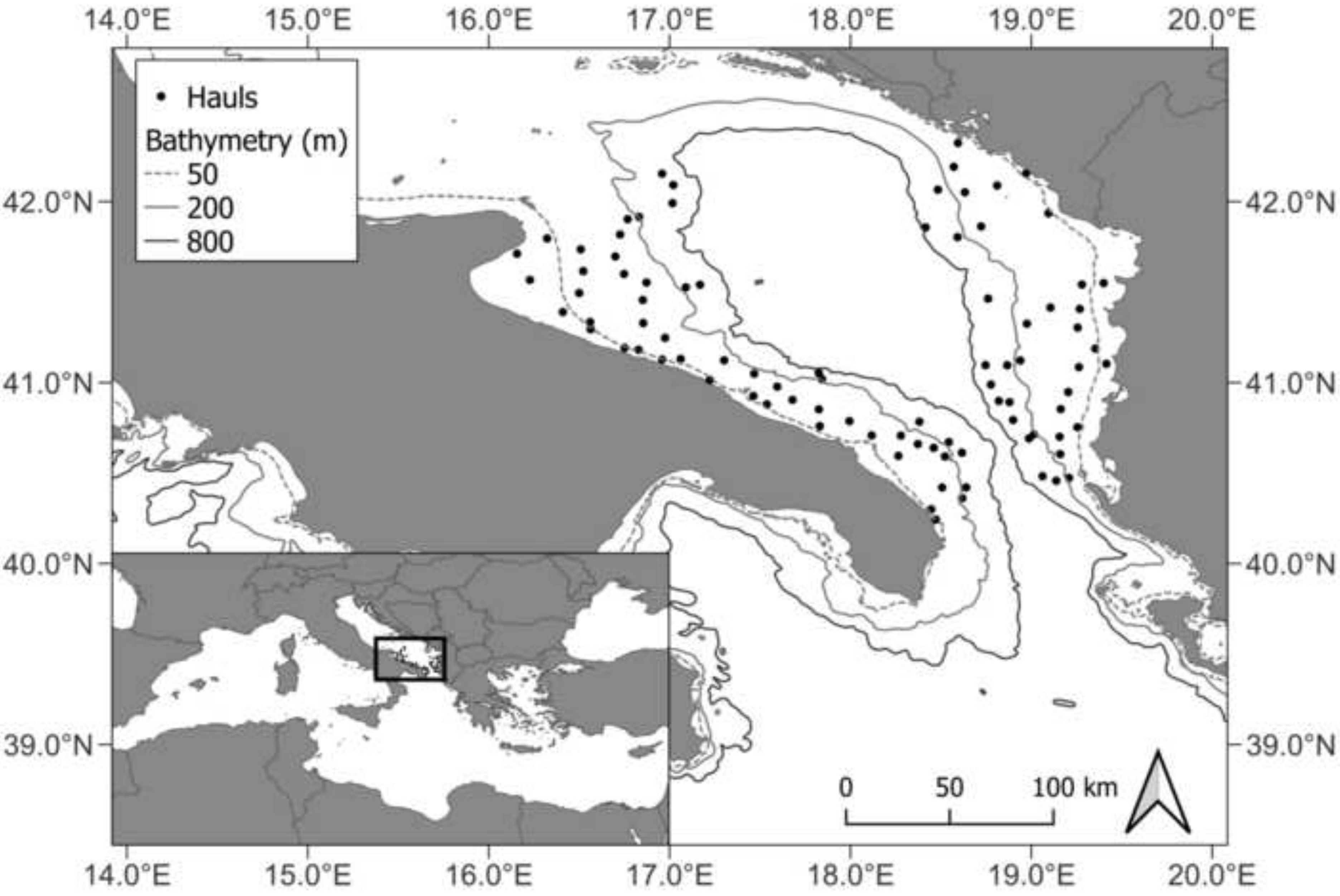
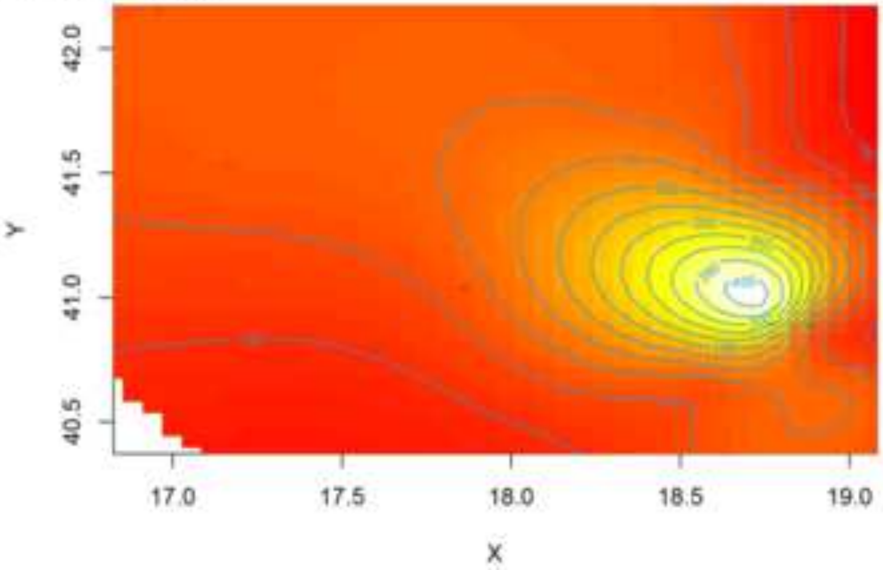
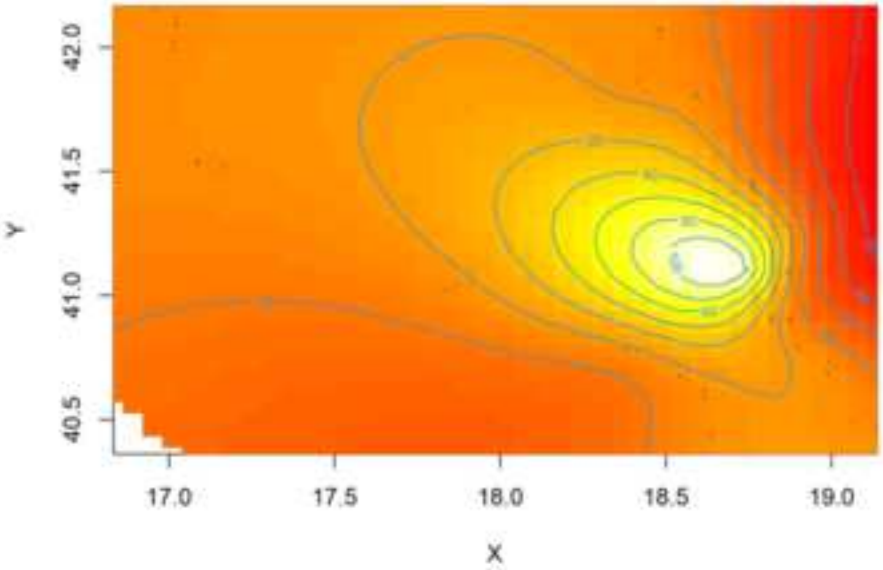

14.0°E
15.0°E
16.0°E
17.0°E
18.0°E
19.0°E
20.0°E
42.0°N
41.0°N
40.0°N
39.0°N
● Hauls
Bathymetry (m)
50
200
800
0
50
100 km

Figure2

(a) 2012-2014



(b) 2015-2017



(c) 2018-2020

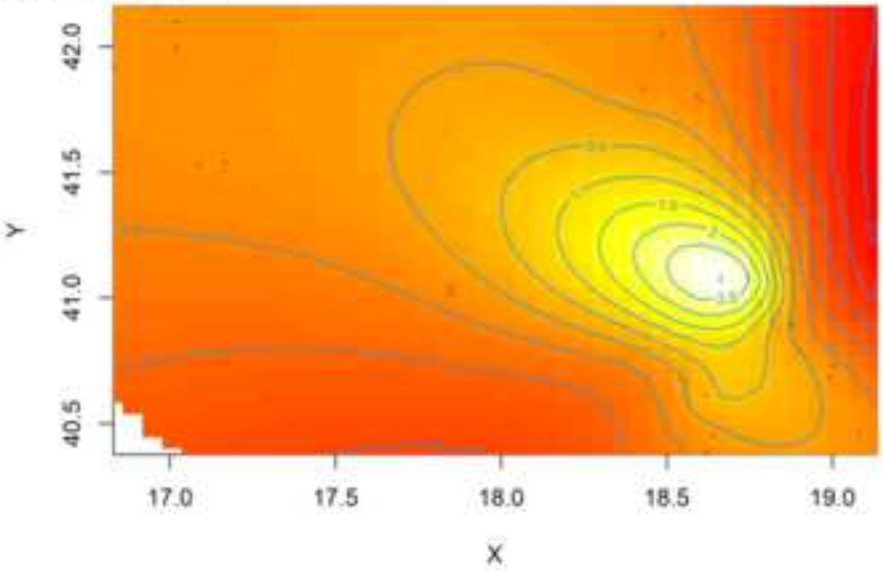
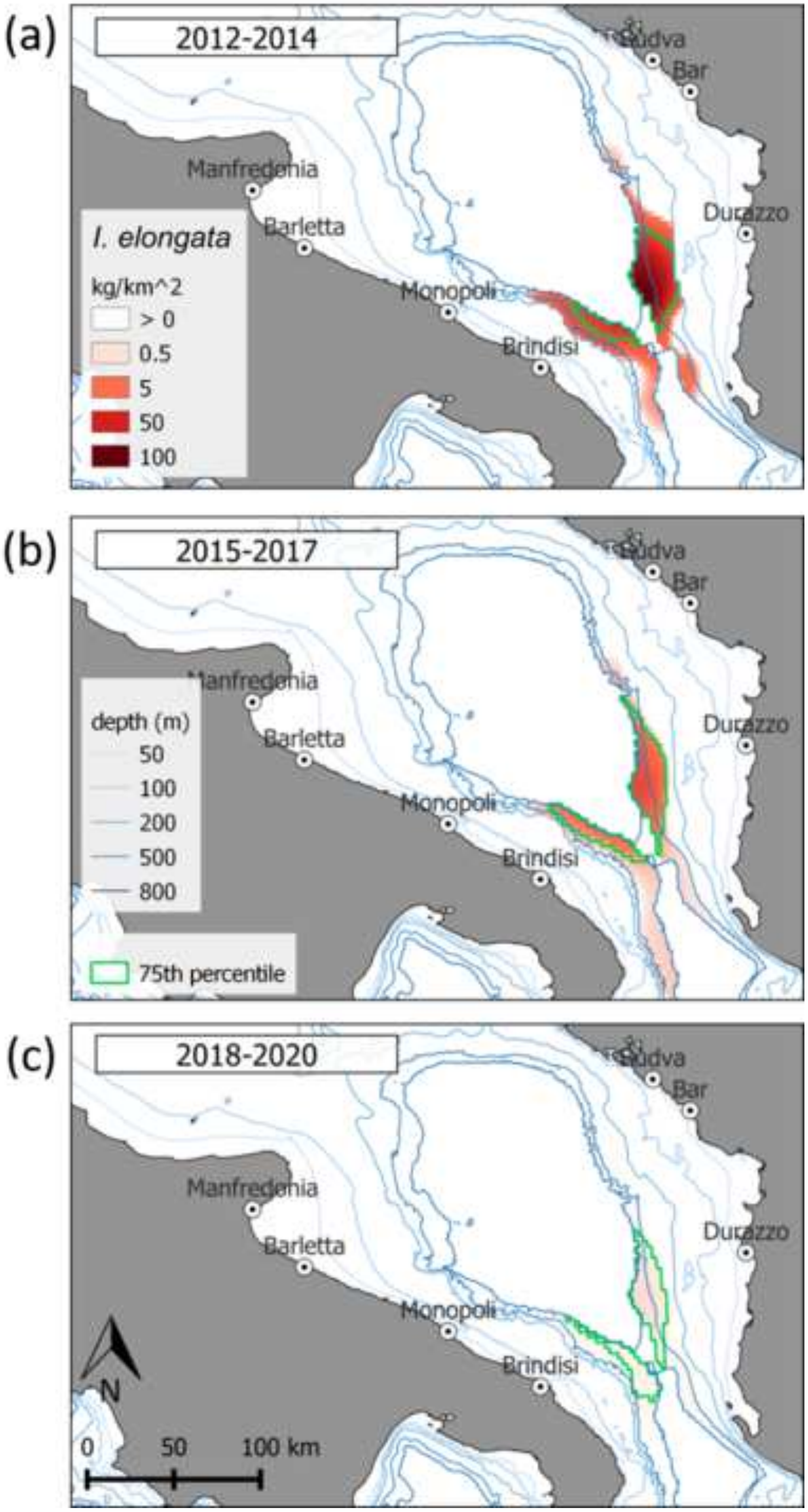
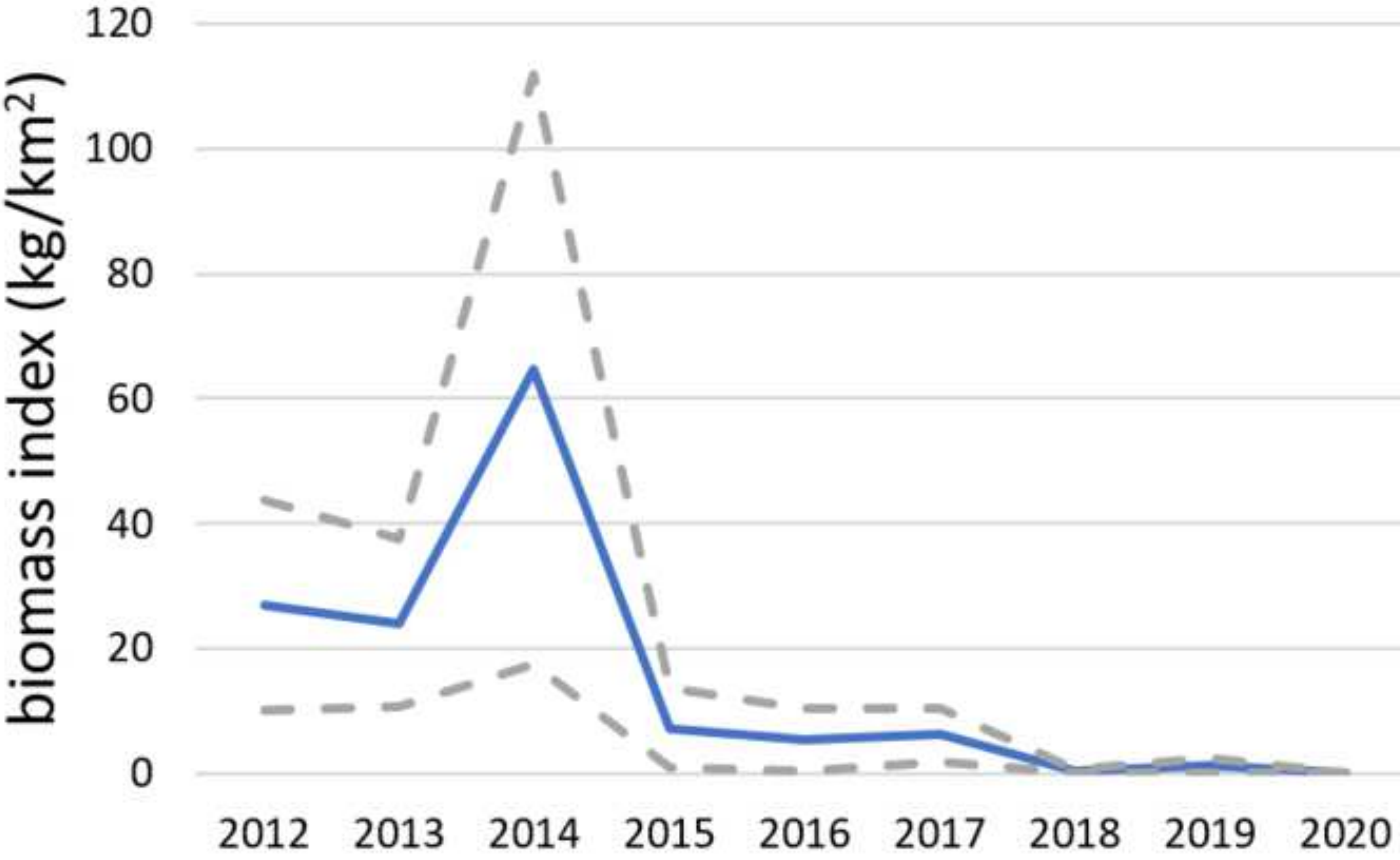
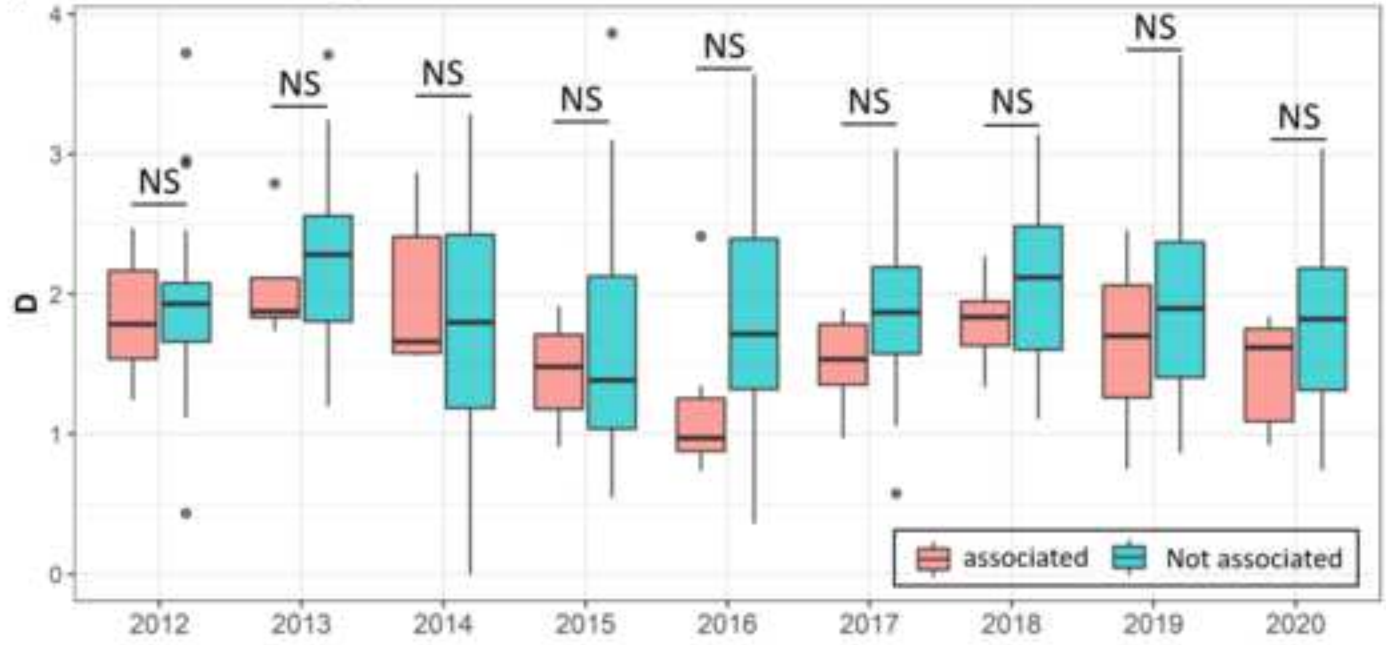


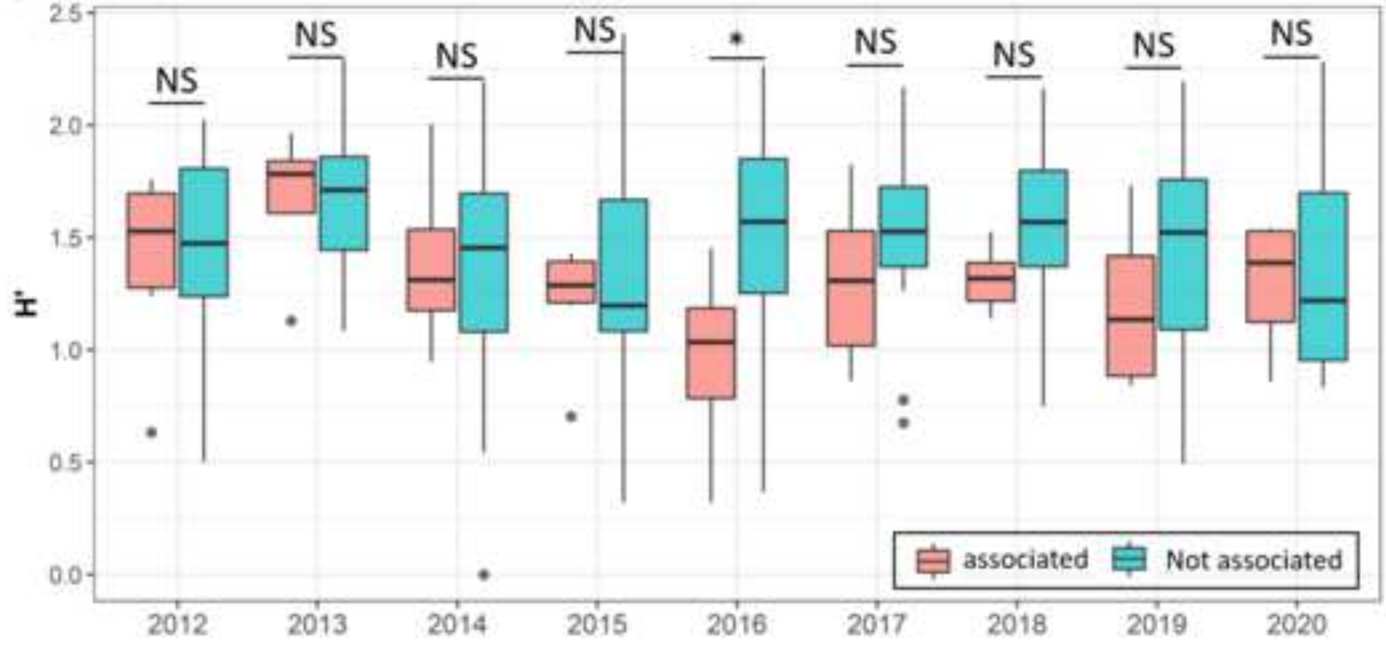
Figure3


(a)
2012-2014
(b)
2015-2017
(c)
2018-2020
Budva
Bar
Manfredonia
Barletta
Monopoli
Brindisi
Durazzo
I. elongata
kg/km^2
> 0
0.5
5
50
100
depth (m)
50
100
200
500
800
75th percentile
N
0
50
100 km


biomass index (kg/km²)
120
100
80
60
40
20
0
2012
2013
2014
2015
2016
2017
2018
2019
2020



(a) **BENTHOS - Margalef's index**



(b) **BENTHOS - Shannon's index**

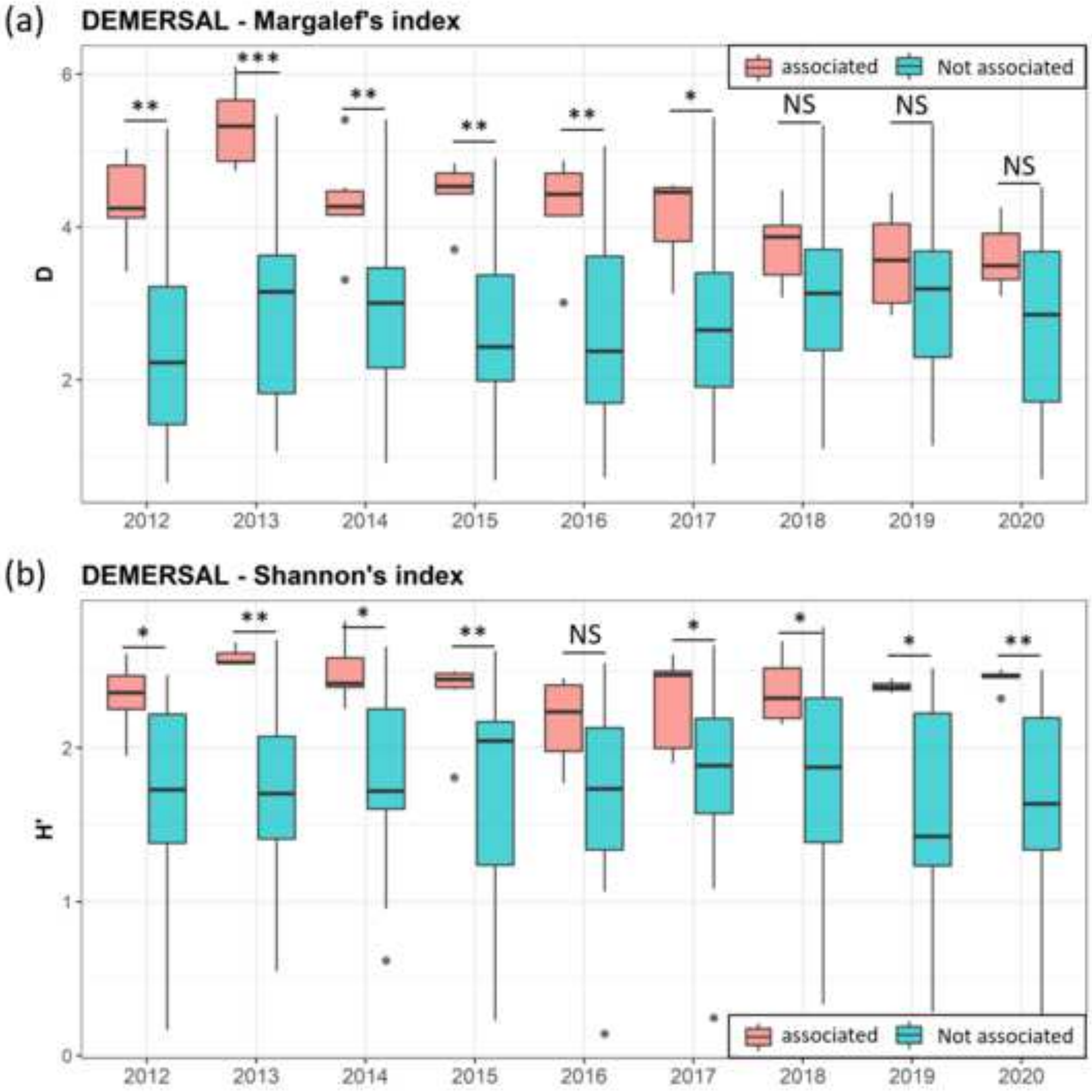

(a)
DEMERSAL - Margalef's index
associated
Not associated
D
6
4
2
**
***
**
**
**
*
NS
NS
NS
2012
2013
2014
2015
2016
2017
2018
2019
2020
(b)
DEMERSAL - Shannon's index
H'
2
1
0
*
**
*
**
NS
*
*
*
**
associated
Not associated
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure7

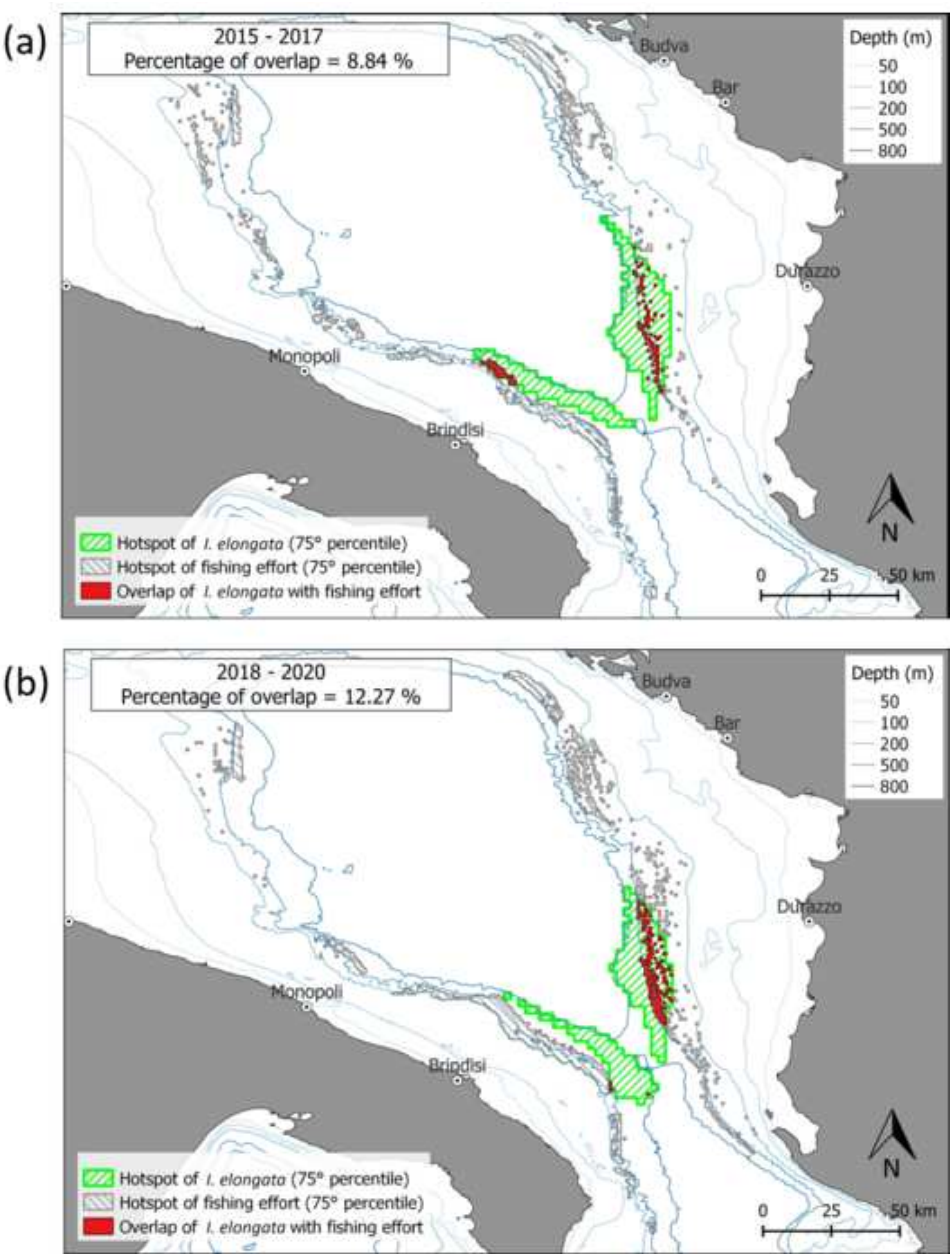
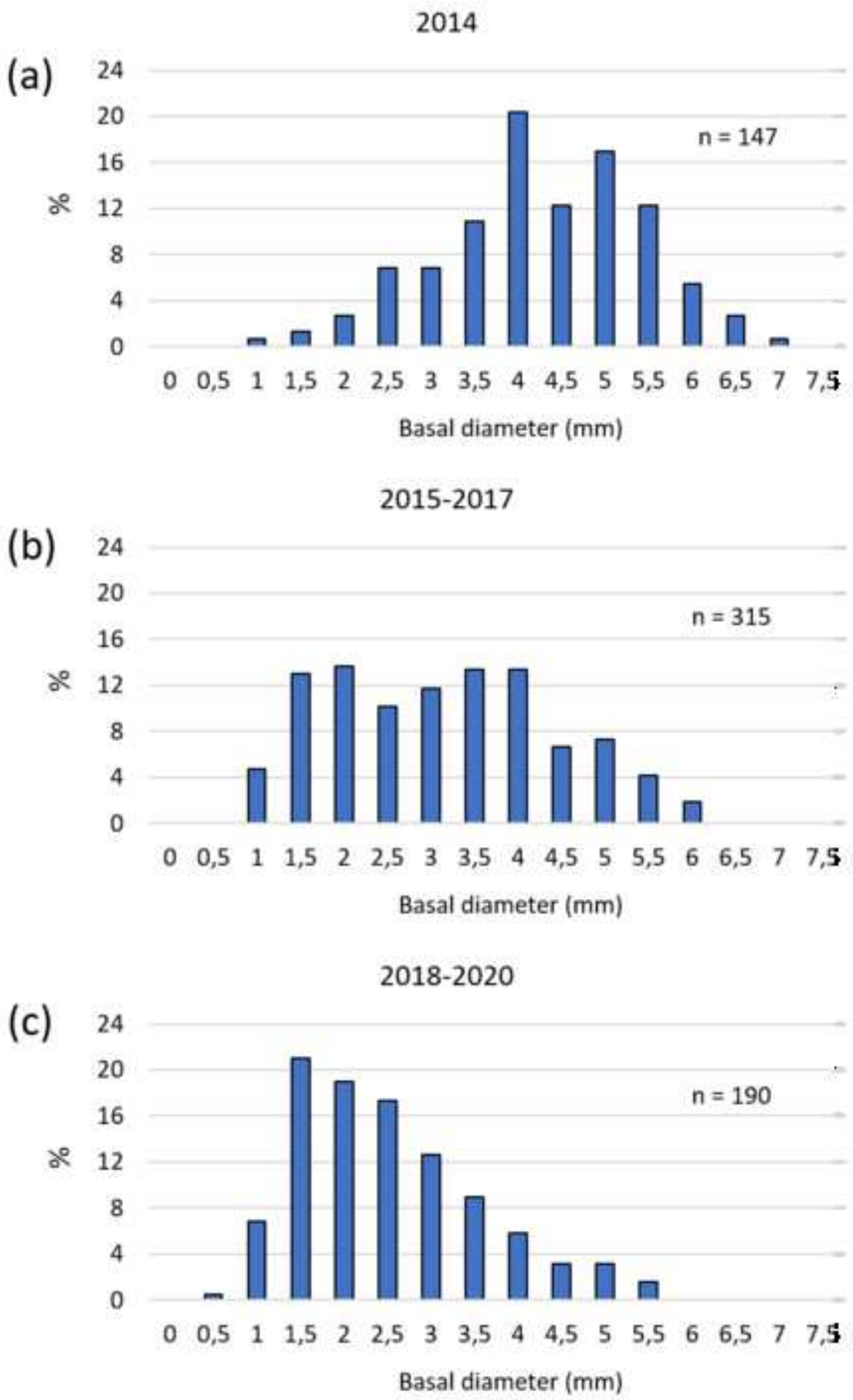
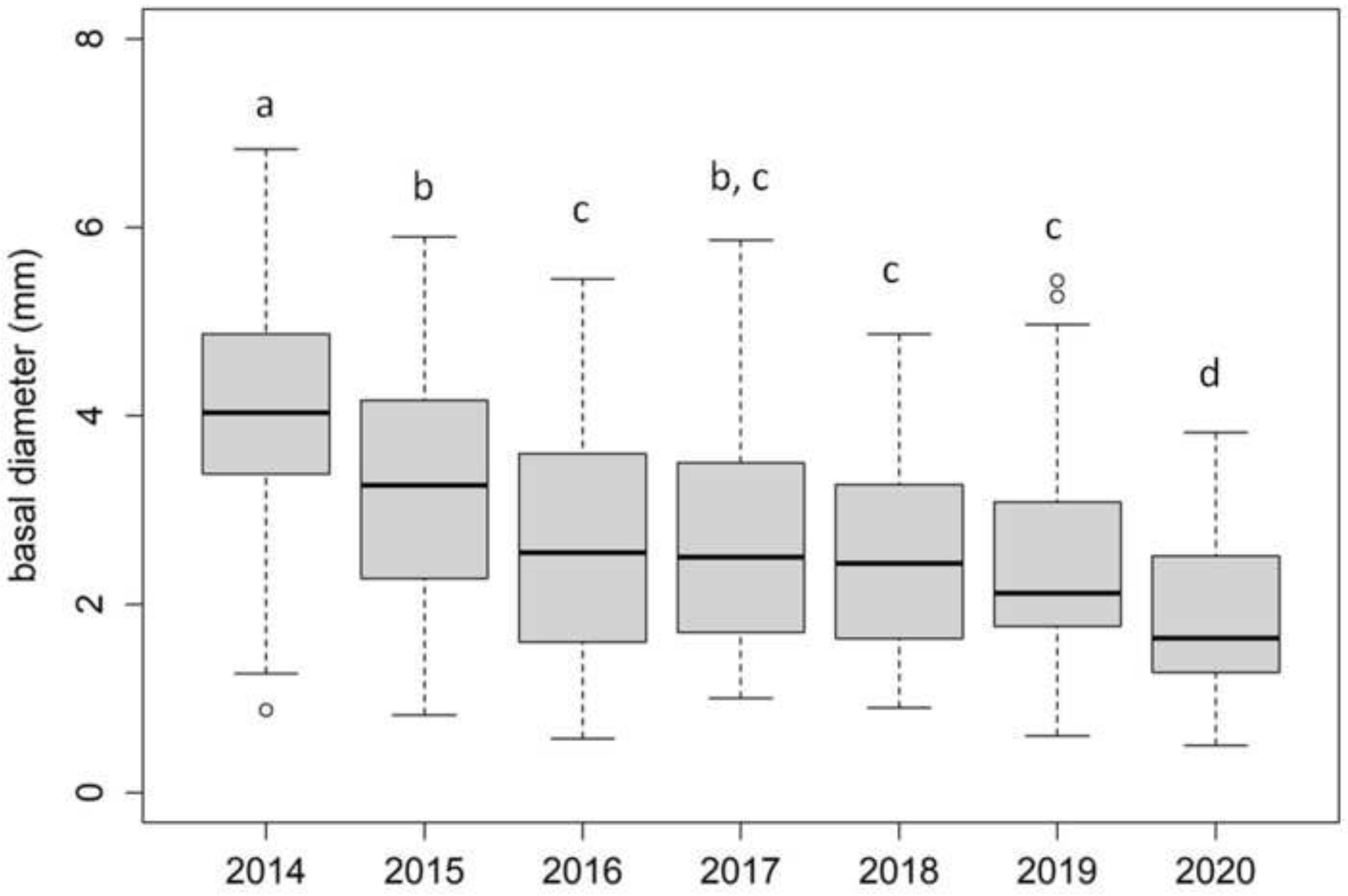

(a)
2015 - 2017
Percentage of overlap = 8.84 %
Depth (m)
50
100
200
500
800
Budva
Bar
Durazzo
Monopoli
Brindisi
N
0
25
50 km
Hotspot of I. elongata (75° percentile)
Hotspot of fishing effort (75° percentile)
Overlap of I. elongata with fishing effort
(b)
2018 - 2020
Percentage of overlap = 12.27 %
Depth (m)
50
100
200
500
800
Budva
Bar
Durazzo
Monopoli
Brindisi
N
0
25
50 km
Hotspot of I. elongata (75° percentile)
Hotspot of fishing effort (75° percentile)
Overlap of I. elongata with fishing effort

Figure8


(a)
2014
n = 147
%
24
20
16
12
8
4
0
0 0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5
Basal diameter (mm)
(b)
2015-2017
n = 315
%
24
20
16
12
8
4
0
0 0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5
Basal diameter (mm)
(c)
2018-2020
n = 190
%
24
20
16
12
8
4
0
0 0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5
Basal diameter (mm)


basal diameter (mm)
0
2
4
6
8
2014
2015
2016
2017
2018
2019
2020
a
b
c
b, c
c
c
d

Dear Editor,

We are delighted of positive feedback from reviewers about our revised manuscript. We answered all minor comments of reviewer 2 below and corrected the references list as suggested.

We hope you will find this version of our manuscript suitable for publication in Hydrobiologia,

All the best

Sébastien Alfonso

Also on behalf of the coauthors

Reviewer #2: This review represents a third review of the submitted manuscript.
The manuscript is greatly improved and I would accept it for publication with some very minor corrections below and please check the references, they are still not fully elaborated, particularly the on-line ones.
We are delighted of the positive feedback from the reviewer concerning our revision. We thank him/her very much for providing us detailed feedback to fix last points before publication. Below, we answered the comments and did modify the manuscript and the reference list accordingly.

Line 210: change "On the contrary" to "In contrast…"
This has been corrected (L210).

Line 247 I am not quite sure of the syntax for "as well the results of GAM model also show" do you mean "as the results of the GAM model indicate"
The sentence has been corrected (L247).

Line 267 change to "…of the IF in the southern…"
Corrected (L267).

Line 268 change to "…at least in the area…"
This has been modified (L268).

Line 271 delete "more recently" to change to "…Lembo, 2011), in recent years, there has…."
This has been corrected as suggested (L271).

Line 277 should it be "…how the number of fishing vessels dedicated to…"
This has been corrected (L277).

Line 284 delete the space between 38.8 and %
Corrected.

Line 294 can you define CWC in this first use (it is shown a few lines down, just move it up)
Thank you for pointing that. This has been corrected (L294).

Line 320 change to "whereas the Shannon-Wiener..." and then delete the second full stop a few words later.
This has been corrected (L320).

Line 321 change to "...good discriminatory ability towards species richness..."
This has been corrected (L321).

Line 323 change to "... that can exhibit a slower change in deep-sea..."
This has been corrected (L323).

Line 337 change to "...and the cephalopod..." (singular)
This has been corrected (L337).

Line 340 it is not clear what you mean "...are to show higher diversity of the macrofaunal community associated with I. elongata (Cartes..." do you mean "...exhibit a higher macrofaunal community diversity (Cartes..."
Indeed we aimed to say that "Mature colonies (i.e., larger colonies with higher density) of I. elongata exhibit a higher macrofaunal community diversity" as the reviewer pointed out. This has been now corrected in the revised version (L340).

Line 342 change to "Basal diameter is correlated....."
Corrected as suggested (L341).

Line 349 you seem to talk about your data, but then quote Bo and Carbonara refs. You need to break the sentence to show that you showed a reduction in size over the periods and that this could is probably attributed to fishing impact delete the refs here because you cover this in the next sentence with the Carbonara ref and the following one with both the Bo and Carbonara refs.
Indeed, thank you for pointing that. We removed the references in the sentences.

Line 371 change to "...a significant decrease in biomass...."
This has been corrected (L370).

Refs still not quite there: Cartes 2020 missing the Journal detail and missing italic I on the Isidella
Cartes, J.E., Díaz-Viñolas, D., González-Irusta, J.M. et al. The macrofauna associated to the bamboo coral Isidella elongata: to what extent the impact on isideidae affects diversification of deep-sea

fauna. Coral Reefs 41, 1273-1284 (2022). https://doi.org/10.1007/s00338-022-02243-w
This missing information has been added (L430).

Line 433 italics for second Isidella
This has been corrected (L433).

Line 448 - I found a bit more on this reference citation
Chimienti, Giovanni, Mastrototaro, Francesco, D'Onghia, Gianfranco. "Mesophotic and Deep-Sea Vulnerable Coral Habitats of the Mediterranean Sea: Overview and Conservation Perspectives" In Advances in the Studies of the Benthic Zone, edited by Luis Soto. London: IntechOpen, 2019. 10.5772/intechopen.90024
This has been corrected.

Line 449 Coll ref in full
Coll M, Piroddi C, Steenbeek J, Kaschner K, Ben Rais Lasram F, et al. (2010) The Biodiversity of the Mediterranean Sea: Estimates, Patterns, and Threats. PLoS ONE 5(8): e11842. doi:10.1371/journal.pone.0011842
This has been corrected (L456).

There's a few others too, please check them again, they should be cited fuller.....D'Onghia 2012, Danovaro 2020, EUMOFA 2019,… please try and get them all, particularly the e-journals Plos1, FMARS, Intech.
These references have been corrected. We also checked the other references. Please see the changes in the revised list of references.