



Evidences of human impact on megabenthic assemblages of bathyal sediments in the Alboran Sea (western Mediterranean)

Jordi Grinyó, Claudio Lo Iacono, Martina Pierdomenico, Suzanne Conlon, Guillem Corbera, Eulàlia Gràcia

► To cite this version:

Jordi Grinyó, Claudio Lo Iacono, Martina Pierdomenico, Suzanne Conlon, Guillem Corbera, et al.. Evidences of human impact on megabenthic assemblages of bathyal sediments in the Alboran Sea (western Mediterranean). Deep Sea Research Part I: Oceanographic Research Papers, 2020, 165, pp.103369 -. 10.1016/j.dsr.2020.103369 . hal-03493746

HAL Id: hal-03493746

<https://hal.science/hal-03493746>

Submitted on 17 Oct 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Evidences of human impact on megabenthic assemblages of bathyal sediments in the Alboran Sea (western Mediterranean)

Jordi Grinyó^{a,b,*}, Claudio Lo Iacono^{a,c}, Martina Pierdomenico^d, Suzanne Conlon^c, Guillem Corbera^c, Eulàlia Gràcia^a

^a Institut de Ciències del Mar (CSIC), Pg. Marítim de la Barceloneta 37-49, 08003, Barcelona, Spain

^b Sorbonne Université, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, Banyuls-sur-Mer, France

^c National Oceanography Centre, University of Southampton Waterfront Campus, European Way, Southampton SO14 3ZH, UK

^d Istituto per lo studio degli impatti Antropici e Sostenibilità in ambiente marino (CNR-IAS), Roma, Via della Vasca Navale 79, 00146 Rome, Italy

*corresponding author:

jordigrinyo85@gmail.com, grinyo@icm.csic.es

Abstract

Megabenthic assemblages in deep-sea sedimentary environments receive far less attention than those occurring on rocky environments, despite they have been widely impacted by destructive trawling activities, mainly due to their association with important commercial species. ROV dives conducted on bathyal muds of the Alboran Sea continental slope (western Mediterranean) were used to characterize megabenthic assemblages, as well as assess their response to trawling and benthic litter. We identified a multispecific assemblage, dominated by the isidid *Isidella elongata*, and two monospecific assemblages composed by the sea-pens *Funiculina quadrangularis* and *Kophobelemnion stelliferum*. These assemblages are defined as vulnerable marine ecosystems by international institutions. Trawled areas exhibit significant low densities of habitat-forming species and a striking impoverishment of habitat complexity and diversity. Plastic debris and lost fishing gears were the most abundant components of the marine litter. This study highlights the destructive effects of human activities on bathyal muds, emphasizing the need for urgent conservation measures.

Keywords: Mediterranean Sea, vulnerable marine ecosystems, megabenthos, soft sediments, bottom trawling, marine litter.

1. Introduction

The present-day advances in underwater technologies eased the access to scientific Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs) and high-frequency imaging systems, able to operate at high depths during increasingly long acquisition periods (Wynn et al., 2014; Aguzzi et al., 2019; Price et al., 2019; Bo et al., 2020). These advances generate a sudden expansion on the deep-sea benthic ecology studies, and related physical processes based on image analysis and high-resolution acoustic mapping (e.g. Benoist et al., 2019; Corbera et al., 2019). In parallel, the technological expansion in marine sciences enhanced the awareness that human-related activities exert a strong and pervasive impact on deep-sea ecosystems, with a detrimental effect on habitat complexity and biodiversity (de Moura-Neves et al., 2015; Clark et al., 2019).

Image-based investigations of deep-sea habitats were mainly focused on benthic communities or key structuring species occurring on hard substrates (Mortensen and Buhl-Mortensen, 2005; Althaus et al., 2009; Price et al., 2019), while similar studies on deep-sea sedimentary settings are scarce (Robert and Juniper, 2012; De Leo et al., 2017). This represents a significant knowledge gap, considering that deep-sea sediments are among the most widespread benthic habitats in the world, covering vast areas of continental shelves, slopes and abyssal plains (Gray, 2002). Deep-sea sedimentary environments have been traditionally considered as barren fields sparsely populated by megabenthic organisms (Jones et al., 2007). However, in specific areas, deep-sea sedimentary floors have been shown to host three-dimensional complex megabenthic assemblages, such as sponge grounds or sessile anthozoan aggregations (de Moura-Neves et al., 2015; Maldonado et al., 2015). These assemblages locally enhance biomass and act as biodiversity hotspots, as they provide habitat for a large variety of associated species, including a wide range of species of economic interest

62 (Maynou and Cartes, 2012; de Moura-Neves et al., 2015; Maldonado et al., 2017;
63 Mastrototaro et al., 2017; Pierdomenico et al., 2018).

64 Deep-sea benthic communities are generally composed of fragile organisms having
65 very slow recovering rates (Clark et al., 2019). Consequently, the impact of over-
66 exploiting human activities produce extremely long-lasting degrading effects
67 (Jobstvogt et al., 2014; Vanreusel et al., 2016; Clark et al., 2019).

68 In 2006, the need to preserve Vulnerable Marine Ecosystems (VMEs) from the
69 negative impacts caused by human activities, led to the development of specific
70 management and conservation measures to prevent their degradation (UNGA, 2007).

71 To achieve this goal, several international strategies, such as the “*International*
72 *guideline for the management of the deep-sea fisheries in the high seas*” (FAO, 2009)
73 or the EU’s Marine Strategy Directive (2008/56/CE), have been developed during the
74 last decade. Deep-sea soft sedimentary environments of the Mediterranean Sea host
75 several VMEs, mainly represented by the isidid *Isidella elongata* and the
76 pennatulaceans *Funiculina quadrangularis* and *Kophobelemnion stelliferum*.

77 Amongst the many anthropogenic impacts on the marine environment, bottom
78 trawling is the widest spread physical disturbance in the world’s seabed (Watling,
79 2013; Hiddink et al., 2017). Impacts associated to bottom trawling include removal or
80 damage to epibenthic fauna, reduction of habitat complexity and alteration of
81 sedimentary and geochemical processes (e.g. De Leo et al., 2017; Hiddink et al.,
82 2017; Paradis et al., 2019). With bottom trawling progressively expanding to deeper
83 environments, VMEs associated to sedimentary bottoms have undergone a vast
84 decimation (Sardà et al., 2004; Gerovasileiou et al., 2019; Pusceddu et al., 2014),
85 restricting their distribution to isolated regions or areas inaccessible to trawlers, such

86 as sub-vertical walls or regions surrounded by rocky outcrops (Bo et al., 2015;
87 Pierdomenico et al., 2018).

88 Marine litter represents a further extremely pervasive and fast-growing anthropogenic
89 pollution affecting the world's oceans (Bergmann et al., 2015). Specifically, benthic
90 marine debris, defined as the macro-litter that settles on the seafloor (Spengler and
91 Costa, 2008), can damage benthic organisms through entanglement or coverage
92 (Pham et al., 2014; Bergman et al., 2015). Litter and especially plastic debris are a
93 considerable source of persistent organic pollutants and chemical additives, which are
94 toxic to marine species (Rochman et al., 2013). The breakdown products of plastic,
95 the so-called microplastics, are proven to be ingested by a variety of organisms, with
96 potential ecotoxicological effects still poorly assessed (Browne et al., 2013; Carreras-
97 Colom et al., 2018; Cau et al., 2019a).

98 Most of the information regarding VMEs of deep-sea sediments derives from invasive
99 sampling gears (e.g. experimental trawling, epi-benthic sledge) (Gili and Ros, 1987;
100 Maynou and Cartes, 2012; Mastrototaro et al., 2013), which despite providing
101 relevant information on species occurrence, deliver limited knowledge on sessile taxa
102 abundance, assemblage composition, habitat characteristics and their state of
103 conservation (Soltwedel et al., 2009; Chimienti et al., 2018). Recently, several image-
104 based studies carried out in the canyon heads of the Gulf of Lion and Tyrrhenian Sea,
105 and the open slope of the Balearic archipelago, have provided new insights on the
106 VMEs of sedimentary environments, highlighting in most cases their poor
107 conservation status (e.g. Fabri et al., 2014; Mastrototaro et al., 2017; Pierdomenico et
108 al., 2018). Overall, our knowledge of deep-sea assemblages located on soft bottoms is
109 still limited and thus, it is urgent to improve our understanding of these VMEs in

order to support sound conservation and management measures (Maldonado et al., 2015; Mastrototaro et al., 2015).

Based on the analyses of ROV footage collected within a depth range of 500-860 m, we aim at (1) characterizing the composition of deep megabenthic assemblages found on sedimentary bottoms of the Alboran Sea (western Mediterranean), and (2) quantify the effects of human activities on these assemblages, with a major focus on changes in habitat complexity and biodiversity caused by bottom trawling.

2. Material and Methods

2.1. The Alboran Sea

The Alboran Sea is the westernmost basin of the Mediterranean, which is enclosed between the Iberian Peninsula and the North Africa, connected to the Atlantic Ocean through the Straits of Gibraltar (Fig. 1). The Alboran Sea displays a relatively complex seafloor geomorphology, including three main sub-basins (i.e. West, East and South Alboran Basins) separated by the Alboran Ridge, a major NE-SW oriented structural high (Muñoz et al., 2008; Lo Iacono et al., 2014; Gràcia et al., 2006, 2012, 2019; Fig. 1). The shelf of the Alboran Sea displays a variable extension, from 3.5 to 12 km, and is bounded by the shelf edge at a depth of 100-115 m. The slope is 10 to 50 km wide and displays variable gradients, connecting to the base of slope at a depth between 575 and 1000 m, transitioning to the deep basins. The sediment dynamics of the margin are strongly controlled by the prevailing along-slope current regimes, which gave origin to large contourite deposits (Ercilla et al., 2016, 2019, Juan et al., 2016). They are locally interrupted by turbidite fans, mass-wasting deposits and volcanic outcrops (Muñoz et al., 2008; Lo Iacono et al., 2008; Ercilla et al., 2019). The Alboran Sea is mainly characterized by a siliciclastic sedimentation controlled by the river sources, together with the aeolian inputs as the main source of terrigenous

sediments (Moreno et al., 2002). Nevertheless, the high input of organic-rich sediments is associated to the relatively high-productivity of this basin, in contrast with the general oligotrophic characteristics of the Mediterranean Sea (Oguz et al., 2014). Phytoplankton primary productivity is mainly related to the local circulation pattern, controlled by the entrance of Atlantic surface waters into the Mediterranean and the development of anticyclonic gyres (Sarhan et al., 2000). Oceanographic conditions in the Alboran Sea are strictly related to the interaction between Atlantic and Mediterranean water masses, which create a regional thermohaline circulation (Vargas-Yáñez et al., 2010). The Atlantic waters (AW), warmer and less salty than Mediterranean ones ($T \sim 15^\circ\text{C}$, $S \sim 36.2$ psu, $T \sim 13.5^\circ\text{C}$, $S \sim 38.4$ psu, respectively), enter the Alboran Sea through the Straits of Gibraltar and flow within the first 150–200 m of the water column at a velocity of ~ 50 to up to $150\text{ cm}\cdot\text{s}^{-1}$ (Milot and Taupier-Letage, 2005). The AW circulation is driven by two semi-permanent anticyclonic gyres: The Western Alboran Gyre and the Eastern Alboran Gyre (Renault et al., 2012; Fig. 1). Deeper than the AW, the colder and salty Mediterranean Water ($T \sim 13.5^\circ\text{C}$, $S \sim 38.4$ psu), named Levantine Intermediate Water (LIW), flows towards the Straits of Gibraltar at $\sim 10\text{ cm}\cdot\text{s}^{-1}$ (García Lafuente et al., 1998) (Fig. 1). The LIW extends down to 600 - 700 m and flows above the underlying high density western Mediterranean deep water (< 12.7 - 12°C , $S \sim 38.40$ - 38.52 psu), whose circulation is largely conditioned by the local physiography of the basin (Milot, 2009). Despite the lack of exhaustive studies on the deep-sea benthic assemblages of sedimentary substrates in the Alboran Sea, muddy substrates in interspersed patches within hard frameworks of cold-water coral communities have been reported to host colonies of *I. elongata* and the pennatulacean *K. stelliferum* (Hebbeln et al. 2009).

2.2. The ROV video acquisition

A total of six dives were recorded during the oceanographic expedition "SHAKE", onboard the R/V "Sarmiento de Gamboa" (May-June, 2015) (SHAKE Cruise: CGL2011-3005-C02-02) (Fig. 1, Table 1). Dives were carried out with the ROV "Max-Rover", owned by the Hellenic Centre for Marine Research. It was equipped with a HD video camera (1920x1080 pixels), a manipulator arm for sampling tasks and two parallel laser beams (10 cm apart) that provided a reference scale to measure targets and define a fixed width of 1 m for the subsequent video analysis. ROV positioning was achieved by means of an ultra-short baseline (USBL) transponder mounted on the vehicle, which tracked their positioning every 3 seconds, approximately. Dives were conducted on both, northern and southern sectors of the eastern Alboran Sea between 500 and 860 m depth (Table 1), along three areas characterized by the occurrence of active faults: Carboneras Fault, North-South Faults, Al-Idrissi Fault (Gràcia et al., 2006, 2012, 2019; Fig. 1). The ROV moved at a constant speed of ~0.3 knots. Along each dive, voucher organisms were collected to confirm the taxonomic identification determined in the image analyses. Sampled organisms were fixed and preserved in 10% formalin for further analyses, were identified with the support of taxonomic experts and a manual on deep megabenthic fauna of the Mediterranean Sea (Fournier et al., 2017).

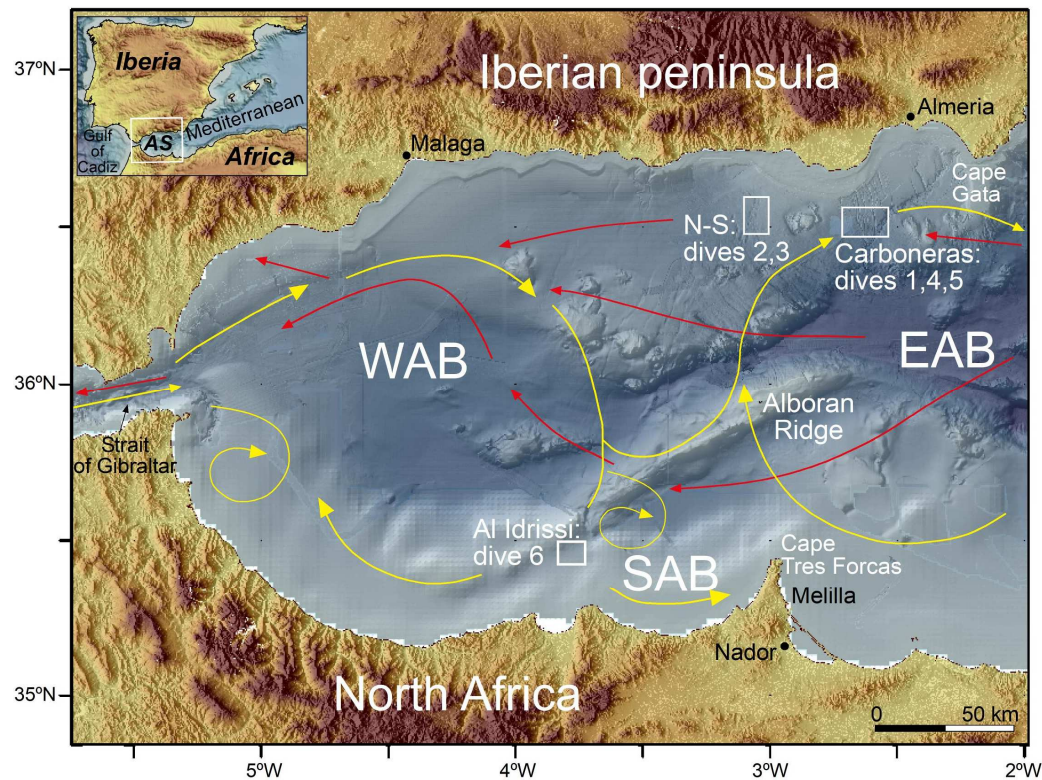


Fig. 1. Topographic and bathymetric map of the Alboran Sea, white rectangles indicate the location of dives, whose location correspond to different fault systems: North-South fault system (N-S), Carboneras fault system and Al-Idrissi Fault System. WAB: West Alboran Basin, EAB: East Alboran basin, SAB: South Alboran Basin. Yellow and red lines indicate the simplified patterns of the Atlantic Water (AW) gyres and the Mediterranean Levantine Intermediate Waters (LIW), respectively. Upper left inset: Western Mediterranean region indicate the Alboran Sea (AS).

2.3. Video analysis

Quantitative video analysis was performed according to the methodology described in Grinyó et al. (2016), using the software Final Cut Pro 7 (Apple Inc.). When the ROV was stopped or moving in loops, sequences were removed to avoid over-estimation of megabenthic organisms' abundance and dive length. Where the ROV was too detached from the seafloor or suspended sediments prevented a clear view of the seafloor, sequences were considered unusable and discarded from analyses. ROV dives covered a total distance of 5842 m, of which 5521 m was considered suitable for post-processing video analysis, corresponding to 94.5% of the total footage.

Video analysis was aimed at quantifying the encountered megabenthic organisms, the lebensspuren items (i.e. sedimentary forms produced by metazoans biological activity) (Fig. 2), trawl marks and marine litter. All these items were quantified within a width of 1 m (estimated from the laser beam distance). Lebensspuren was classified into four categories: furrows, mounds, holes and trail marks (Fig. 2).

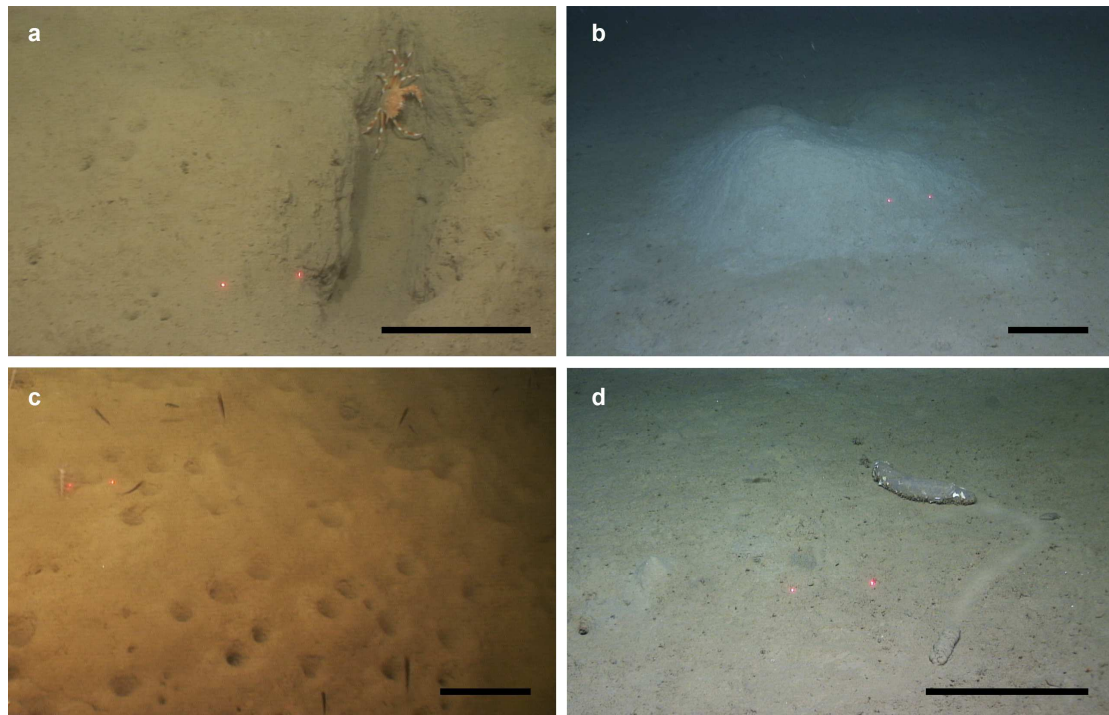


Fig. 2. Lebensspuren categories: a) furrow with a *Batynectes maravigna* crab inside, b) mound, c) hole aggregations, and d) trail-mark generated by *Mesothuria intestinalis*. Scale bar: 20 cm.

Litter items were categorized according to their composition into five classes: plastics debris (i.e. plastic bags, bottles, small plastic fragments), lost fishing gears (long-lines and nets), metal debris, glass bottles and clothes. Additionally, two categories of substratum were defined: untrawled and trawled bottoms. Sediment texture and seafloor gradients were not considered in the video analysis due to the homogeneity of these variables. Each observation (organism, trawl mark, lebensspuren, marine

litter) was assigned a position within the dive, following the methodology described by Grinyó et al. (2016).

2.4. Data treatment

2.4.1. Megabenthic fauna occupancy and abundance

To measure megabenthic fauna occupancy (i.e. the frequency of occurrence in the set of sampling units) and abundance (i.e. the number of individuals per sampling unit) and to assess megabenthic assemblage composition, each dive was split into 2 m² sampling units (0.7 m width and 2.9 m long). A total of 1904 sampling units were obtained. Each sampling unit was characterized by the abundance of organisms, number of sessile megabenthic species, lebensspuren and litter items. On the basis of trawl mark presence, sampling units were classified as trawled or untrawled.

2.4.2. Sessile megabenthic assemblage composition

Sessile megabenthic assemblages, defined here as assemblages constituted by sessile and low motile invertebrates such as echinoderms (Grinyó et al., 2018), were identified based on species composition by means of a non-metric multidimensional scaling ordination (nMDS) of the sampling units, with species abundances being square root transformed, and ordination performed via a Bray-Curtis dissimilarity matrix. Adonis permutation multivariate analysis of variance and subsequent pairwise tests were used to test for significant differences amongst assemblages. The nMDS and adonis test were performed using the R-language function “metaMDS” and “Adonis”, available in the vegan library of the R software platform (Oksanen et al., 2016). Species occurring less than 3 times were excluded from the nMDS analysis.

2.4.3. Influence of anthropogenic impacts

Anthropogenic impact was assessed by estimating the occurrence of trawl marks and the density and typology of litter in each sampling unit. The effect of human disturbance on megafauna was analyzed within dives by comparing the frequency of occurrence of each megabenthic species in trawled (sampling units where trawl-marks were present) and un-trawled (sampling units where trawl marks were absent) sampling units, with similar environmental conditions in terms of substrate and inclination. Furthermore, we quantified the variation in habitat complexity and diversity between trawled (dives where trawl marks were present) and untrawled (dives where trawl marks were absent) areas, by comparing lebensspuren abundance (Gage, 1996) and the variation in species turnover (beta-diversity) by means of a randomized species accumulation curve (De Leo et al., 2014). This statistical approach allows us to find the average species accumulation curve and its standard deviation from random permutations of data (n=100), eluding misrepresentation in the curves due to differences in species abundance and sampling effort (Gotelli and Colwell, 2001). Megabenthic species, also including decapods and ichthyofauna, were considered to calculate the randomized species accumulation curve, although species that present positive phototactism were not considered (e.g. myctophids or squids). Randomized species accumulation curves were calculated with R-language function “specaccum”, using the vegan library of the R software platform (Oksanen et al., 2016).

3. Results

3.1. Description of physical characteristics along ROV dives

Dive lengths ranged between 168 m to 1700 m depth (Table 1). In all the dives, the seafloor was considered sub-horizontal and consisted of muddy sediments. A total of nine pockmarks were observed, one in dive 4 and eight in dive 5 (Table 1).

Pockmarks displayed a circular shape, with diameters ranging between 1.5 and 3 m and a maximum depth of ~40-50 cm. No carbonate concretions nor fluid or gas release were observed within the pockmarks, suggesting that these features are currently inactive.

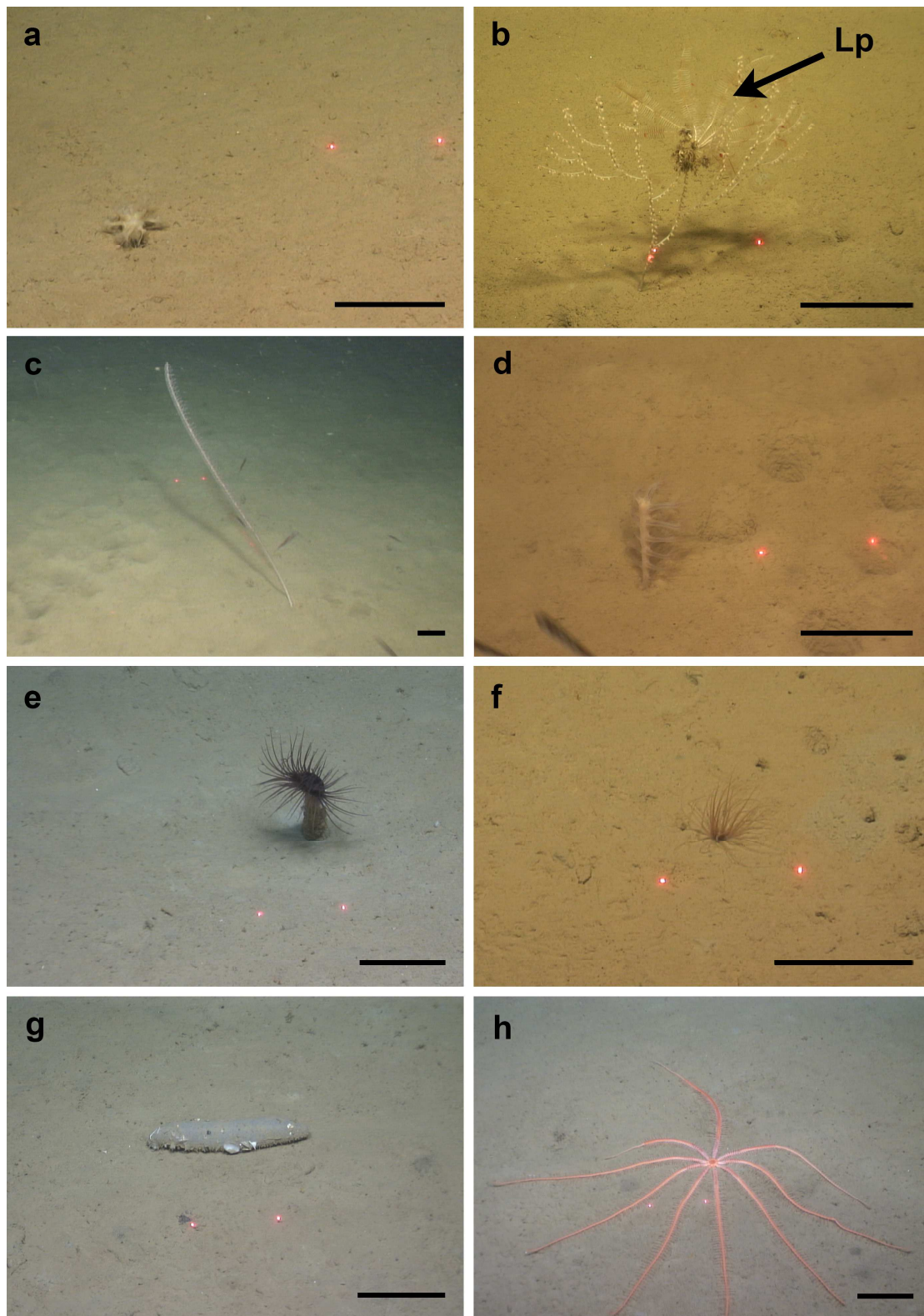
Table 1 Location (geographic coordinates in WGS84), length, pockmark abundance and depth (minimum and maximum depth) of the SHAKE ROV dives. CFS: Carboneras fault system, NSFS: North-South fault system, AIFS: Al-Idrissi fault system, and Dv: Dive.

Zone	Dv	Start		End		Length (m)	N° of Pockmarks	Depth range (m)
		Lat° N	Lon° W	Lat° N	Lon° W			
CFS	1	36.524	3.088	36.519	3.077	1700	0	704 - 722
NSFS	2	36.481	2.695	36.481	2.694	1109	0	639 - 685
NSFS	3	36.515	3.051	36.520	3.052	1368	1	638 - 688
CFS	4	36.532	2.619	36.541	2.618	168	0	836 - 860
CFS	5	35.498	3.737	35.504	3.739	725	8	821 - 842
AIFS	6	36.501	2.660	36.503	2.662	773	0	500 - 526

3.2. Megabenthic organisms: Occupancy and abundance

A total of 447 organisms from 9 different species belonging to 5 different phyla were observed in the study area (Fig. 3 and Table 2), occurring in 17.3% of the 1904 sampling units. The bamboo coral *Isidella elongata*, the cerianthid *Arachnanthus oligopodus* and the sponge *Thenea muricata* (Figs. 3a, 3b and 3f) were the most abundant species, representing 26.4%, 23.7% and 16.6% of all observed organisms, respectively. *A. oligopodus* was the most frequent species, occurring in 30.7% of the occupied sampling units, followed by both *I. elongata* and *T. muricata*, which both occurred in 21.6% of the occupied sampling units (Table 2). Abundance and frequency progressively decreased from the asteroid *Hymenodiscus coronata* to the crinoid *Leptometra phalangium* and the holothurian *Mesothuria intestinalis* (Table 2).

286 The remaining species accounted for less than 5% of all observed organisms and
287 occurred in less than 6% of sampling units (Table 2).



288
289 Fig. 3. Most common sessile and low motile megabenthic species occurring in the Alboran
290 sedimentary bottom. a) *Thenea muricata*, b) *Isidella elongata* and *Leptometra phalangium* (Lp), c)

Funiculina quadrangularis, d) *Kophobelemnion stelliferum*, e) *Cerianthus membranaceus*, f) *Arachnanthus oligopodus*, g) *Mesothuria intestinalis*, and h) *Hymenodiscus coronata*. Scale bar: 10 cm.

Table 2 Total and relative abundance of sessile megabenthic species together with their occupancy (n° of sampling units occupied by a species) and frequency (% of occurrence in the whole set of occupied sampling units) in the study area. Average and maximum density of each sessile species within the occupied sampling units (n=329) are also shown. ind: individuals.

Class	Species	Abundance		Occupancy		Average density \pm SD	Max density
		Number	(%)	Number	(%)	(ind. m ⁻²)	(ind. m ⁻²)
Desmospongia	<i>Thenea muricata</i>	74	16.6	71	21.6	1.04 \pm 0.2	2
Anthozoa	<i>Isidella elongata</i>	118	26.4	71	21.6	1.5 \pm 0.9	7
	<i>Arachnanthus oligopodus</i>	106	23.7	101	30.7	1.03 \pm 0.2	2
	<i>Kophobelemnion stelliferum</i>	21	4.7	20	6.1	1.04 \pm 0.2	2
	<i>Cerianthus membranaceus</i>	17	3.8	17	5.2	1	1
	<i>Funiculina quadrangularis</i>	7	1.6	7	2.1	1	1
Crinoidea	<i>Leptometra phalangium</i>	35	7.8	26	7.9	1.2 \pm 0.6	3
Astroidea	<i>Hymenodiscus coronata</i>	36	8	36	10.9	1	1
Holothuria	<i>Mesothuria intestinalis</i>	33	7.4	33	10	1	1

3.3. Sessile megabenthic assemblage composition

Three megabenthic assemblages, distributed along the six ROV dives, could be identified in the nMDS: two monospecific assemblages composed by few colonies of the pennatulaceans *K. stelliferum* and *F. quadrangularis* respectively, and a multispecific group composed of *I. elongata* (28%), *A. oligopodus* (25%), *T. muricata* (18%), *H. coronata* (9%), *L. phalangium* (8%), *M. intestinalis* (8%) and *Cerianthus membranaceus* (4%) (Fig. 4). The Adonis test and subsequent pairwise test revealed that all three assemblages were significantly different (p<0.001) from one another.

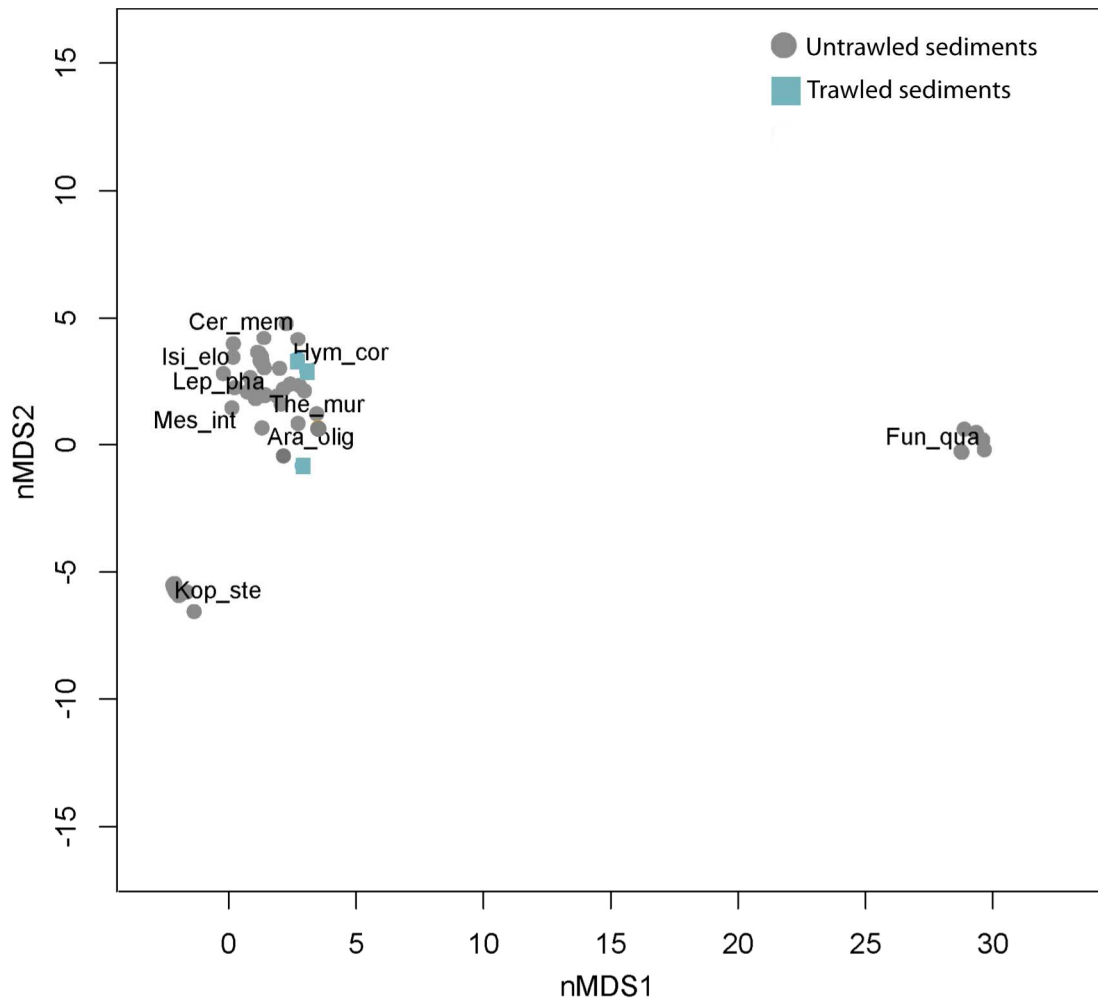


Fig. 4. Non-metric multi-dimensional scaling (nMDS) ordination plot, data were square root transformed, and ordination performed via a Bray-Curtis dissimilarity matrix): Sampling units containing sessile organisms and echinoderms are represented considering trawling presence (9 sampling units) and trawling absence (320 sampling units). Ara_oli = *Arachnanthus oligopodus*, Cer_mem = *Cerianthus membranaceus*, Fun_qua = *Funiculina quadrangularis*, Hym_cor = *Hymenodiscus coronata*, Isi_elo = *Isidella elongata*, Kop_ste = *Kophobelemnion stelliferum*, Lep_pha = *Leptometra phalangium*, Mes_int = *Mesothuria intestinalis*, The_mur = *Thenea muricata*.

3.4. Distribution of anthropogenic impacts

Marine litter was observed in all the ROV dives, except dive 6 (Table 3). Overall, 44 items were found, with plastics debris being the most abundant component (46%),

followed by lost fishing gears (41%), metallic debris (7%), such as a cot and an empty
 butane cylinder (Fig. 5a), glass bottles (4%) (Fig. 5b) and clothes (2%) (Fig. 6). In
 dives 4 and 5, 33% and 100% of marine litter items were found within pockmarks
 (Figs. 5c, 5d and 7c). Marine litter average densities ranged between 0.001 ± 0.09 to
 0.01 ± 0.002 items m^{-2} , with maximum densities of 2 items m^{-2} occurring within
 pockmarks. Trawl marks were observed in three of the six dives (Fig. 5e, 5f), with
 almost the totality of them concentrated in dive 3 (Table 3). A total of 93 trawl marks
 were observed, affecting 93 sampling units (4.88% of all sampling units).

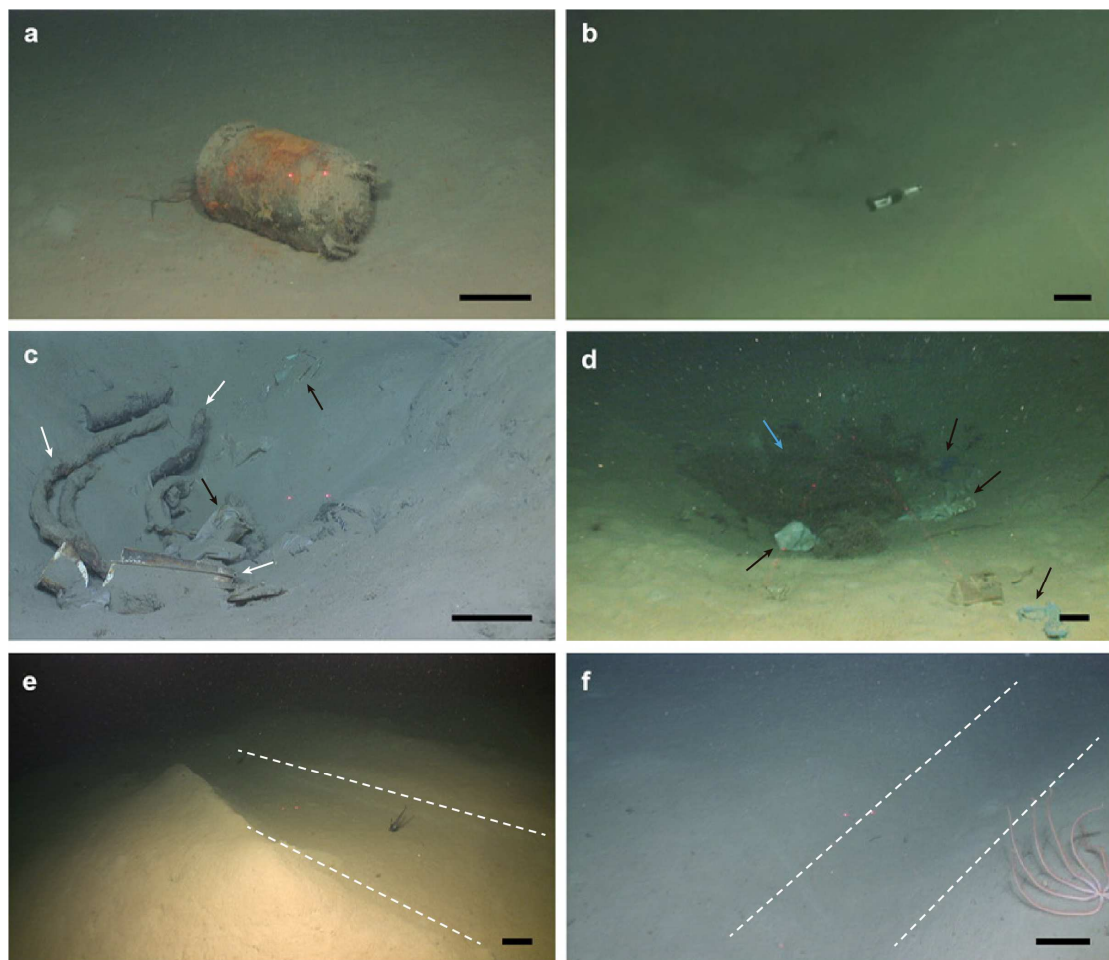


Fig. 5. Evidences of anthropogenic impact on the deep-sea sedimentary floor of the Alboran
 Sea: a) butane cylinder, b) glass bottle, debris accumulation inside pockmarks, c) reinforced
 rope, metal plates and plastic debris, d) lost net and light plastic debris, e) trawl-mark with
 macrourid fish, f) old trawl-mark with *Hymenodiscus coronata*. Scale bar: 20 cm. white

arrows: metallic debris, black arrows: plastic debris, blue arrow: lost net, discontinuous line:
 trawl mark delimitation.

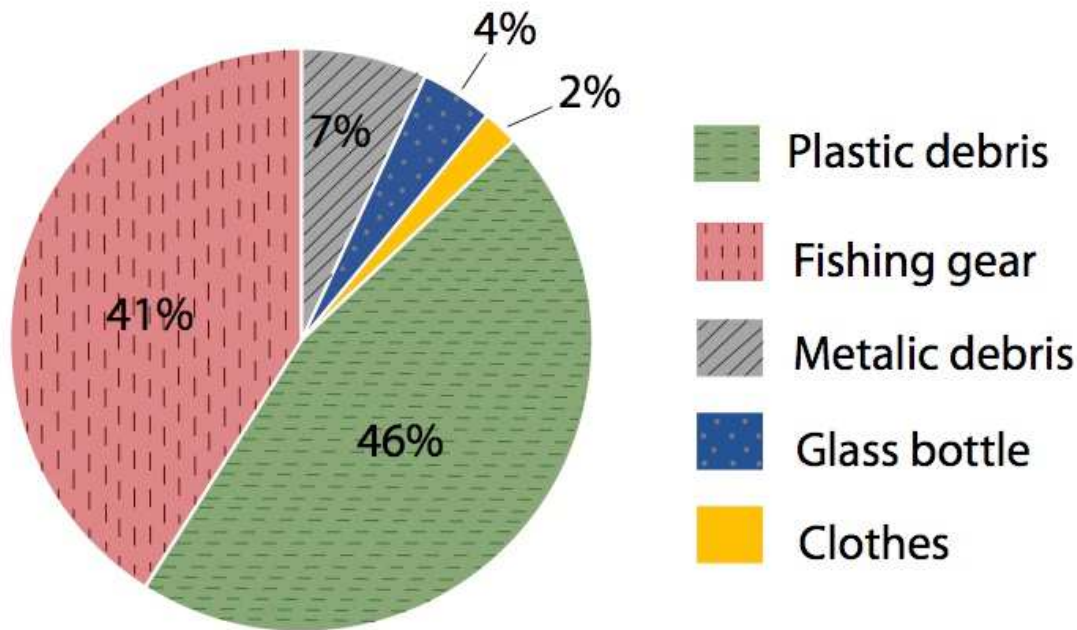
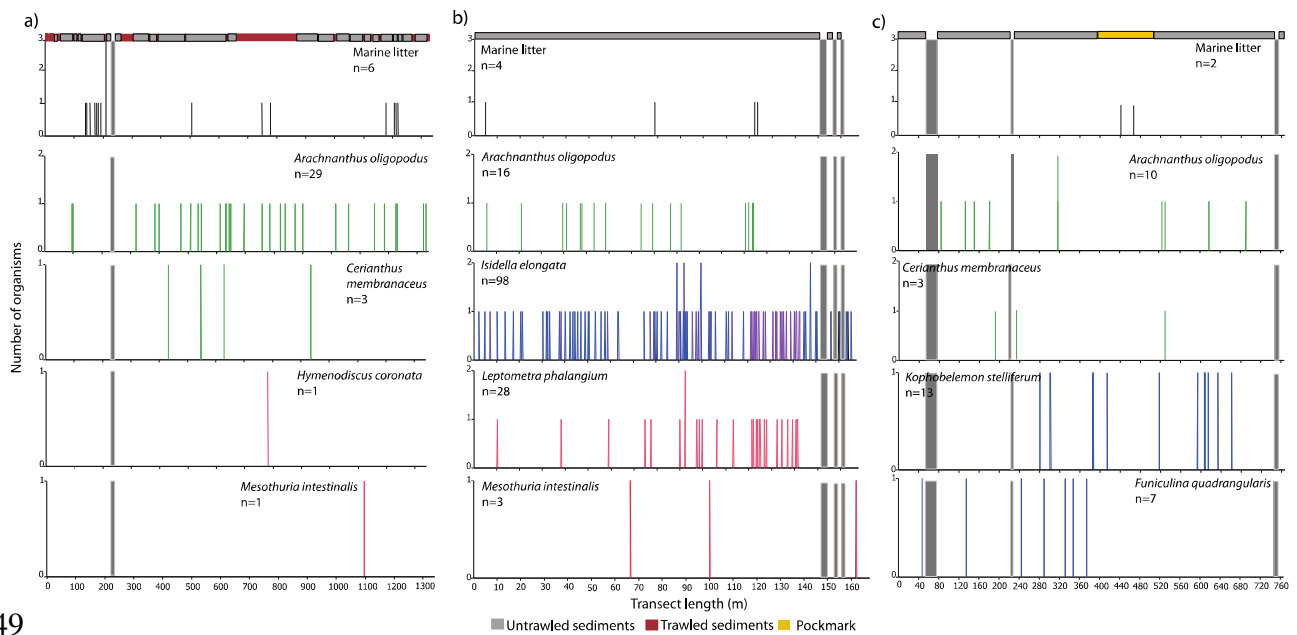


Fig. 6. Marine litter composition.

Table 3 Abundance and frequency of the occurrence of marine litter and trawl-marks in the study area. Sampling units with organisms (SO): number of sampling units simultaneously occupied by sessile megabenthic species and marine litter items or trawl-marks. CFS: Carboneras fault system, NSFS: North South fault system, AIFS: Al-Idrissi fault system; Dv: dive, Av. Density: Average density.

Zone	Dv	Marine litter				Trawl marks			
		Abundance (N°)	Occupancy (N°)	Av. density (Mean±SD)	SO (N°)	Abundance (N°)	Occupancy (N°)	Av. density (Mean±SD)	SO (N°)
CFS	1	15	1	0.01±0.002	0	6	6	0.002±0.04	1
NSFS	2	7	4	0.060±0.200	1	0	0	0	0
NSFS	3	14	16	0.015±0.102	0	84	84	0.081±0.215	7
CFS	4	1	2	0.001±0.092	0	3	3	0.004±0.043	1
CFS	5	7	4	0.014±0.131	0	0	0	0	0
AIFS	6	0	0	0	0	0	0	0	0



349

350 Fig. 7. Density plots showing variation of the abundance of different species and
 351 anthropogenic impacts along representative dives. (a) Density plots of an area impacted by
 352 bottom trawling (dive 3). (b) Density plots of an untrawled area covered by an *I. elongata*
 353 meadow (dive 4). (c) Density plots of an untrawled area with pockmarks. This area was
 354 dominated by the sea pens *F. quadrangularis* and *K. stelliferum* (dive 6). Vertical gray lines
 355 indicate dive sequences that could not be analyzed due to a poor image quality, n=number of
 356 litter items/individuals/colonies. Sessile taxa with retractile and non-retractile capacity have
 357 been marked in green and blue, respectively. *Isidella elongata* colonies epiphyted by *L.*
 358 *phalangium* are marked in purple. Taxa with motile capacity have been marked in red.

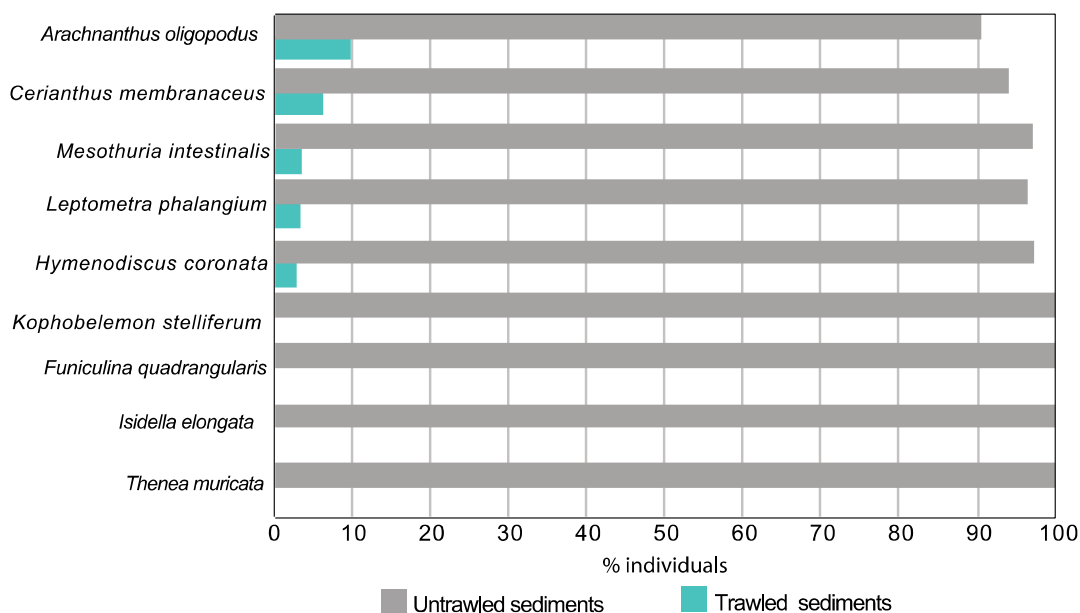
359

360 3.5. Relationship between anthropogenic impacts and sessile megabenthic fauna

361 With the exception of a lost gear line, which occurred next to an *I. elongata* colony
 362 within dive 2 (Table 3), marine litter and megabenthic species did not co-occur. Only
 363 9 out of the 93 sampling units containing trawl-marks were colonized by megabenthic
 364 species (Table 3), mainly represented by *A. oligopodus*, *C. membranaceus* and, to a
 365 lesser extent, by *M. intestinalis*, *L. phalangium* and *H. coronata* (Figs. 7a ,8).
 366 Overall, megabenthic densities in dives where trawl-marks were present (0.5 ± 0.2 ind.

367 m^{-2} mean \pm SD) were significantly lower (Adonis, PSEUDO-F = 26.9, $p < 0.001$) than
 368 those where trawl-marks were absent (1.5 ± 0.7 ind. m^{-2} mean \pm SD).

369 Uprising non-retractile sessile species were exclusively found on untrawled sediment
 370 (Figs. 7b, 7c and 8).

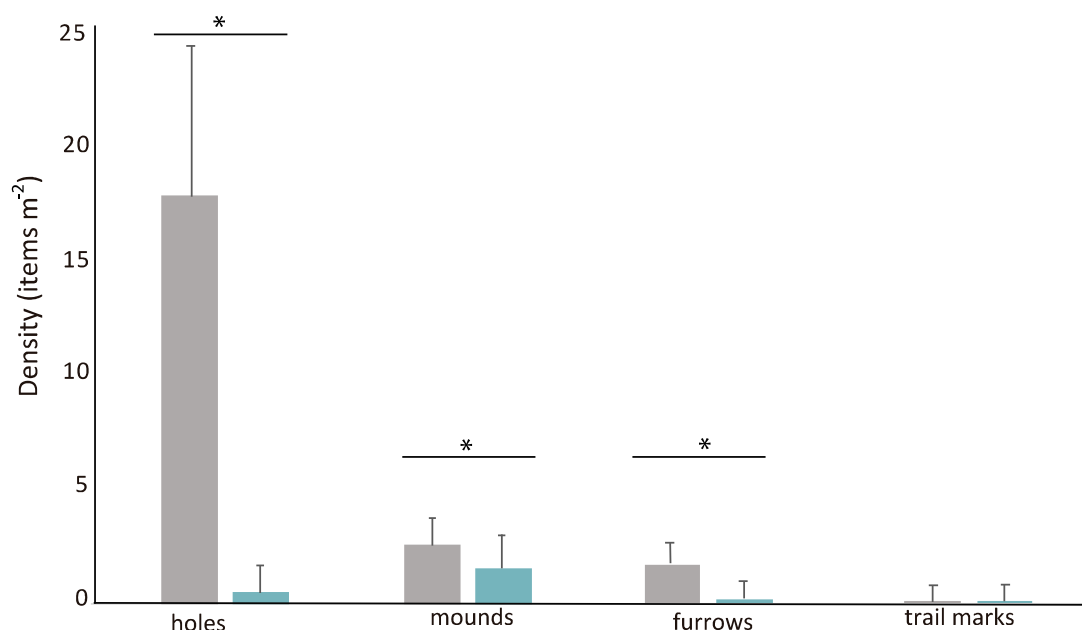


371
 372 Fig. 8. Percentage of occurrence of sessile and low motile species in untrawled (grey) and
 373 trawled (green) sampling units. untrawled sampling units: 320, trawled sampling units: 9.

374

375 3.6. Variations in habitat complexity and biodiversity in trawled vs un-trawled 376 areas

377 A total of 15730 lebensspuren items were observed, occurring on 67.5% of the
 378 sampling units. Holes were the most abundant category (90%) followed by mounds
 379 (8%), furrows (1.3%) and trail-marks (0.7%) (Fig. 9). Overall, lebensspuren densities
 380 in dives where trawled marks were absent (26 ± 16 mean \pm SD items m^{-2}) were
 381 significantly higher (Adonis, PSEUDO-F = 1778, $p < 0.001$) than those where trawling
 382 was present (1.8 ± 3.2 mean \pm SD items m^{-2}). Such pattern was observed for all
 383 lebensspuren categories with the exception of trail-marks, for which no significant
 384 differences were found (Fig. 9).



386

387

388 Fig. 9. Histograms comparing mean densities of different lebensspuren items in untrawled
 389 (grey) and trawled (green) dives. * Represents significant differences ($p < 0.001$, Adonis).
 390 Error bars represent the standard deviation. A total 527 sampling units from dives where
 391 trawling was present and 622 sampling units where trawling was absent were used.

392

393 Species richness was higher on untrawled dives, where 26 megabenthic species were
 394 observed, than in trawled dives, where 22 species were found. A similar pattern was
 395 observed for species turnover, which resulted higher in untrawled dives than in
 396 trawled ones (Fig. 10).

397

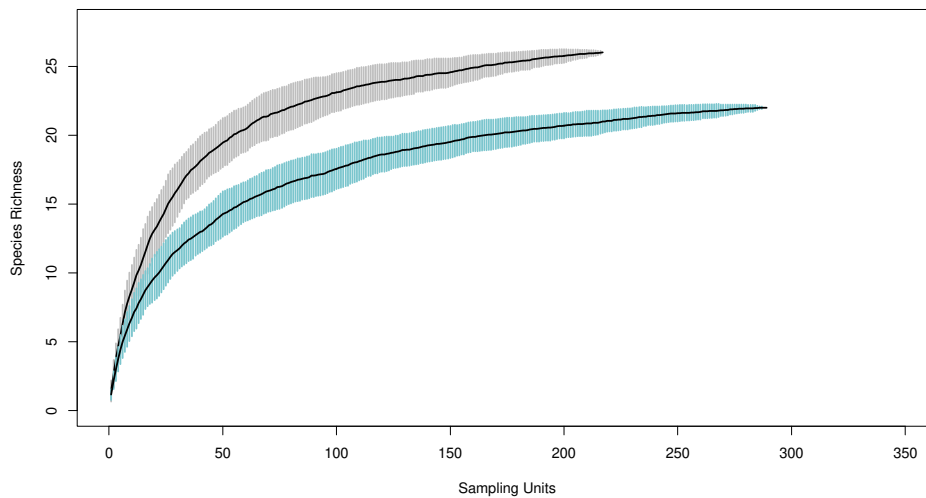


Fig. 10. Randomized species accumulation curve calculated for trawled (green) and untrawled dives (grey). Colored areas around the curve represent the confidence intervals from standard deviation. A total of 290 sampling units from dives where trawling was present and 218 sampling units from dives where trawling was absent were used for this analysis.

4. Discussion

4.1. Sessile megabenthic assemblages

The three megabenthic assemblages identified in this study (Fig. 4) were sparsely populated and dominated by passive suspension feeders (Table 1), agreeing with previous observations on the Mediterranean bathyal mud environments (Pérès, 1967; Emig, 1997; Mastrototaro et al., 2013, 2017). This contrasts with the bathyal soft sediment assemblages in more productive oceanic basins, such as those found in New Zealand or California, which received high amounts of phytodetrital material and are dominated by dense aggregations of deposit feeders (Smith and Hamilton, 1983; De Leo et al., 2010).

The two monospecific assemblages observed in this study were respectively dominated by the sea-pens *Funiculina quadrangularis* and *Kophobelemnion stelliferum* (Figs. 3c, 3d and 4), both being common inhabitants of bathyal muds of the western Mediterranean Sea (Gili and Ros, 1987; Fabri et al., 2014; De La Torriente

et al., 2018), where they have already been reported to form monospecific assemblages (Pérès, 1967; Mastrototaro et al., 2013; Pierdomenico et al., 2018). Although *F. quadrangularis* were described to form dense aggregations on Mediterranean bathyal muds (Pérès and Picard, 1964), the low densities observed in this study resemble previous observations from shelf-edge and submarine canyon environments of the western Mediterranean (Fabri et al., 2014; Grinyó et al., 2018; Pierdomenico et al., 2018). Conversely, *K. stelliferum* assemblages presented high densities than those reported by Mastrototaro et al. (2013) in Santa Maria di Leuca (Ionian Sea - Central Mediterranean). De Clippele et al. (2015) observed that both species increase diversity at a local scale. Certainly, 22% of *K. stelliferum* colonies, found in the present study, were associated with decapods and macrourid fishes, reinforcing the general consensus that this species may provide shelter and act as a feeding grounds for associated species (De Clippele et al., 2015). Conversely, *F. quadrangularis* colonies were not associated to any other megabenthic species. However, this observation might have been affected by the low number of colonies reported on this study.

The multispecific assemblage was widely represented, occurring in 99% of the occupied sampling units (Fig. 4). In this assemblage, the bamboo coral *Isidella elongata* (Fig. 3b) was the most abundant species (Table 1), forming meadows that extended over wide areas (Fig. 7b), which punctually reach densities up to 7 colonies m⁻². These density values are substantially higher than those recorded in other regions of the Mediterranean Sea (Mastrototaro et al., 2017; Pierdomenico et al., 2018; Ingrassia et al., 2019), where *I. elongata* reached maximum densities of 2.5 colonies m⁻² (Bo et al., 2015). *I. elongata* populations appeared to be in good conservation status, as no dead colonies were observed and partial necrosis was present in less

than 6% of the observed colonies. This low necrosis ratio contrasted with what has been observed in impacted *I. elongata* populations located on trawling grounds of the western Mediterranean (Pierdomenico et al., 2018). *I. elongata* has a major ecological role in bathyal environments of the Mediterranean Sea, providing essential habitat for several ichthyic and decapod species (Cartes et al., 2013; Mastrototaro et al., 2017), representing a secondary biological hard substratum, elevated from the surrounding sediments (Mastrototaro et al., 2017). On this regard, 47% of *I. elongata* colonies where epiphyted by the crinoid *Leptometra phalangium* (Fig. 3b), and to a lesser extent, by the decapod *Anamathia rissoana*. More than 90% of *L. phalangium* individuals occurred on top of *I. elongata* colonies, generally hosting 1 crinoid (1.7 ± 1.0 ind./colony mean \pm SD), although largest colonies (>20 cm height) could host up to 5 crinoids. Since *L. phalangium* is a suspension feeder, it is likely that these crinoids are using *I. elongata* colonies as a physical support allowing to be detached from the seafloor and gaining exposure to more intense and food-rich currents, favoring their feeding rates. A similar functional relationship has been observed in the bathyal muds of the Balearic archipelago between *I. elongata* and the crinoid *Antedon mediterraneum* (Mastrototaro et al., 2017).

Among the other uprising sessile fauna that integrated the multispecific assemblage, we encountered the Demosponge *Thenia muricata* and the Cerianthids *Arachnanthus oligopodus* and *Cerianthus membranaceus* (Figs. 3a, e and f). *Thenia muricata* has been described as a typical inhabitant of Mediterranean bathyal muds (Vacelet, 1969; Maldonado et al., 2015). In the study area, this species presented a sparse distribution and occurred in low densities, in accordance with other studies from the western Mediterranean (Santín et al., 2018). Conversely, cerianthids were amongst the most abundant species (38% of all sessile fauna), contrasting with previous observations

depicting them as a rare group in Mediterranean bathyal muds (Cartes et al., 2009; Mastrototaro et al., 2013). Up to date, information regarding megabenthic assemblages in deep sedimentary seafloor, mostly derives from experimental bottom trawls or benthic sledges (e.g. Gili and Ros, 1987; Pansini and Musso, 1991; Maynou and Cartes, 2012; Mastrototaro et al., 2013). Although these gears have provided a great amount of occurrence data, they cannot be considered trustworthy from a quantitative point of view, often providing weak information about the abundance and distribution of sessile species (Chimienti et al., 2018). This lack of reliability is magnified for those species that have soft bodies and burrowing or withdrawing behaviors (Durden et al., 2015; Chimienti et al., 2018). Therefore, since cerianthids rapidly and fully retract into sediments, it is likely that the abundance of this groups in Mediterranean bathyal muds has been widely underestimated.

The asteroid *Hymenodiscus coronata* and the holothurian *Mesothuria intestinalis* (Figs. 3g and h), typical inhabitants of Mediterranean abyssal muds (Mecho et al., 2018), occurred as isolated individuals, being the most sparsely distributed component of the multispecific assemblage (Figs. 7a and b). In open slope environments, both species have generally presented low abundances (Mecho et al., 2018), although *M. intestinalis* has been observed to form massive aggregations coinciding with increments of labile organic matter (Cartes et al., 2009).

The multispecific assemblage occurred on untrawled sediments (95% sampling units), trawled sediments (3.5% sampling units) and on pockmark fields (0.5% sampling units) (Figs. 4, 7b and 7c). Although active pockmarks can potentially influence species distribution and abundance due to the influence of fluid seepage on water chemistry (Zeppilli et al., 2012), in the study area no chemical nor physical changes were observed through the water column (gas seepage) or surrounding sediments

(carbonate crusts) in correspondence to these features. This suggests that inactive pockmarks in this area do not exert any direct influence on megabenthic fauna distribution.

No environmental parameters are able to explain the segregation among assemblages, which could be identified from the video analyses. However, according to Peres and Picard (1964), this segregation may derive from substrate fluidity. While, *F. quadrangularis* and *K. stelliferum* are associated to viscous muds *I. elongata* is associated to compact muds (Peres and Picard, 1964). Therefore, further studies are warranted to assess potential differences in the physical, geological and geochemical characteristics of the sediments (e.g. grain-size, porosity, water content, composition, and organic content) to further understand which natural processes contribute to drive the distribution of these assemblages.

4.2. Marine litter

Litter observations in this study resemble what has already been observed in other deep Mediterranean environments, where plastic represents the most abundant component (Cau et al., 2019b; Pierdomenico et al., 2019a; Gerigny et al., 2019). Most marine litter items occurred in low densities, despite higher concentrations within pockmarks, which hosted plastic bags and fishing gears (Figs. 5c and f). In line with previous observations, pockmarks may act as a sink (Taviani et al., 2013; Mecho et al., 2018), constraining bottom-currents around them and inducing the accumulation of lighter litter, such as plastic bags or certain fishing-related debris (i.e. long-line fragments). Although the mechanisms behind the accumulation of large and heavier debris, such as steel reinforced rope (Fig. 5c), remain largely unknown, it is reasonable to hypothesize that heavy items mostly derive from ships' discard. A

maritime-based origin for heavy litter in open-slope environments has been suggested for other areas of the Mediterranean and North-Atlantic Ocean (Ramírez-Llodra et al., 2013; Pham et al., 2014).

It is worth mentioning, that over 25% of global traffic of trading ships use the north Alboran Sea (around 60000 transits per year), making it the world's second busiest sea route (IUCN, 2007). For navigation safety reasons, the International Maritime Organization (IMO) established two mandatory routes named "traffic separation schemes" that divide the northern Alboran Sea. One of this traffic separation schemes, is coincident with the Carboneras and the North-South fault systems (Fig. 1). This could explain the contrasting situation observed between dives performed in the northern Alboran Sea and the Al Idrissi dive where no marine litter items were observed (Table. 3). However, this pattern should be carefully considered based on the small sampling effort made on the south Alboran Sea.

Finally, no interactions between marine litter and motile or sessile fauna were observed in the ROV dives, in contrast with what has been observed in regions with higher litter densities (Pierdomenico et al., 2019a; 2019b).

4.3. The impact of bottom trawling

Despite the low sampling effort of our study (six ROV dives covering 5521 m) our results clearly show that bottom trawling affected sessile megabenthic species distribution and abundance, and caused a reduction in habitat complexity and beta diversity (Figs. 9 and 10). *I. elongata*, *T. muricata*, *F. quadrangularis* and *K. stelliferum* were restricted to untrawled sampling units (Fig. 8). These species are extremely sensitive to bottom trawling (Massutí and Reñones 2005; Mastrototaro et al., 2013; Pierdomenico et al., 2018) and used to be common components of the

543 Mediterranean trawling by-catch (Relini et al., 1986; Gili and Ros, 1987; Pansini and
544 Musso, 1991). In fact, in ROV dives where trawl marks were present they presented
545 significantly lower densities (0.5 ± 0.1 ind. m^{-2} mean \pm SD; Adonis, PSEUDO-F=15.28;
546 $p < 0.0001$) than those where trawl marks were absent (0.87 ± 0.73 ind. m^{-2} mean \pm SD).
547 These species populations have been widely decimated in the last decades, and are
548 now mostly restricted to areas inaccessible to bottom trawling (Mastrototaro et al.,
549 2013; 2017; Bo et al., 2015; Santín et al., 2018).

550 In trawled sampling units, occupancy was rather low and was restricted to cerianthids
551 and echinoderms (Fig. 8). Cerianthids might be able to withstand bottom trawling
552 through their ability to rapidly retract within tubes that are rooted tens of centimeters
553 below the sediment surface (Picton and Manuel, 1985). Echinoderms in deep
554 Mediterranean environments are extremely susceptible to the destructive effects of
555 bottom trawling, being unable to escape or withstand them (Smith et al., 2000; Cartes
556 et al., 2009). Thus, the presence of *H. coronata* in trawled sampling units (Fig. 8)
557 might be explained by its motile capacity, which may allow re-occupancy of sampling
558 units after the passage of trawl gears. However, several *H. coronata* individuals
559 displayed a peculiar behavior in trawled sampling units. Individuals were observed on
560 the edge of trawl marks extending their arms into the water column (Fig. 5f). In this
561 slightly uplifted position, suspension feeders may be able to reach water layers
562 exposed to more intense hydrodynamics, improving their feeding rates (Carlier et al.,
563 2009).

564 Lebensspuren density and megabenthic diversity were higher in untrawled dives than
565 in trawled ones (Figs. 9 and 10), resembling similar patterns observed in other bathyal
566 Mediterranean environments (Mastrototaro et al., 2017). As nets, trawl-doors and
567 chains are dragged on the seafloor, sedimentary structures are flattened and

bioturbator and habitat-forming species are removed or damaged (Auster et al., 1996; Olsgard et al., 2008; Pierdomenico et al., 2018), resulting in a reduction of habitat complexity and, therefore, local biodiversity (Probert et al., 1997). Indeed, bottom trawling can greatly alter benthic ecosystem functioning and productivity (Jennings et al., 2001), potentially having crucial long-term consequences for local fisheries (Victorero et al., 2018). Considering the low recuperation rates of most species characterizing the observed assemblages (Maynou and Cartes 2012), our study's findings arise grave concern on the conservation status of these vulnerable benthic assemblages in the deep muddy bottoms of the Alboran Sea.

5. Conclusions

- Three megabenthic assemblages dominated by *Funiculina quadrangularis*, *Kophobelemnion stelliferum* and *Isidella elongata* respectively, were found in bathyal sedimentary environments of the Alboran Sea, within a depth range of 500-860 m.
- *I. elongata* and *K. stelliferum* were associated to motile taxa suggesting that these species may provide shelter and feeding grounds for associated species.
- Marine litter occurred in low densities. Plastic and fishing gears were the most abundant component of marine litter. Local circulation of bottom currents may force the accumulation of marine litter within pockmark depressions.
- Our results yield clear evidences that bottom trawling decreased the abundance of habitat forming species and lebensspuren items, reducing habitat complexity and negatively affecting biodiversity, however more extensive studies would be advisable to confirm this trend.

Acknowledgements

The data for this study were collected during the Spanish national project SHAKE (CGL2011-3005-C02-02). We acknowledge the EU Eurofleets-2 Project, which provided the ROV Max Rover from the Hellenic Centre for Marine Research (Greece) during the SHAKE cruise (IRIS project - Embarked Equipment 2013 Call EF2-EE-003. GA 312762), Finally, we gratefully acknowledge all the participants on the SHAKE cruise and the crew on board of the R/V “Sarmiento de Gamboa” and Professor Pablo J. Lopez from the University of Seville for his help to identify several megabenthic species.

Author contribution

Jordi Grinyó: Conceptualization, methodology, data curation, formal analysis, writing - original draft; Writing - review & editing.

Claudio Lo Iacono: Conceptualization, methodology, writing - original draft; writing - review & editing.

Martina Pierdomenico: Conceptualization, methodology, writing - review & editing.

Suzanne Conlon: Methodology, data curation.

Guillem Corbera: Visualization, writing - review & editing.

Eulàlia Gràcia: Conceptualization, Writing - review & editing, Resources, Funding acquisition.

References

Aguzzi, J., Chatzievangelou, D., Marini, S., Fanelli, E., Danovaro, R., Flögel, S., Lebris, N., Juanes, F., De Leo, F.C., Del Rio, J., Thomsen, L., Costa, C., Riccobene, G., Tamburini, C., Lefevre, D., Gojak, C., Poulain, P.-M., Favali, P., Griffa, A., Purser, A., Cline, D., Edgington, D., Navarro, J., Stefanni, S., D'Hondt, S., Priede, I.G., Rountree, R., Company, J.B., 2019. New High-Tech Flexible Networks for the Monitoring of Deep-Sea Ecosystems. *Environ. Sci. Technol.* 53, 6616–6631. doi:10.1021/acs.est.9b00409

Althaus, F., Williams, A., Schlacher, T.A., Kloser, R.J., Green, M.A., Barker, B.A., Bax, N.J., Brodie, P., Schlacher-Hoenlinger, M.A., 2009. Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. *Mar. Ecol. Prog. Ser.* 397, 279–294. doi:10.3354/meps08248

Auster, P.J., Malatesta, R.J., Langton, R.W., Watting, L., Valentine, P.C., Donaldson, C.L.S., Langton, E.W., Shepard, A.N., Babb, W.G., 1996. The impacts of mobile fishing gear on seafloor habitats in the gulf of Maine (Northwest Atlantic): Implications for conservation of fish populations. *Rev. Fish. Sci.* 4, 185–202.

doi:10.1080/10641269609388584

- Benoist, N.M.A., Bett, B.J., Morris, K.J., Ruhl, H.A., 2019. A generalised volumetric method to estimate the biomass of photographically surveyed benthic megafauna. *Prog. Oceanogr.* 178, 102188. doi:10.1016/j.pocean.2019.102188
- Bergmann, M., Gutow, L., Klages, M., 2015. Marine Anthropogenic Litter. *Springer*. doi:10.1007/978-3-319-16510-3_15
- Bo, M., Bavestrello, G., Angiolillo, M., Calcagnile, L., Canese, S., Cannas, R., Cau, Alessandro, Elia, M.D., Oriano, F.D., Follesa, M.C., Quarta, G., Cau, A., 2015. Persistence of Pristine Deep-Sea Coral Gardens in the Mediterranean Sea (SW Sardinia). *PLoS One* 1–21. doi:10.1371/journal.pone.0119393
- Bo, M., Coppari, M., Betti, F., Massa, F., Gay, G., Cattaneo-Vietti, R., Bavestrello, G., 2020. Unveiling the deep biodiversity of the Janua Seamount (Ligurian Sea): first Mediterranean sighting of the rare Atlantic bamboo coral *Chelidonisis aurantiaca* Studer, 1890. *Deep Sea Res. Part I Oceanogr. Res. Pap.*, 156, 103186. doi:10.1016/j.dsr.2019.103186
- Bouchet, P., Taviani, M., 1992. The Mediterranean deep-sea fauna: pseudopopulations of Atlantic species? *Deep Sea Res. Part I Oceanogr. Res. Pap.* 39, 169–184. doi:10.1016/0198-0149(92)90103-Z
- Browne, M.A., Niven, S.J., Galloway, T.S., Rowland, S.J., Thompson, R.C., 2013. Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. *Curr. Biol.* 23, 2388–2392. doi:10.1016/j.cub.2013.10.012
- Carreras-Colom, E., Constenla, M., Soler-Membrives, A., Cartes, J.E., Baeza, M., Padrós, F., Carrassón, M., 2018. Spatial occurrence and effects of microplastic ingestion on the deep-water shrimp *Aristeus antennatus*. *Mar. Pollut. Bull.* 133, 44–52. doi:10.1016/j.marpolbul.2018.05.012
- Carlier, A., Le Guilloux, E., Olu, K., Sarrazin, J., Mastrototaro, F., Taviani, M., Clavier, J., 2009. Trophic relationships in a deep mediterranean cold-water coral bank (Santa Maria di Leuca, Ionian sea). *Mar. Ecol. Prog. Ser.* 397, 125–137. doi:10.3354/meps08361
- Cartes, J.E., Maynou, F., Fanelli, E., Romano, C., Mamouridis, V., Papiol, V., 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. *J. Sea Res.* 61, 244–257. doi:10.1016/j.seares.2009.01.005
- Cartes, J.E., Lo Iacono, C., Mamouridis, V., López-Pérez, C., Rodríguez, P., 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 Res. Part I Oceanogr. Res. Pap.* 76, 52–65. doi:10.1016/j.dsr.2013.01.006

- Cau, A., Avio, C.G., Dessì, C., Follesa, M.C., Moccia, D., Regoli, F., Pusceddu, A., 2019a. Microplastics in the crustaceans *Nephrops norvegicus* and *Aristeus antennatus*: Flagship species for deep-sea environments? *Environ. Pollut.* 255, 113107. doi:10.1016/j.envpol.2019.113107
- Cau, A., Bellodi, A., Moccia, D., Mulas, A., Porcu, C., Pusceddu, A., Follesa, M.C., 2019b. Shelf-life and labels: A cheap dating tool for seafloor macro litter? Insights from MEDITS surveys in Sardinian sea. *Mar. Pollut. Bull.* 141, 430–433. doi:10.1016/j.marpolbul.2019.03.004
- Chimienti, G., Angeletti, L., Rizzo, L., Tursi, A., Mastrototaro, F., 2018. ROV vs trawling approaches in the study of benthic communities: the case of *Pennatulula rubra* (Cnidaria: Pennatulacea). *J. Mar. Biol. Assoc. United Kingdom* 98, 1859–1869. doi:10.1017/s0025315418000851
- Clark, R.M., Bouden, A.D., Rowden, A.A., Stewart, R., 2019. Little Evidence of Benthic Community Resilience to Bottom Trawling on Seamounts After 15 Years. *Front. Environ. Sci.* 7, 1–16. doi:10.3389/fmars.2019.00063
- Corbera, G., Lo Iacono, C., Gràcia, E., Grinyó, J., Pierdomenico, M., Huvenne, V.A.I., Aguilar, R., Gili, J.M., 2019. Ecological characterisation of a Mediterranean cold-water coral reef: Cabliers Coral Mound Province (Alboran Sea, western Mediterranean). *Prog. Oceanogr.* 175, 245–262.
- De Clippele, L.H., Buhl-Mortensen, P., Buhl-Mortensen, L., 2015. Fauna associated with cold water gorgonians and sea pens. *Cont. Shelf Res.* 105, 67–78. doi:10.1016/j.csr.2015.06.007
- De La Torriente, A., Serrano, A., Fernández-Salas, L.M., García, M., Aguilar, R., 2018. Identifying epibenthic habitats on the Seco de los Olivos Seamount: species assemblages and environmental characteristics. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 135, 9–22. doi:10.1016/j.dsr.2018.03.015
- De Leo, F.C., Smith, C.R., Rowden, A.A., Bowden, D.A., Clark, M.R., 2010. Submarine canyons: Hotspots of benthic biomass and productivity in the deep sea. *Proc. R. Soc. B Biol. Sci.* 277, 2783–2792. doi:10.1098/rspb.2010.0462
- De Leo, F.C., Vetter, E.W., Smith, C.R., Rowden, A.A., McGranaghan, M., 2014. Spatial scale-dependent habitat heterogeneity influences submarine canyon macrofaunal abundance and diversity off the Main and Northwest Hawaiian Islands. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 104, 267–290. doi:10.1016/j.dsr2.2013.06.015
- De Leo, F.C., Gauthier, M., Nephin, J., Mihály, S., Juniper, S.K., 2017. Bottom trawling and oxygen minimum zone influences on continental slope benthic community structure off Vancouver Island (NE Pacific). *Deep Sea Res. Part II Top. Stud. Oceanogr.* 137, 404–419. doi:10.1016/j.dsr2.2016.11.014
- de Moura Neves, B., Edinger, E., Hillaire-Marcel, C., Saucier, E.H., France, S.C.,

- Treble, M.A., Wareham, V.E., 2015. Deep-water bamboo coral forests in a muddy Arctic environment. *Mar. Biodivers.* 45, 867–871. doi:10.1007/s12526-014-0291-7
- Directive, M.S.F., 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy. *OJEU* 164, 19–40.
- Durden, J.M., Bett, B.J., Jones, D.O.B., Huvenne, V.A.I., Ruhl, H.A., 2015. Abyssal hills – hidden source of increased habitat heterogeneity, benthic megafaunal biomass and diversity in the deep sea. *Prog. Oceanogr.* 137, 209–218. doi:10.1016/j.pocean.2015.06.006
- Emig, C.C., 1997. Bathyal zones of the Mediterranean continental slope: an attempt. *Publ. Espec. Inst. Esp. Ocean.* 23, 23–33.
- Ercilla, G., Juan, C., Hernández-Molina, F.J., Bruno, M., Estrada, F., Alonso, B., Casas, D., Farran, M., Llave, E., Gracia, M., Vázquez, J.T., D'Acremont E., Gorini, C., Palomino, D., Valencia, J., El Moumni, B., Ammar A., 2016. Significance of bottom currents in Deep-sea morphodynamics: An example from the Alboran Sea. *Mar. Geol.* 378, 157–170.
- Ercilla, G., Juan, C., Periañez, R., Alonso, B., Abril, J.M., Estrada, F., Casas, D., Vázquez, J.T., d'Acremont, E., Gorini, C., El Moumni, B., 2019. Influence of along slope processes on modern turbidite systems and canyons in the Alboran Sea (southwestern Mediterranean). *Deep Sea Res. Part I Oceanogr. Res. Pap.* 144, 1–16.
- Fabri, M.C., Pedel, L., Beuck, L., Galgani, F., Hebbeln, D., Freiwald, A., 2014. Megafauna of vulnerable marine ecosystems in French mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 104, 184–207. doi:10.1016/j.dsr2.2013.06.016
- FAO. (2009). Report of the technical consultation on international guidelines for the management of deep-sea fisheries in the high seas. 881, FAO, 98.
- Fourt M., Goujard, A., Pérez, T., Chevaldonné P., 2017. Guide de la faune profonde de la mer Méditerranée. Explorations des roches et canyons sous-marins des côtes françaises. *Museum national d'Histoire naturelle*, Paris.
- Gage, J.D., 1996. Why are there so many species in deep-sea sediments? *J. Exp. Mar. Bio. Ecol.* 200, 257–286. doi:10.1016/S0022-0981(96)02638-X
- Garcia Lafuente, J., Vargas, J. M., Sarhan, T., Plaza, F., Vargas, M., Cano, N., 1998. Observations on the currents at station N in the Straits of Gibraltar, from October 1995 to May 1996. *Informes Técnicos-Instituto Español de Oceanografía* (España).
- Gerigny, O., Brun, M., Fabri, M.C., Tomasino, C., Moigne, M. Le, Jadaud, A., Galgani, F., 2019. Sea floor litter from the continental shelf and canyons in

786 French Mediterranean Water: Distribution, typologies and trends. *Mar. Pollut.*
787 *Bull.* 146, 653–666. doi:10.1016/j.marpolbul.2019.07.030
788

789 Gerovasileiou, V., Smith, C.J., Kiparissis, S., Stamouli, C., Dounas, C., Mytilineou,
790 C., 2019. Updating the distribution status of the critically endangered bamboo
791 coral *Isidella elongata* (Esper, 1788) in the deep Eastern Mediterranean Sea.
792 *Reg. Stud. Mar. Sci.* 28, 100610. doi:10.1016/j.rsma.2019.100610
793

794 Gili, J.M., Ros, J.D., 1987. Types of bottoms and benthic cnidaria from the trawling
795 grounds (Littoral and Bathyal off Catalonia (NE Spain)). *Vie Milieu* 37, 85–98.
796

797 Gotelli, N.J., Colwell, R.K., 2001. Quantifying biodiversity: Procedures and pitfalls in
798 the measurement and comparison of species richness. *Ecol. Lett.* 4, 379–391.
799 doi:10.1046/j.1461-0248.2001.00230.x
800

801 Gràcia, E., Pallàs, R., Soto, J.I., Comas, M., Moreno, X., Masana, E., Santanach, P.,
802 Diez S., García, M., Dañobeitia, J.J., and HITS Team (2006). Active Faulting
803 offshore SE Spain (Alboran Sea): Implications for earthquake hazard assessment
804 in the Southern Iberian Margin. *Earth Planet. Sci. Lett.*, 241, 734–749.

805

806 Gràcia, E., Bartolomé, R., Lo Iacono, C., Moreno, X., Stich, D., Martínez-Díaz, J.J.,
807 Bozzano, G., Martínez-Loriente, S., Perea, H., Masana, E., Dañobeitia, J.J., Tello,
808 O., Sanz, J.L., Carreño, E., and EVENT-SHELF team (2012). Acoustic and
809 seismic imaging of the active Adra Fault (NE Alboran Sea): In search for the
810 source of the 1910 Adra Earthquake. *Natural Hazards and Earth System*
811 *Sciences*, 12, 3255–3267. doi:10.5194/nhess-12-3255-2012.
812

813 Gràcia, E., Grevemeyer, I., Bartolome, R., Perea, H., Martínez-Loriente, S., de la
814 Peña, L.G., Villasenor, A., Klinger, Y., Lo Iacono, C., Diez, S., Calahorrano, A.,
815 Camafort, M., Costa, S., d'Acremont, E., Rabaute, A., and Ranero, C.R. (2019).
816 Earthquake crisis unveils the growth of an incipient continental fault system.
817 *Nature Communications*, 10, 3482 (2019).
818

819 Gray, J.S., 2002. Species richness of marine soft sediments. *Mar. Ecol. Prog. Ser.*
820 244, 285–297. doi:10.3354/meps244285
821

822 Grinyó, J., Gori, A., Ambroso, S., Purroy, A., Calatayud, C., Dominguez-Carrió, C.,
823 Coppari, M., Lo Iacono, C., López-González, P.J., Gili, J.-M., 2016. Diversity,
824 distribution and population size structure of deep Mediterranean gorgonian
825 assemblages (Menorca Channel, Western Mediterranean Sea). *Prog. Oceanogr.*
826 145, 42–56. doi:10.1016/j.pocean.2016.05.001
827

828 Grinyó, J., Gori, A., Greenacre, M., Requena, S., Canepa, A., Lo Iacono, C.,
829 Ambroso, S., Purroy, A., Gili, J.M., 2018. Megabenthic assemblages in the
830 continental shelf edge and upper slope of the Menorca Channel, Western
831 Mediterranean Sea. *Prog. Oceanogr.* 162, 40–51.
832 doi:10.1016/j.pocean.2018.02.002
833

834 Hebbeln, D., Widenberg, C., Beuck, L., Freiwald, A., Wintersteller, P., 2009. Report

and preliminary results of RV POSEIDON Cruise POS 385 “Cold-Water Corals of the Alboran Sea (western Mediterranean Sea)”. *Berichte aus dem Fachbereich der Geowissenschaften der Univ. Bremen* 1–79.

Hiddink, J.G., Jennings, S., Sciberras, M., Szostek, C.L., Hughes, K.M., Ellis, N., Rijnsdorp, A.D., McConnaughey, R.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, C.R., Amoroso, R.O., Parma, A.M., Suuronen, P., Kaiser, M.J., 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proc. Natl. Acad. Sci. U.S.A.* 114, 8301–8306. doi:10.1073/pnas.1618858114

Ingrassia, M., Martorelli, E., Bosman, A., Chiocci, F.L., 2019. *Isidella elongata* (Cnidaria: Alcyonacea): First report in the Ventotene Basin (Pontine Islands, western Mediterranean Sea). *Reg. Stud. Mar. Sci.* 25, 100494. doi:10.1016/j.rsma.2018.100494

Jennings, S., Dinmore, T.A., Duplisea, D.E., Warr, K.J., Lancaster, J.E., 2001. Trawling disturbance can modify benthic production processes. *J. Anim. Ecol.* 70, 459–475. doi:10.1046/j.1365-2656.2001.00504.x

Jobstvagt, N., Hanley, N., Hynes, S., Kenter, J., Witte, U., 2014. Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. *Ecol. Econ.* 97, 10–19. doi:10.1016/j.ecolecon.2013.10.019

Jones, D.O.B., Bett, B.J., Tyler, P.A., 2007. Megabenthic ecology of the deep Faroe–Shetland channel: A photographic study. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 54, 1111–1128. doi:10.1016/j.dsr.2007.04.001

Juan, C., Ercilla, G., Hernández-Molina, J., Estrada, F., Alonso, B., Casas, D., García, M., Farran, M., Llave, E., Palomino, D., Vázquez, J-T., Medialdea, T., Gorini, C., D’Acremont, E., El Moumni, B., Ammar, A. 2016. Seismic evidence of current-controlled sedimentation in the Alboran Sea during the Pliocene and Quaternary: Palaeoceanographic implications. *Mar. Geol.*, 378, 292–311

Lo Iacono, C., Gràcia, E., Diez, S., Bozzano, G., Moreno, X., Dañobeitia, J., Alonso, B., 2008. Seafloor characterization and backscatter variability of the Almería Margin (Alboran Sea, SW Mediterranean) based on high-resolution acoustic data. *Mar. Geol.*, 250, 1–18.

Lo Iacono, C., Gràcia, E., Ranero, C.R., Emelianov, M., Huvenne, V.A.I., Bartolomé, R., Booth-Rea, G., Prades, J., Ambroso, S., Dominguez, C., Grinyó, J., Rubioh, E., Torrenth, J., 2014. The West Melilla cold water coral mounds, Eastern Alboran Sea: Morphological characterization and environmental context. *Deep. Res. Part II Top. Stud. Oceanogr.* 99, 316–326. doi:10.1016/j.dsr2.2013.07.006

Maldonado, M., Aguilar, R., Blanco, J., Garcia, S., Serrano, A., Punzón, A., 2015. Aggregated clumps of lithistid sponges: a singular, reef-like bathyal habitat with relevant paleontological connections. *PloS one*, 10, e0125378.

Maldonado, M., Aguilar, R., Bannister, R.J., James, J., Conway, K.W., Dayton, P.K.,

- Cristina, D., Gutt, J., Kelly, M., Kenchington, E.L.R., Leys, S.P., Shirley, A., Tendal, O.S., Rapp, H.T., Klaus, R., Young, C.M., 2015. Sponge Grounds as Key Marine Habitats: A Synthetic Review of Types, Structure, Functional roles and Conservation Concerns, in: *Animal Forest*. pp. 3–39. doi:10.1007/978-3-319-17001-5
- Massutí, E., Reñones, O., 2005. Demersal resource assemblages in the trawl fishing grounds off the Balearic Islands (western Mediterranean). *Sci. Mar.* 69, 167–181. doi:10.3989/scimar.2005.69n1167
- Mastrototaro, F., Maiorano, P., Vertino, A., Battista, D., Indennitate, A., Savini, A., Tursi, A., D’Onghia, G., 2013. A *facies* of *Kophobelemnon* (Cnidaria, Octocorallia) from Santa Maria di Leuca coral province (Mediterranean Sea). *Mar. Ecol.* 34, 313–320. doi:10.1111/maec.12017
- Mastrototaro, F., Chimienti, G., Capezzuto, F., Carlucci, R., Williams, G., 2015. First record of *Protophilum carpenteri* (Cnidaria: Octocorallia: Pennatulacea) in the Mediterranean Sea. *Ital. J. Zool.* 82, 61–68. doi:10.1080/11250003.2014.982218
- Mastrototaro, F., Chimienti, G., Acosta, J., Blanco, J., Garcia, S., Rivera, J., 2017. *Isidella elongata* (Cnidaria: Alcyonacea) *facies* in the western Mediterranean Sea: visual surveys and descriptions of its ecological role. *Eur. Zool. J.* 84, 209–225. doi:10.1080/24750263.2017.1315745
- Maynou, F., Cartes, J.E., 2012. Effects of trawling on fish and invertebrates from deep-sea coral *facies* of *Isidella elongata* in the western Mediterranean. *J. Mar. Biol. Assoc. United Kingdom* 92, 1501–1507. doi:10.1017/S0025315411001603
- Mecho, A., Aguzzi, J., De Mol, B., Lastras, G., Ramirez-Llodra, E., Bahamon, N., Company, J.B., Canals, M., 2018. Visual faunistic exploration of geomorphological human-impacted deep-sea areas of the north-western Mediterranean Sea. *J. Mar. Biol. Assoc. United Kingdom* 98, 1241–1252. doi:10.1017/S0025315417000431
- Millot, C., Taupier-Letage, I., 2005. Circulation in the Mediterranean sea. In: *The Mediterranean Sea*, pp. 29–66. Springer, Berlin, Heidelberg.
- Millot, C., 2009. Another description of the Mediterranean Sea outflow. *Prog. Oceanogr.* 82, 101–124. doi:10.1016/j.pocean.2009.04.016
- Moreno, A., Cacho, I., Canals, M., Prins, M.A., Sánchez-Goñi, M.F., Grimalt, J.O., Weltje, G.J., 2002. Saharan dust transport and high-latitude glacial climatic variability: The Alboran Sea record. *Quat. Res.* 58, 318–328. doi:10.1006/qres.2002.2383
- Mortensen, P.B., Buhl-Mortensen, L., 2005. Deep-water corals and their habitats in The Gully, a submarine canyon off Atlantic Canada. In: A. Freiwald & J.M. Roberts (Eds.) *Cold-water corals Ecosystems*. Springer, Berlin, Heidelberg. pp. 247–277.

935 Muñoz, A., Ballesteros, M., Montoya, I., Rivera, J., Acosta, J., Uchupi, E., 2008.
 936 Alborán Basin, southern Spain—part I: geomorphology. *Mar. Petrol. Geol.*, 25,
 937 59–73.
 938
 939 Oguz, T., Macias, D., Garcia-Lafuente, J., Pascual, A., Tintore, J., 2014. Fueling
 940 plankton production by a meandering frontal jet: A case study for the Alboran
 941 sea (Western Mediterranean). *PLoS One* 9. doi:10.1371/journal.pone.0111482
 942
 943 Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D.,
 944 Minchin, P. R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, Henry, M.,
 945 Stevens, H., Szoecs, E., Wagner H., 2016. vegan: Community Ecology Package.
 946 R package version 2.4–1. (<https://CRAN.R-project.org/package=vegan>).
 947
 948 Olsford, F., Schaanning, M.T., Widdicombe, S., Kendall, M.A., Austen, M.C., 2008.
 949 Effects of bottom trawling on ecosystem functioning. *J. Exp. Mar. Bio. Ecol.*
 950 366, 123–133. doi:10.1016/j.jembe.2008.07.036
 951
 952 Pansini, M., Musso, B., 1991. Sponges from trawl-exploitable bottoms of Ligurian
 953 and Tyrrhenian seas: distribution and ecology. *Mar. Ecol.* 12, 317–329.
 954 doi:10.1111/j.1439-0485.1991.tb00261.x
 955
 956 Paradis, S., Pusceddu, A., Masqué, P., Puig, P., Moccia, D., Russo, T., Lo Iacono, C.,
 957 2019. Organic matter contents and degradation in a highly trawled area during
 958 fresh particle inputs (Gulf of Castellammare, southwestern Mediterranean).
 959 *Biogeosciences* 16, 4307–4320. doi:10.5194/bg-16-4307-2019
 960
 961 Pères JM, Picard J. (1964). Nouveau manuel de bionomie benthique de la mer
 962 Méditerranée. *Rec. Trav. Stn. Mar. Endoume* 31, 1–137.
 963
 964 Pères, J., 1967. The Mediterranean benthos. *Oceanogr. Mar. Biol. an Annu. Rev.* 5,
 965 449–533.
 966
 967 Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., Canals, M.,
 968 Company, J.B., Davies, J., Duineveld, G., Galgani, F., Howell, K.L., Huvenne,
 969 V.A.I., Isidro, E., Jones, D.O.B., Lastras, G., Morato, T., Gomes-Pereira, J.N.,
 970 Purser, A., Stewart, H., Tojeira, I., Tubau, X., Van Rooij, D., Tyler, P.A., 2014.
 971 Marine litter distribution and density in European seas, from the shelves to deep
 972 basins. *PLoS One* 9. doi:10.1371/journal.pone.0095839
 973
 974 Picton, B.E., Manuel, R.L., 1985. *Arachnanthus sarsi* Carlgén, 1912: a redescription
 975 of a cerianthid anemone new to the British Isles. *Zool. J. Linnaean Soc.* 83:343–
 976 349.
 977
 978 Pierdomenico, M., Russo, T., Ambroso, S., Gori, A., Martorelli, E., D'Andrea, L.,
 979 Gili, J.M., Chiocci, F.L., 2018. Effects of trawling activity on the bamboo-coral
 980 *Isidella elongata* and the sea pen *Funiculina quadrangularis* along the Gioia
 981 Canyon (Western Mediterranean, southern Tyrrhenian Sea). *Prog. Oceanogr.*
 982 169, 214–226. doi:10.1016/j.pocan.2018.02.019

983
984 Pierdomenico, M., Casalbone, D., Chiocci, F.L., 2019a. Massive benthic litter
985 funnelled to deep sea by flash-flood generated hyperpycnal flows. *Sci. Rep.* 9, 1–
986 10. doi:10.1038/s41598-019-41816-8
987
988 Pierdomenico, M., Cardone, F., Carluccio, A., Casalbone, D., Chiocci, F., Maiorano,
989 P., D’Onghia, G., 2019b. Megafauna distribution along active submarine
990 canyons of the central Mediterranean: Relationships with environmental
991 variables. *Prog. Oceanogr.* 171, 49–69. doi:10.1016/j.pocean.2018.12.015
992
993 Price, D.M., Robert, K., Callaway, A., Lo Iacono, C., Hall, R.A., Huvenne, V.A.I.,
994 2019. Using 3D photogrammetry from ROV video to quantify cold-water coral
995 reef structural complexity and investigate its influence on biodiversity and
996 community assemblage. *Coral Reefs.* 38, 1007–1021. doi:10.1007/s00338-019-
997 01827-3
998
999 Probert, P.K., McKnight, D.G., Grove, S.L., 1997. Benthic invertebrate bycatch from
1000 a deep-water trawl fishery, Chatham Rise, New Zealand. *Aquat. Conserv.* 7, 27–
1001 40.
1002
1003 Pusceddu, A., Bianchelli, S., Martin, J., Puig, P., Palanques, A., Masque, P.,
1004 Danovaro, R., 2014. Chronic and intensive bottom trawling impairs deep-sea
1005 biodiversity and ecosystem functioning. *Proc. Natl. Acad. Sci.* 111, 8861–8866.
1006 doi:10.1073/pnas.1405454111
1007
1008 Ramírez-Llodra, E., De Mol, B., Company, J.B. Coll M., Sardà, F., 2013. Effects of
1009 natural and anthropogenic processes in the distribution of marine litter in the
1010 deep Mediterranean Sea. *Prog. Oceanogr.* 118, 273–287.
1011
1012 Relini, G., Peirano, A., Tunesi, L., 1986. Osservazioni sulle comunità dei fondi
1013 strascicabili del Mar Ligure Centro-Orientale. *Boll. degli Ist. di Biol. della R.*
1014 *Univ. di Genova* 52, 139–161.
1015
1016 Renault, L., Oguz, T., Pascual, A., Vizoso, G., Tintore, J., 2012. Surface circulation in
1017 the Alborn Sea (western Mediterranean) inferred from remotely sensed data. *J.*
1018 *Geophys. Res. Ocean.* 117, 1–11. doi:10.1029/2011JC007659
1019
1020 Robert, K., Juniper, S.K., 2012. Surface-sediment bioturbation quantified with
1021 cameras on the NEPTUNE Canada cabled observatory. *Mar. Ecol. Prog. Ser.*
1022 453, 137–149. doi:10.3354/meps09623
1023
1024 Robles, R., Berraho, A., Caminas, J. A., Najih, M., Alcántara, A., Simard, F. 2007.
1025 Conservation et développement durable de la mer d’Alboran: éléments
1026 stratégiques pour sa gestion future. *Centre de Coopération pour la Méditerranée,*
1027 *Union Mondiale pour la Nature (UICN)*, 66.
1028
1029 Rochman, C.M., Hoh, E., Kurobe, T., Teh, S.J., 2013. Ingested plastic transfers
1030 hazardous chemicals to fish and induces hepatic stress. *Sci. Rep.* 3, 1–7.
1031 doi:10.1038/srep03263
1032

- Santín, A., Grinyó, J., Ambroso, S., Uriz, M.J., Gori, A., Dominguez-Carrió, C., Gili, J.-M., 2018. Sponge assemblages on the deep Mediterranean continental shelf and slope (Menorca Channel, Western Mediterranean Sea). *Deep Sea Res. Part I Oceanogr. Res. Pap.* 131, 75–86. doi:<https://doi.org/10.1016/j.dsr.2017.11.003>
- Sardà, F., Calafat, A., Flexas, M.M., Tselepides, A., Canals, M., Espino, M., Tursi, A., 2004. An introduction to Mediterranean deep-sea biology. *Sci. Mar.* 68, 7–38. doi:10.3989/scimar.2004.68s37
- Sarhan, T., Lafuente, J.G., Vargas, M., Vargas, J.M., Plaza, F., 2000. Upwelling mechanisms in the northwestern Alboran Sea. *J. Mar. Syst.* 23, 317–331.
- Smith, C.J., Papadopoulou, K.N., Diliberto, S., 2000. Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. *ICES J. Mar. Sci.* 57, 1340–1351. doi:10.1006/jmsc.2000.0927
- Smith, C.R., Hamilton, S.C 1983. Epibenthic megafauna of a bathyal basin off southern California: patterns of abundance, biomass and dispersion. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 30, 907–928.
- Soltwedel, T., Jaekisch, N., Ritter, N., Hasemann, C., Bergmann, M., Klages, M., 2009. Bathymetric patterns of megafaunal assemblages from the arctic deep-sea observatory HAUSGARTEN. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 56, 1856–1872.
- Spengler, A., Costa, M.F., 2008. Methods applied in studies of benthic marine debris. *Mar. Pollut. Bull.* 56, 226–230.
- Taviani, M., Angeletti, L., Ceregato, A., Foglini, F., Frogliia, C., Trincardi, F., 2013. The Gela Basin pockmark field in the strait of Sicily (Mediterranean Sea): Chemosymbiotic faunal and carbonate signatures of postglacial to modern cold seepage. *Biogeosciences* 10, 4653–4671. doi:10.5194/bg-10-4653-2013
- United Nations, (2007). Resolution 61/105 adopted by the General Assembly on Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. Resolution 61/105 adopted by the General Assembly 61/105, ONU, 23.
- Vacelet, J., 1969. Eponges de la Roche du Large et de l'étage bathyal de Méditerranée (Récoltes de la soucoupe plongeante Cousteau et dragages). *Mem. du Museum Natl. d'Histoire Nat.* 59, 145–219.
- Vanreusel, A., Hilario, A., Ribeiro, P.A., Menot, L., Arbizu, P.M., 2016. Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. *Sci. Rep.* 6, 1–6. doi:10.1038/srep26808

1082 Vargas-Yáñez, M., Zunino, P., Benali, A., Delpy, M., Pastre, F., Moya, F., García-
1083 Martínez, M.C., Tel, E., 2010. How much is the western Mediterranean really
1084 warming and salting. *J. Geophys. Res.* 115, 1–12. doi: 10.1029/2009JC005816.
1085

1086 Victorero, L., Robert, K., Robinson, L.F., Taylor, M.L., Huvenne, V.A.I., 2018.
1087 Species replacement dominates megabenthos beta diversity in a remote seamount
1088 setting. *Sci. Rep.* 8, 1–11. doi:10.1038/s41598-018-22296-8
1089

1090 Watling, L., 2013. Deep-sea trawling must be banned. *Nature* 501, 7.
1091 doi:10.1038/501007a
1092

1093 Wynn, R.B., Huvenne, V.A.I., Le Bas, T.P., Murton, B.J., Connelly, D.P., Bett, B.J.,
1094 Ruhl, H.A., Morris, K.J., Peakall, J., Parsons, D.R., Sumner, E.J., Darby, S.E.,
1095 Dorrell, R.M., Hunt, J.E., 2014. Autonomous Underwater Vehicles (AUVs):
1096 Their past, present and future contributions to the advancement of marine
1097 geoscience. *Mar. Geol.* 352, 451–468. doi:10.1016/j.margeo.2014.03.012
1098

1099 Zeppilli, D., Canals, M., Danovaro, R., 2012. Pockmarks enhance deep-sea benthic
1100 biodiversity: A case study in the western Mediterranean Sea. *Divers. Distrib.* 18,
1101 832–846. doi:10.1111/j.1472-4642.2011.00859.x