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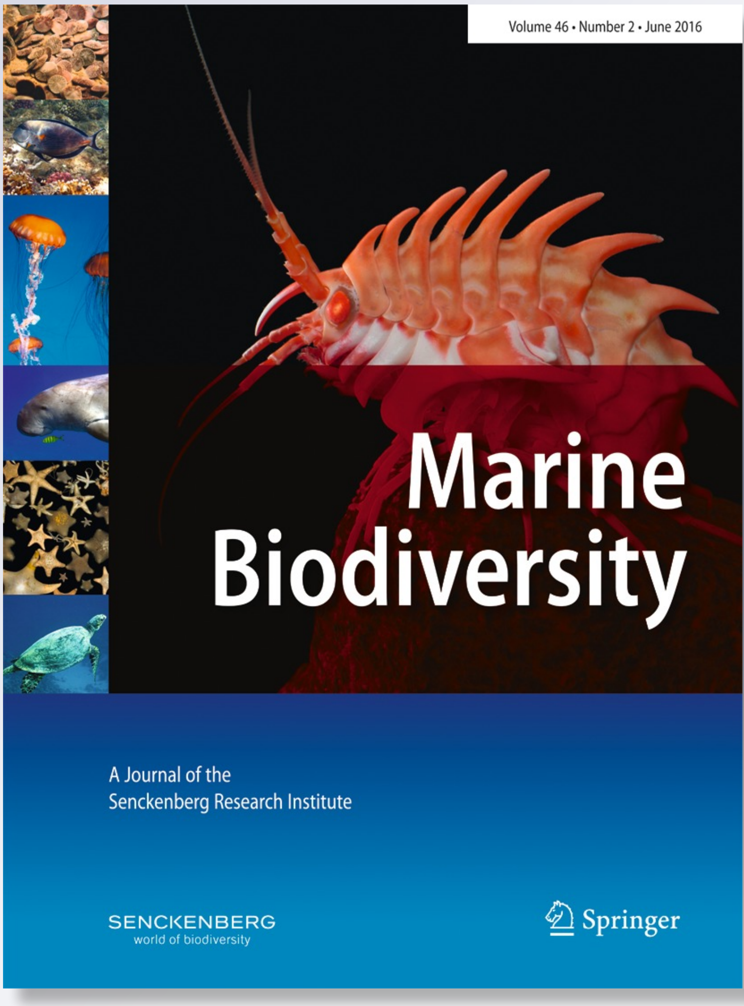

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SHORT COMMUNICATION

From chemosynthesis-based communities to cold-water corals: Vulnerable deep-sea habitats of the Gulf of Cádiz

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Abstract The Gulf of Cádiz (GoC) represents an area of ecological importance within the northeastern Atlantic Ocean due to the presence of Mediterranean and Atlantic water masses, a heterogeneous seafloor and a biological confluence. Nevertheless, information on the presence of vulnerable deep-sea habitats is still very scarce and it is of importance for further habitat monitoring within the context of the Habitats and Marine Strategy Framework Directives and for improving conservation and resource extraction management. From 2010 to 2012, fluid migration and emission related edifices (e.g., mud volcanoes, diapirs) from the Spanish continental margin of the GoC have been explored using a remotely operated vehicle (ROV; Liropus 2000) and an underwater camera sled (UCS; APHIA 2012) as well as several devices for collecting sediment and fauna. Different vulnerable deep-sea habitats have been observed, including anoxic bottoms with bacterial mats, sea-pen communities, sponge aggregations, antipatharian and gorgonian communities and also cold-water coral banks. Some of these habitats are included in conservation lists of the habitat directive and in international conventions (OSPAR, RAC/SPA), however some of them are located in areas of the GoC that are exposed to intense trawling. The diversity of habitats detected in the Spanish continental margin of the GoC highlights the importance of seepage related edifices as inducers of seabed and habitat heterogeneity in deep-sea areas.

Keywords Scleractinians · Bacterial mats · Cold seep · Vulnerable habitats · Gulf of Cádiz

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Introduction

Mud volcanoes (MVs) are seafloor edifices that result from the release of mud, hydrocarbon and fluids in gas-rich areas over pressured sediments (Dimitrov 2002; Levin 2005; Gontharet et al. 2007). In general, MVs may contain heterogeneous types of substrates, from mud breccia sediments (clastic sedimentary fragments of rocks embedded in a mud matrix extruded by mud volcanoes), that are enriched in methane and sulphide, to hard bottoms composed of authigenic carbonates (e.g., slabs, chimneys) that are formed from the anaerobic oxidation of methane by archaeobacteria (Martín-Puertas et al. 2006; León et al. 2007; Magalhaes et al. 2012). These hard structures increase the complexity of the anoxic muddy bottoms by promoting the settlement of hard bottom species that may colonize sensitive habitats but do not occur in adjacent soft bottoms (Cordes et al. 2010; Rueda et al. 2012a). An interesting feature of MVs is their development through time which, according to León et al. (2007), generally starts with an active mud flow extrusion, including mud-breccia and building of the cone-shaped volcanic edifice, followed by a moderate to low seepage (collapse of the edifice and formation of extensive hydrocarbon-derived authigenic carbonates) and with latent conditions (formation of hard grounds and colonisation by heterotrophic organisms), with the possibility of re-activation of a mud flow extrusion. The geological history of each MV and the contemporary local environmental factors may influence the habitats and the benthic communities that occur within them (Levin 2005; Cunha et al. 2013). The Gulf of Cádiz (GoC) represents an extensive seepage area, with more than 50 MVs identified so far, supporting a broad diversity of chemosymbiotic and heterotrophic organisms, and, therefore, forming a biodiversity hotspot (Cunha et al. 2013). Nevertheless, the available information on habitat types and their biological components is still very scarce for some areas of the GoC, such as those of the Spanish continental margin (Rueda et al. 2012a, b; González-García et al. 2012) in comparison to the large amount of information for MVs of the Moroccan Margin (Cunha et al. 2013 and references therein). Due to the high variability observed worldwide in cold seeps (e.g., MVs, pockmarks) in relation to depth, seepage activity, substratum types or hydrodynamics (Levin 2005), information on MVs from different sectors of the GoC is still needed for improving the current knowledge on the typology and distribution of habitats occurring on each MV located at different depths, affected by different water masses and displaying different fluid emissions. Some of the habitats occurring in MVs may also deserve protection and monitoring under the current European directives (e.g., Habitat and Marine Strategy Framework Directives) or conventions for the protection of the marine environment (e.g., OSPAR:).

Due to the scarcity of information on deep-sea bottoms of the Spanish continental margin of the GoC, the project INDEMARES-CHICA (LIFE +) explored fifteen edifices formed by fluid migration and/or emission (Albolote, Gazul, Cristóbal Colón, Juan Sebastián Elcano, Anastasya, Enano, Tarsis, Pipoca, Magallanes, Enmedio, Chica, Hespérides, Almazán, St. Petersburg and Aveiro) and some of their adjacent bottoms between 300–1100 m water depth, covering the investigation of some environmental and biological aspects. The main aims of the present study are to document the occurrence of vulnerable marine habitats of the GoC, adding notes on their common biota and environmental scenarios. The present study reports the presence of different vulnerable deep-sea habitats that are not so common within the European continental margins, and are located in areas of the GoC that are exposed to extraction of marine resources (e.g., trawling fisheries), and therefore require urgent conservation strategies according to the current European Union (EU) directives and conventions.

Materials and methods

The fifteen explored edifices are located at the upper and middle slope of the Spanish continental margin of the GoC, including MVs, diapirs and diapir/MV complexes, as well as other seafloor features located nearby such as collapse depressions, carbonate mounds and contourite deposits (Fig. 1). Most of these edifices have been identified from multibeam data gathered during previous sampling expeditions and projects (e.g., TASYO, MVSEIS), but they have been explored with more precision during expeditions of the project INDEMARES-CHICA (LIFE +). The bathymetrical and geophysical data were acquired using a multibeam swath-bathymetry system (EM 300, EM710) and a topographic parametric sonar (TOPAS PS18) sub-bottom profiler. From these data, backscatter signals were obtained in order to create a map of seabed image reflectivity using Caris v6.1 and ArcGis softwares. After that, the edifices and adjacent seafloor were explored with the remotely operated vehicle (ROV) LIROPUS 2000 (model Super Mohawk II) (n=7 transects) and an underwater camera sled (UCS; APHIA 2012; n=32 transects) (Fig. 1, Table 1) for obtaining zenithal and also transversal images (UCS only) of the seafloor. Underwater imagery was geo-referenced by means of a transponder (HiPAP 500) attached to the ROV and UCS that conveyed the positions of the ROV and UCS in relation to the research vessel along the transects using "super short base line and short base line" principles. The vessel was also equipped with a Kongsberg K-Pos dynamic positioning (DP) system to keep the vessel within a specified position, and heading limits which offers precise navigation for exploring small and specific areas such as the summits of small MVs. Underwater images were captured between 0.5 and 2.5 m from the seafloor, during 1–3 hours (ROV) and 0.6-1 hour (UCS) per transect. Mean explored distances were between 223 and 1050 m for ROV transects and between 80 and 397 m for UCS transects. Explored distances for each transect are given in Table 1. Two 532-nm laser beams mounted on the UCS and ROV and separated by 40 cm and 10 cm, respectively, were used for scaling underwater images. All video transects were then processed with MAGIX Video deluxe 17 Premium and qualitative annotations on habitat types, and species were taken along each transect and geo-referenced. Single frames were subsequently extracted from the video records and processed with Image J for obtaining measurements of some biological (e.g., densities, colony size, coverage) and geological features (size of authigenic carbonates, coral rubble density) observed in each transect. Species were identified from underwater images, from beam-trawl (BT) samples collected in those areas (sampling area ca. 2000 m^2 and targeting epifaunal and demersal organisms from sedimentary and non-sedimentary habitats) and from box cores which also allowed the characterisation of the sediments (sampling area ca. 0.09 m^2 and targeting epifaunal and infaunal organisms from sedimentary habitats). Areas of certain habitats (e.g., cold-water coral banks) were estimated by spatially coupling results of underwater transects, faunistic samples and R/V Ramón Margalef, respectively.

Near-bottom seawater measurements (temperature, salinity, current speed) were carried out in February 2011 using a SeaBird SBE25 CTD profiler (temperature and salinity) and a

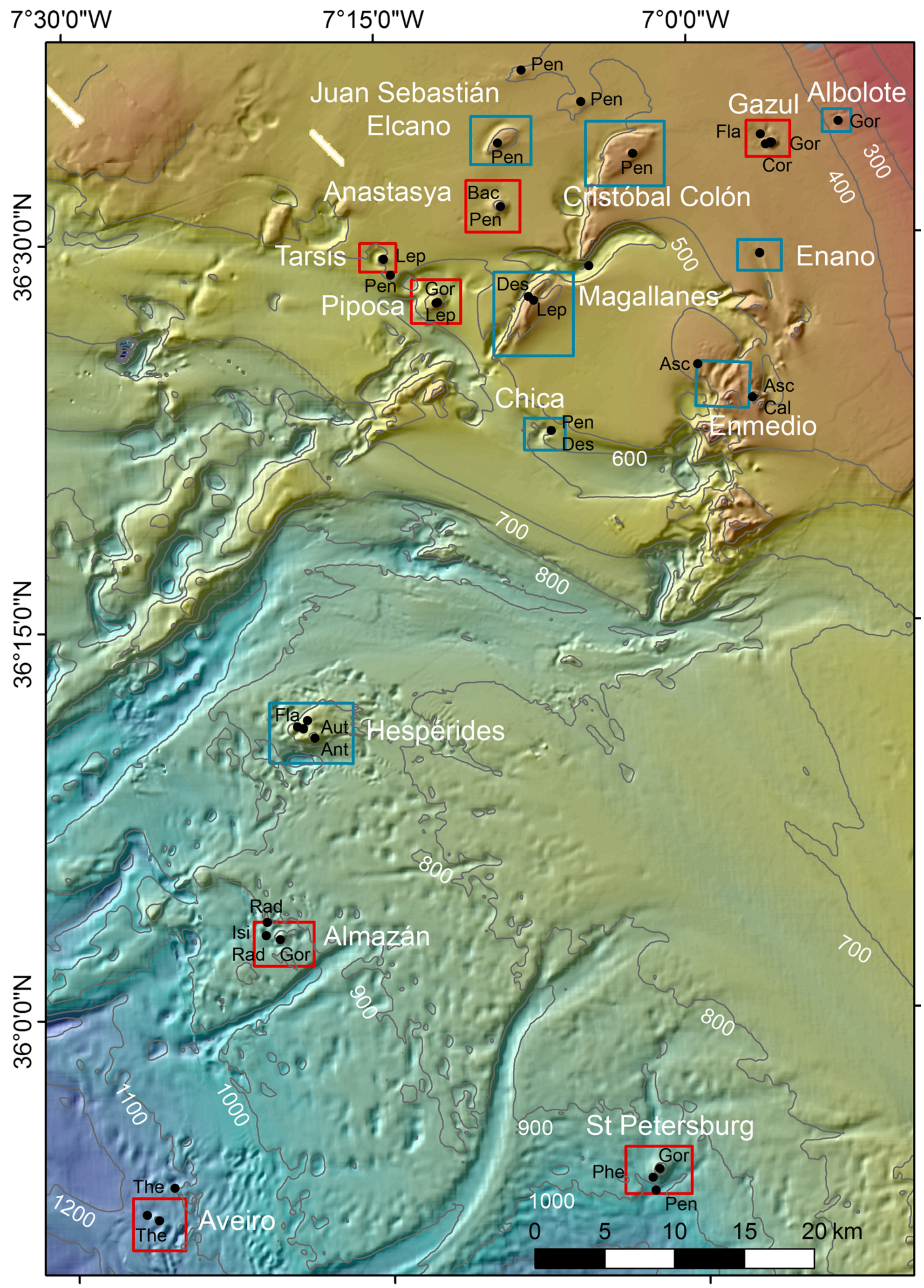

Fig. 1 Location map of seafloor edifices related to fluid migration and venting in the Spanish continental margin of the Gulf of Cádiz, and areas where underwater images have been taken (black circles), with notes on the predominant habitat found on them. Mud volcanoes: Red frames; Diapirs or MV/diapir complexes: Blue frames. Habitat codes are indicated in Table 2

WHS 300 kHz/T-RDI LADCP (lowered acoustic doppler current profiler; near-bottom current speed) in each of the areas where habitats from this study occur. Trawling activity information was obtained from trawlers equipped with vessel monitoring systems (VMSs) during 2011. Trawling location data was analyzed with R software using the VMStools package and was subsequently spatially geo-referenced using ArcMap 10. The trawling activity in each studied area was then ranked as low (less than 5 records of trawlers during 2011), medium (between 5 and 30 records) and high (more than 30 records).

Results and discussion

The studied MV field is mainly exposed to the highly saline (36.1-36.9 psu) and warm (ca. 13 °C) Mediterranean Outflow Water (MOW) that forms a strong bottom current flowing towards the W and NW. The MOW usually runs in the GoC at depths from 450–500 m to 1200 m, and it is intercalated below the North Atlantic Central Water (NACW; 35.6-36.5 psu and 11-17 °C) and above the less saline (34.9-35.2 psu) and cold (3-8 °C) North Atlantic Deep Water (NADW)

Table 1 Location and details of transects of underwater imagery performed with the ROV LIROPUS 2000 and UCS APHIA 2012 in the study area

Transect	Date	Latitude start	Longitude start	Depth start	Latitude end	Longitude end	Depth end	Length transect (m)	Edifice
UCS01	10/04/2012	36° 33 33 N	6° 56 3.3 W	362.0	36° 33 33 N	6° 56 3.3 W	395.0	319.2	Gazul
UCS02	16/04/2012	36° 34 20.4 N	6° 52 43.9 W	341.1	36° 34 21 N	6° 52 46.7 W	352.2	80.2	Albolote
UCS03	16/04/2012	36° 35 15.9 N	7° 5 2.3 W	471.7	36° 35 16.7 N	7° 5 7.2 W	474.7	155.0	La Pepa
UCS04	16/04/2012	36° 36 30.8 N	7° 7 51.4 W	473.7	36° 36 33.8 N	7° 7 59.4 W	484.9	221.1	Bicentenario
UCS05	17/04/2012	36° 29 17.4 N	7° 14 39.8 W	503.0	36° 29 20.8 N	7° 14 43.7 W	548.5	133.3	Tarsis
UCS06	17/04/2012	36° 28 37.2 N	7° 14 17.5 W	590.1	36° 28 45.9 N	7° 14 25.5 W	595.4	396.9	Tarsis adjacent
UCS07	17/04/2012	36° 28 56.5 N	7° 4 48 W	685.0	36° 28 53.3 N	7° 4 54.3 W	690.0	184.6	Gusano Channel
UCS08	18/04/2012	36° 22 32.4 N	7° 6 45.4 W	667.1	36° 22 34.4 N	7° 6 49.9 W	637.7	128.4	Chica
UCS09	18/04/2012	36° 24 56.7 N	6° 59 42.7 W	408.4	36° 25 4.3 N	6° 59 41.2 W	430.5	265.4	Enmedio
UCS10	18/04/2012	36° 29 12.8 N	6° 56 36.3 W	463.0	36° 29 19.2 N	6° 56 41.8 W	460.1	358.5	Enano
UCS11	19/04/2012	36° 27 42.6 N	7° 7 48.7 W	456.3	36° 27 48.9 N	7° 7 45.1 W	474.6	232.2	Magallanes
UCS12	19/04/2012	36° 27 33.8 N	7° 7 35.1 W	397.6	36° 27 40.3 N	7° 7 29.4 W	417.2	289.5	Magallanes
UCS13	20/04/2012	36° 11 17.6 N	7° 19 8.8 W	754.1	36° 11 13.1 N	7° 19 14 W	697.7	215.4	Hespérides summit
UCS14	20/04/2012	36° 11 27.7 N	7° 18 41.3 W	736.4	36° 11 31.4 N	7° 18 45.2 W	732.3	157.9	Hespérides NE
UCS15	20/04/2012	36° 10 52.4 N	7° 18 23.7 W	674.2	36° 10 44.8 N	7° 18 22.5 W	684.4	272.8	Hespérides S
UCS16	20/04/2012	36° 11 10.2 N	7° 18 53.6 W	695.6	36° 11 12 N	7° 18 55.8 W	671.7	83.1	Hespérides middle
UCS17	21/04/2012	36° 2 58.5 N	7° 20 9.7 W	855.4	36° 3 4.6 N	7° 20 12.7 W	828.7	213.2	Almazán SW flank
UCS18	21/04/2012	36° 3 8.9 N	7° 20 49 W	936.7	36° 3 14 N	7° 20 55 W	913.0	240.2	Almazán W depression
UCS19	21/04/2012	36° 3 43.1 N	7° 20 51.1 W	949.6	36° 3 40.5 N	7° 20 46.4 W	943.1	150.1	Almazán N depression
UCS20	22/04/2012	35° 52 10 N	7° 26 7.5 W	1105.5	35° 52 14.9 N	7° 26 12.4 W	1064.5	221.9	Aveiro SE flank
UCS21	22/04/2012	35° 52 29.1 N	7° 26 45.1 W	1172.0	35° 52 22.8 N	7° 26 44.9 W	1143.1	198.6	Aveiro W depression
UCS22	22/04/2012	35° 53 29.2 N	7° 25 21.2 W	1109.0	35° 53 26.8 N	7° 25 27.3 W	1071.7	194.5	New relief
UCS23	23/04/2012	35° 53 51.4 N	7° 2 23.9 W	863.9	35° 53 54.7 N	7° 2 14.1 W	835.5	278.4	St. Petersburg summit
UCS24	23/04/2012	35° 53 30.6 N	7° 2 37.9 W	900.8	35° 53 35 N	7° 2 40 W	953.4	216.9	St. Petersburg SW Base
UCS25	23/04/2012	35° 53 2.5 N	7° 2 34.7 W	992.9	35° 53 4.5 N	7° 2 26.7 W	1003.8	249.0	St. Petersburg depression
UCS26	24/04/2012	36° 23 37.7 N	6° 57 6.6 W	383.6	36° 23 45.2 N	6° 57 10.3 W	352.5	258.8	Enmedio
UCS27	24/04/2012	36° 33 40.1 N	7° 9 10.5 W	469.2	36° 33 46.1 N	7° 9 2.2 W	429.9	283.3	Juan Sebastián Elcano
UCS28	24/04/2012	36° 33 33.7 N	6° 56 5.5 W	409.3	36° 33 33.1 N	6° 56 0.1 W	348.0	186.2	Gazul
ROV01	11/04/2012	36° 33 29.1 N	6° 56 15.7 W	447.4	36° 33 28.5 N	6° 56 14.5 W	424.4	464.6	Gazul
ROV02	11/04/2012	36° 33 26.6 N	6° 55 52.8 W	354.8	36° 33 38.7 N	6° 55 54.6 W	392.6	789.8	Gazul
ROV03	11/04/2012	36° 33 47.2 N	6° 56 32.5 W	446.2	36° 33 53.1 N	6° 56 27.4 W	481.0	463.8	Gazul depression
ROV04	11/04/2012	36° 33 9.9 N	7° 2 29.6 W	427.4	36° 33 18.3 N	7° 2 48.2 W	372.6	762.6	Cristóbal Colon
ROV05	12/04/2012	36° 31 9.3 N	7° 8 57.6 W	460.0	36° 31 21.4 N	7° 9 4.8 W	431.3	548.9	Anastasya
ROV06	12/04/2012	36° 27 26 N	7° 12 1.6 W	528.9	36° 27 40.2 N	7° 12 6.3 W	490.5	1049.6	Pipoca
ROV07	12/04/2012	36° 27 33.4 N	7° 12 14.3 W	483.6	36° 27 33.9 N	7° 12 10.8 W	483.1	223.1	Pipoca SW flank

(Ochoa and Bray 1991; Ambar et al. 1999; Nelson et al. 1999; Serra et al. 2005; Criado-Aldenueva et al. 2006). Nevertheless, water temperatures and salinities are minimal at the Gazul MV (13.1 °C, 35.9 psu), the summit of which is at a depth of 365 m, and maximal at the Anastasya and Pipoca MVs (ca. 13.8 °C and 36.8 psu), the summits of which are at depths of 457 and 503 m, respectively (Table 2). Near-bottom currents are strong at the Gazul MV (current speeds > 0.3 m s^{-1}) and Pipoca MV (ca. 0.2 m s^{-1}), but are weak at the Anastasya MV (0.1 m s^{-1}) (Table 2).

In Gazul, one of the shallowest MVs ever explored in the GoC, a cold-water coral (CWC) bank was observed on the northwestern flank close to the summit, covering an approximate area of ca. 40 hectares (estimated from video transects and reflectivity data) and dominated by the scleractinian *Madrepora oculata* that is intermixed with some disperse colonies of *Lophelia pertusa* and *Dendrophyllia cornigera* (Fig. 2). Densities of *M. oculata* colonies reached a maxima of ca. 10 colonies m^{-2} (range 1–19 colonies . m^{-2}) with colony heights ranging from 5 to 25 cm (estimated from laser beams attached to the ROV). The associated benthic community is highly rich in species with more than 250 spp. found to date, representing a biodiversity hotspot when compared to adjacent bottoms within the GoC (ca. 50 spp. in the soft bottoms nearby Gazul) (Fernandez-Zambrano 2010). Similar numbers of species have been found in other CWC

Table 2 Some of the habitat types found in the different explored areas within the Spanish continental margin of the Gulf of Cádiz, with notes on their location, relation to European directives and conventions, biological features (dominant/typical/strictly associated species), water and substrate characteristics and trawling activity. T: temperature; S: salinity; NBC: near-bottom current speed; %OM: percentage of organic matter in the sediment; Eh: redox potential in the sediment

Habitat type	Habitat directive	Biological features	Location	Substrate	Water column	Trawling
Anoxic mud breccia bottoms with chemosynthesis-based communities (Bac)	1180 - Submarine structures made by leaking gases	Bacterial mats, *Siboglinum* sp., *Lucinoma asapheus, Acharax gadirae, Solemya elarraichensis, Calliax* sp.,	Anastasya, Pipoca, Hespérides, Almazán, Aveiro, St Petersburg	Silt and Clay %OM: 5.6 - 8.3 % Eh: −388 -20.1 mV	T: 13.8 °C S: 36.7 psu NBC: 0.1 m s^{-1}	Low to medium
Poorly colonized authigenic carbonate (chimneys and slabs) bottoms (Aut)	1180 - Submarine structures made by leaking gases	Serpulids (*Serpula, Vermiliopsis*), brachiopods (*Novocrania, Megathiris*), Hidrozoans (*Acryptolaria, Campanularia*), incrustant sponges (*Terpios*)	Pipoca, Chica, Enano, Enmedio, Hespérides	Carbonate chimneys, slabs and crusts	T: 13.2-13.8 °C S: 35.9 - 36.6 psu NBC: 0.1-0.2 m s^{-1}	Low to medium
Cold-water coral reefs dominated by *Lophelia pertusa* y/o *Madrepora oculata* (Cor)	1170 - Reefs	*Lophelia pertusa, Madrepora oculata, Eunice norvegica, Epitonium spp.,*	Gazul	Carbonate chimneys, slabs and crusts and coral rubble	T: 13.1 °C S: 35.9-36.0 psu NBC: 0.3 m s^{-1}	Low
Bathyal rocky bottoms with *Callogorgia verticillata* (Gor)	1170 - Reefs	*Callogorgia verticillata, Simnia nicaensis,*	Chica, Enmedio	Large carbonate slabs and chimneys	T: 13.5 °C S: 36.5 psu NBC: 0.1-0.2 m s^{-1}	Low
Bathyal rocky or dead coral bottoms with gorgonians (*Acanthogorgia, Bebryce, Placogorgia*) (Gor)	1170 - Reefs	*Acanthogorgia hirsuta, A. granulata, Anamenia gorgonophila, Bebryce mollis, Swiftia pallida, Placogorgia massiliensis*	Pipoca, Gazul, Almazán	Carbonate chimneys, slabs and crusts	T: 13.1-13.8 °C S: 35.9-36.8 psu NBC: 0.2-0.3 m s^{-1}	Medium
Bathyal rocky bottoms with black corals (*Leiopathes, Antipathella*) (Ant)	1170 - Reefs	*Leiopathes glaberrima, Antipathella subpinnata, Stichopathes*	Gazul, Chica, Hespérides	Carbonate chimneys, slabs and crusts	T: 13.1-13.2 °C S: 35.9-36.0 psu NBC: 0.2-0.3 m s^{-1}	Low
Bathyal rocky bottoms with large hexactinelid sponges (*Asconema*) (Asc)	1170 - Reefs	*Asconema setubalense, Neocomatella europaea*	Gazul, Enmedio, Pipoca, Chica,	Carbonate chimneys, slabs and crusts	T: 13.2-13.8 °C S: 36.0-36.8 NBC: 0.2-0.3 m s^{-1}	Low to medium
Bathyal rocky bottoms dominated by desmosponges (Des)	1170 - Reefs	*Petrosia* sp., *Geodia* sp., *Pachastrella* sp., *Phakellia* sp., *Haliclona* spp.,	Gazul, Chica, Enmedio, Guadalquivir Ridge	Carbonate chimneys, slabs and crusts	T: 13.1-13.2 °C S: 35.9-36.0 psu NBC: 0.2-0.3 m s^{-1}	Low
Bathyal muds with *Pheronema carpenteri* (Phe)	–	*Pheronema carpenteri*	St Petersburg	Silt and Clay %OM: 6.1-9.8 % Eh: −143.7 - 28 mV	–	Low
Bathyal muds with *Thenea muricata* (The)	–	*Thenea muricata*	Pipoca, Chica, Enmedio, Aveiro	Muddy fine sand %OM: 2.9-8.2 % Eh: 41.3-107.6 mV	T: 13.8 °C S: 36.8 psu NBC: 0.2 m s^{-1}	Low to high
Bathyal detritic bottoms with *Leptometra phalangium* (Lep)	–	*Leptometra phalangium*	Pipoca, Tarsis, Guadalquivir Ridge	Detritic and muddy fine sand %OM: 4.9-8.2 % Eh: 41.3-107.6 mV	T: 13.7-13.8 °C S: 36.7-36.8 psu NBC: 0.2 m s^{-1}	Low to medium
Bathyal muds and detritic bottoms with *Flabellum* (Fla)	–	*Flabellum chunii, Flabellum macandrewi, Actinauge richardi*	Gazul, Pipoca, Tarsis, Hespérides	Detritic and muddy fine sand %OM: 2.9-7.2 % Eh: 41.3-216.2 mV	T: 13.2-13.8 °C S: 35.9-36.8 psu NBC: 0.2 m s^{-1}	Low to medium
Bathyal muds with *Isidella elongata* (Isi)	–	*Isidella elongata*	Tarsis, Almazán, Aveiro	Mud and muddy fine sand %OM: 6.6-7.2 % Eh: −103.3 - 50.3 mV	T: 13.7 °C S: 36.7 psu NBC: 0.2 m s^{-1}	Low to medium
Bathyal muds with *Radicipes* (Rad)	–	*Radicipes* spp.	Almazán	Muddy fine and medium sand %OM: 4.3-7.7 % Eh: 133.6-234.5 mV	–	Low
Bathyal muds with sea-pens (Pen)	–	*Kophobelemnon stelliferum, Pennatula aculeata, Funiculina quadrangularis, Protoptilum* sp., *Virgularia* sp.	Anastasya, Tarsis, Pipoca, St Petersburg	Mud and muddy fine sand %OM: 4.9-8.3 % Eh: −67.9 - 50.3 mV	T: 13.7-13.8 °C S: 36.7-36.8 psu NBC: 0.1 - 0.2 m s^{-1}	Low to high

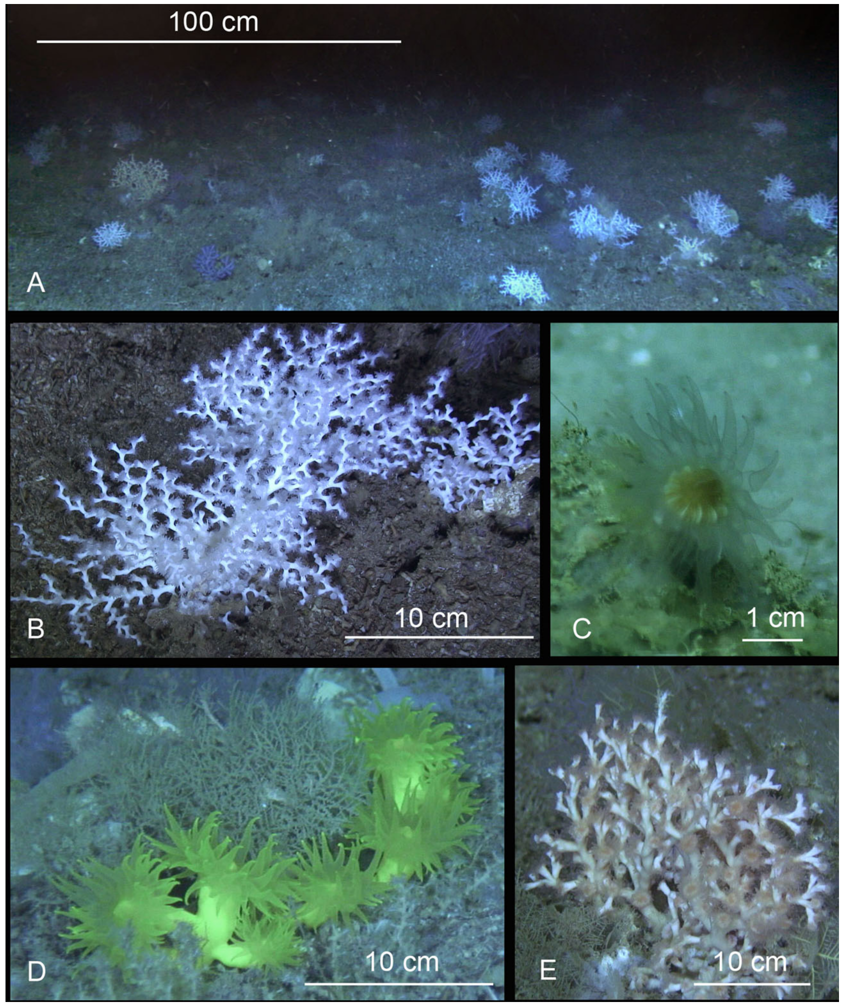

Fig. 2 Scleractinians occurring at the Gazul MV (380-420 m depth): (**a**) Coral bank with *Madrepora oculata* and *Lophelia pertusa* (Habitat 1170 Reefs); (**b**) *M. oculata*; (**c**) *Caryophyllia smithii*; (**d**) *Dendrophyllia cornigera*; (**e**) *L. pertusa*. Pictures taken with the ROV LIROPUS 2000 from the Instituto Español de Oceanografía (IEO)

banks of the Mediterranean (Mastrototaro et al. 2010) and the Atlantic Ocean (Henry and Roberts 2007). The polychaete *Eunice norvegica* (forming parchment-like calcified tubes within living coral branches) was always found in *M. oculata* colonies, and not on other substratum types, unlike most species that were generally found on the corals but also occurred on other substrata. Some species strictly found in this CWC bank included different gastropods that feed on cnidarians (e.g., *Epitonium celesti, E. algerianum*) or sponges (e.g., *Emarginula adriatica, E. multistriata*) that generally occur among the corals. Other dominant species were the poriferans *Haliclona* (*Soestella*) *mucosa* and *Petrosia* cf. *crassa*, the small gorgonians *Acanthogorgia hirsuta, Bebryce mollis* and *Placogorgia* spp., the polychaetes *Filograna implexa, Serpula vermicularis* and *Eunice vittata*, the molluscs *Danilia tinei, Mitrella pallaryi*, *Bathyarca philippiana Asperarca nodulosa* and the echinoderms *Ophiothrix* sp., *Echinus acutus, Cidaris cidaris* and *Hacelia superba*, the latter displaying one of the few known populations within the European continental margin (Rueda et al. 2011). Records on the presence of living colonies of some CWC species in the GoC and the Alboran Sea are scarce (Álvarez-Pérez et al. 2005; Wienberg et al. 2009; Pardo et al. 2011; Fink et al. 2013) and their occurrence in adjacent areas (e.g., Mediterranean Sea) seem restricted to specific areas with adequate environmental conditions such as the Santa Maria di Leuca coral province (Taviani et al. 2005; Vertino et al. 2010), Cap de Creus and Lacaze-Duthiers submarine canyons (Orejas et al. 2009; Gori et al. 2013), among others. In the GoC, most previous records of CWCs were of sparse dead colonies and coral graveyards on ridges, mounds and MVs, due to their widespread occurrence during the last glacial epoch and their strong decline related to the recent warm and oligotrophic conditions of the GoC (Wienberg et al. 2009; Van Rooij et al. 2011). In fact, coral graveyards of this and other scleractinians (e.g., *Dendrophyllia alternata*) are also abundant in some of the explored edifices, especially within the Albolote diapir and Hespérides MV/diapir complex. Other records of living populations of CWCs have been indicated for specific areas of the Strait of Gibraltar (Álvarez-Pérez et al. 2005) and seamounts located between Madeira and the Iberian Peninsula (e.g., Coral Patch seamount, Gorringe Bank) (Wienberg et al. 2013). The presence of a

M. oculata bank in Gazul represents one of the very few records for the GoC and could be related to the lower temperature (13.1 °C) and salinity (35.9-36.0 °C) at the summit of this MV (located at a shallower depth than the MOW), together with the extreme hydrodynamic conditions (current speed > 0.3 m s^{-1}) (Table 2). The strong currents have exposed a large amount of authigenic carbonates of different types and sizes on this MV which provides important hard substrata for CWC settlement (Table 2). Trawling activity in Gazul is very low, compared to that found in other MVs and adjacent bottoms, and this surely benefits the establishment and persistence of populations of this very slow growing scleractinian (Table 2) (González-García et al. 2012). The habitat type formed by CWCs is considered of interest for conservation by the Habitat Directive 92/43/EEC (Habitat 1170 Reefs) and by some conventions of the Atlantic (OSPAR, Coral gardens) and Mediterranean basins (RAC/SPA, Biocenosis of deep-sea corals V.3.1) (Bellan-Santini et al. 2002).

Other vulnerable deep-sea habitats occurring on edifices with hard bottoms composed of authigenic carbonates (e.g., Gazul, Pipoca, Chica, Enano, Enmedio and Hespérides) are: (1) Bathyal rocky bottoms with *Callogorgia verticillata* in Chica and Enmedio (Fig. 3b), harbouring invertebrates that feed on polyps of *C. verticillata* such as the ovulid gastropod *Simnia nicaaensis*; (2) Bathyal rocky and/or dead coral bottoms with gorgonians, such as *Acanthogorgia hirsuta* (mainly at Pipoca), *Bebryce mollis* (mainly at Gazul and Albolote), *Swiftia* (St. Petersburg) or with *Placogorgia* sp. (Almazan) (Fig. 3a), and harbouring species that are highly specific to some of these gorgonians such as the solenogastre *Anamenia gorgonophila* (strictly found on *A. hirsuta*); (3) Bathyal rocky bottoms with black corals (*Leiopathes glaberrima, Anthipathella subpinnata*) in Gazul (dominated by *Anthipathella*) and Hespérides (dominated by *Leiopathes*); (4) Bathyal rocky bottoms with large hexactinellid sponges (*Asconema setubalense*) in Pipoca, Chica, Enmedio and

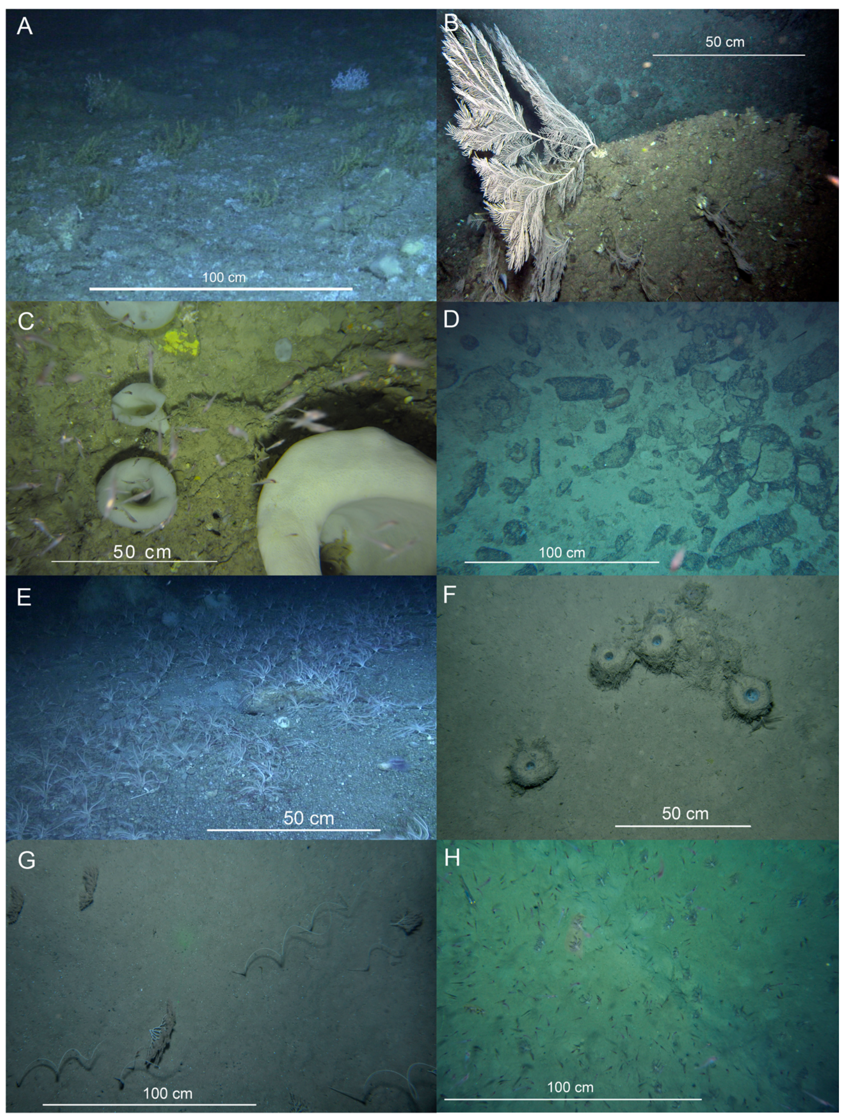

Fig. 3 Different vulnerable deep-sea habitats found in different areas within the MV field of Spanish waters. (**a**) Bathyal rocky bottoms with *Bebryce mollis* at the Gazul MV summit (370 m depth); (**b**) Bathyal rocky bottoms with *Callogorgia verticillata* at the Enmedio diapir (355 m); (**c**) Bathyal rocky bottoms with large hexactinellid sponges (*Asconema setubalense*) at the Enmedio diapir (373 m); (**d**) Poorly colonized authigenic carbonate (chimneys and slabs) bottoms at the Hespérides MV (686 m); (**e**) Bathyal detritic bottoms with *Leptometra phalangium* at the Pipoca MV (526 m); (**f**) Bathyal muds with *Pheronema carpenteri* at the St. Petersburg MV (940 m); (**g**) Bathyal muds with *Isidella elongata* and *Radicipes* at the Aveiro MV (1112 m); and (**h**) Bathyal muds with sea-pens at the St. Petersburg MV (1025 m). Pictures taken with the ROV LIROPUS 2000 and UCS APHIA 2012 from the Instituto Español de Oceanografía (IEO)

Gazul (Fig. 3c) or with desmosponges (*Phakellia, Petrosia, Geodia, Pachastrella*) in Gazul, Chica, Enmedio and the Guadalquivir Ridge (Table 2). In general, these habitat types are more widespread throughout the GoC than those formed by CWCs and occur in areas with slabs and chimneys (Fig. 3d) that are exposed to moderate temperatures (13.1-13.8 °C) and salinities (35.9-36.8 psu), moderate to high near bottom current speeds (generally between 0.2-0.3 m s^{-1}) and low to medium trawling activity (Table 2). All these vulnerable habitats occurring on hard bottoms are included in the Habitat 1170 "Reefs" portion of the Habitat Directive, and some of them are related to the OSPAR habitats list such as "coral gardens" (for those dominated by cnidarians) and "deep-sea sponge aggregations" (dominated by sponges).

At the Anastasya summit, muddy bottoms with filamentous bacterial mats reaching diameters up to 20 cm and displaying a patchy coverage (in most cases < 10 %) are common seafloor features (Fig. 4). Remains of chemosymbiotic bivalves (e.g., *Solemya elarraichensis, Lucinoma asapheus*) can also be found in the sediment due to the presence of dense populations of these infaunal bivalves in the anoxic sediments enriched in methane and sulphide (Rueda et al. 2012b). Sea-pen communities dominated by *Kophobelemnon stelliferum* and *Funiculina quadrangularis* also colonize some areas of the summit and flanks of this MV, where trawling marks on the seafloor are very frequent due to the intense trawling detected over this edifice during the spatial analysis of VMS data (Table 2). The biodiversity of Anastasya is lower (ca. 75 spp.) than that found in other explored edifices (generally > 100 spp.), and this is probably related to the extremophile characteristics of its sediment, the calm hydrodynamic conditions and the high trawling activity (González-García et al. 2012) (Table 2). Other studied MVs displaying chemosynthesis-based communities and high densities of siboglinid polychaetes (>300 indiv m^{-2}) were Hespérides, Almazán, Aveiro and St. Petersburg, but no bacterial mats were clearly visible in the underwater UCS images in those areas. Bacterial mats and siboglinids are common components of chemosynthesis-based communities that depend on the methane and/or sulphide available in cold seep sediments (Levin 2005; Cunha et al. 2013). In nearby areas of the GoC, bacterial mats of similar or even larger sizes have been recorded at the summit of some MVs such as Håkon Mosby (Nordic margin) (Jerosch et al. 2007), Amsterdam (Mediterranean Sea) (Olu–Le Roy et al. 2004), Faro (Portuguese margin) (Niemann et al. 2006) and in cold seeps of the Marmara Sea (Ritt et al. 2011), among others. Moreover, gas bubbling has been observed in MVs located in the Alboran Sea, such as at Carmen (Blinova et al. 2011). The bacterial mats occurring in Anastasya seem smaller than those found in those areas and it is difficult to conclude if this is linked to the lower seepage activity of Anastasya or to the high trawling activity on its soft bottoms that may cause burial and fragmentation of the microbial communities forming

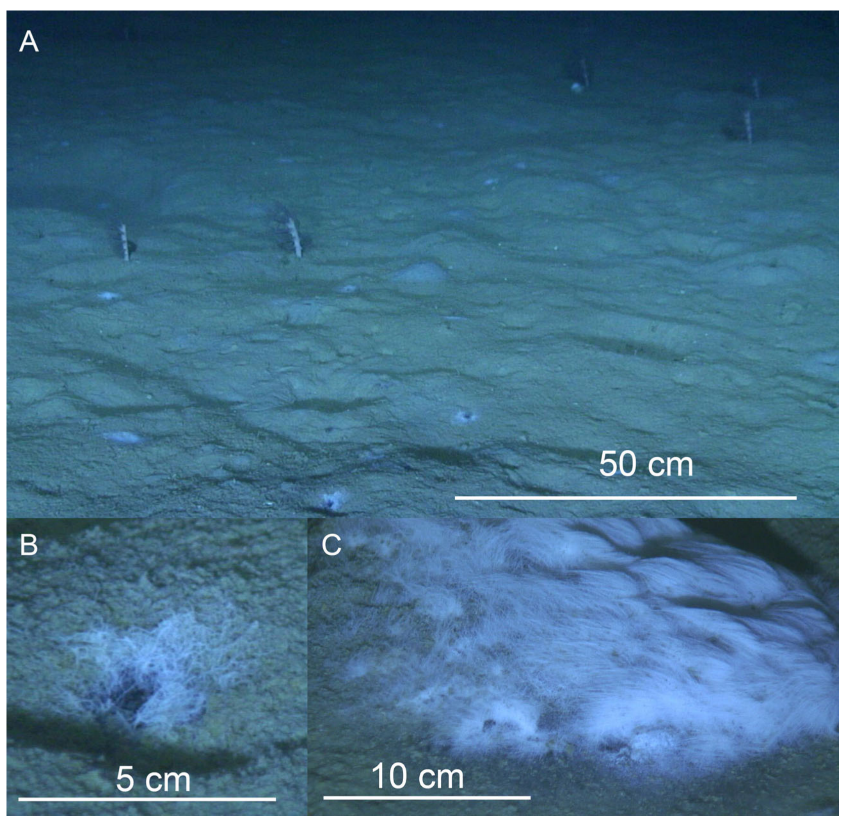

Fig. 4 Anoxic mud breccia bottoms of the Anastasya MV (ca. 460 m depth): (**a**) Sea-pen communities with *Kophobelemnon stelliferum* at low densities (2–5 colonies m^{-2}) and burrows colonized by bacterial mats; (**b**) Detail of burrows covered with bacterial mats; (**c**) Larger patches of bacterial mats found in areas where dense populations of chemosymbiotic bivalves (*Lucinoma asapheus* and *Solemya elarraichensis*) and polychaetes (e.g., *Siboglinum*) also occur. Pictures taken with the ROV LIROPUS 2000 from the Instituto Español de Oceanografía (IEO)

bacterial mats. The presence of bacterial mats, together with dense populations of symbiont-hosting invertebrates in Anastasya, can represent indicators of locally elevated fluxes of sulphide (probably derived from anaerobic oxidation of methane) reaching the seafloor surface at this particular MV, with sediments displaying much lower Eh-redox levels (down to −388 mV) in comparison to other MVs explored in this study (Levin 2005; Cordes et al. 2010; Blinova et al. 2011; Rueda et al. 2012b). Habitats harbouring cold seep communities, including bacterial mats and symbiotic metazoans, are currently included in the Habitat Directive 92/43/EEC (Habitat 1180 Submarine structures made by leaking gasses), and different organizations have suggested the importance of increasing conservation efforts for this type of habitat in both the Atlantic Ocean and the Mediterranean Sea (RAC/SPA, OSPAR) (OSPAR 2010; Bazairi et al. 2010).

Sedimentary habitats are also important and common seafloor components within the the studied MV field of the Spanish continental margin, and some of them also represent vulnerable deep-sea habitats such as: (1) Bathyal detritic bottoms with *Leptometra phalangium*, that have been suggested as sensitive habitats in the Mediterranean Sea (European Commission 2006) and occur in Pipoca, Tarsis and Magallanes (Fig. 3e); (2) Bathyal muds and detritic bottoms with *Flabellum* in Gazul, Tarsis, Pipoca and Hespérides; (3) Bathyal muds with sea-pens (included as "Sea-pen and burrowing megafauna communities" in OSPAR and in the reference list of UNEP-MAC RAC/SPA in Bellan-Santini et al. 2002) in Anastasya, Pipoca, Tarsis and St. Petersburg (Fig. 3h); (4) Bathyal muds with *Isidella elongata* (included in "Coral Gardens" of OSPAR and in the reference list of UNEP-MAC RAC/SPA in Bellan-Santini et al. 2002) in Almazán, Aveiro and Tarsis (Fig. 3g); (5) Bathyal muds with *Radicipes* (included in "Coral Gardens" of OSPAR) in Almazán (Fig. 3g); (6) Bathyal muds with *Pheronema carpenteri* (included in "Deep-sea sponge aggregations" of OSPAR) in Aveiro and St. Petersburg (Fig 3f); and (7) Bathyal muds with *Thenea muricata* (included in "Deep-sea sponge aggregations" of OSPAR) in Pipoca, Chica and Aveiro (Table 2). Some of these habitats seem to be more widespread throughout the GoC (e.g., bathyal muds with sea-pens, bathyal detritic and muddy bottoms with *Flabellum*) than others that are restricted to the scarce hard bottoms of the GoC (e.g., CWC banks). Most of these vulnerable sedimentary habitats generally occur in areas with moderate temperatures (13.2-13.8 °C) and salinities (35.9-36.7 psu), low to moderate current speeds (0.1-0.2 m s^{-1}) and low to high trawling activity (Table 2). These habitats are not included in the Habitat Directive but, as mentioned in the preceding paragraph, some of them have been considered by other conventions for nature conservation (e.g., OSPAR, UNEP-MAC RAC/SPA). The inclusion of some of these habitats in the Habitat Directive is desirable because most anthropogenic activity related to trawling fisheries occur or is expected to occur in deep-sea sedimentary habitats and some of them may become extinct in the near future (Ramírez-Llodra et al. 2011).

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