1 **Deep-sea habitat characterization using acoustic data and underwater imagery in Gazul mud**

2 **volcano (Gulf of Cádiz, NE Atlantic)**

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16 **Abstract**

17 Gazul is the shallowest mud volcano (MV) within the Shallow Field of Fluid Expulsion (SFFE) of
18 the northeastern Gulf of Cádiz (NE Atlantic; 300-1200 m depth). The SFFE represents an
19 important geo- and biodiversity area that was designated as a Site of Community Importance
20 under the European Habitats Directive in 2014. In this study, geological features, habitats and
21 associated biodiversity, as well as anthropogenic impacts, were characterized at the Gazul MV
22 from underwater imagery and multibeam bathymetry. Multivariate methods using the Bray-
23 Curtis similarity index identified six main habitats, each of which harbored a characteristic
24 faunal assemblage that included: (1) sandy ripple bottoms typified by the actiniarian *Actinauge*
25 *richardi*; (2) sandy, muddy, coarse sand and bioclastic bottoms dominated by the solitary coral
26 *Flabellum chunii*; (3) coarse sand and bioclastic bottoms, together with soft sediments covered
27 by scattered methane-derived authigenic carbonates (MDACs) (mixed bottoms), characterized
28 by the echinoid *Cidaris cidaris*; (4) hard bottoms comprising MDACs dominated by a wide
29 variety of sponges and gorgonians; (5) coral-rubble bottoms typified by the presence of
30 colonial scleractinian communities dominated by *Madrepora oculata*; and (6) mixed bottoms
31 characterized by the presence of a styelid ascidian. Slope and water depth were the main
32 factors explaining assemblages' distribution, which was also supported by the presence of
33 MDACs such as slabs, crusts and chimneys on the seafloor, as well as by the geomorphologic
34 diversity of Gazul MV. The results highlight Gazul MV as an eco-biologically important area
35 harboring different vulnerable marine ecosystem (VME) elements with indicator taxa such as
36 scleractinians, sponges, gorgonians and black corals. ROV images revealed abandoned or lost
37 fishing gears and marine debris on the seafloor, indicating anthropogenic impacts in Gazul MV
38 and adjacent areas. Indeed trawling fisheries activities have also been detected in Vessel
39 Monitoring System datasets. A fishery restricted area is recommended in Gazul MV due to the
40 occurrence of diverse VMEs and species included in different conservation directives and
41 conventions.

42 **Keywords:** benthic communities, conservation, deep-sea habitats, mud volcano, ROV,
43 vulnerable marine ecosystem

1. Introduction

Submarine elevations (e.g. seamounts, mounds, diapiric ridges, mud volcanoes) are considered exceptional seafloor features harboring distinct benthic and demersal associated communities and habitats (Samadi et al., 2007; Ramos et al., 2016; Rueda et al., 2016; Corbera et al., 2019), which can even promote large pelagic biodiversity in the open ocean (Morato et al., 2006; Holland and Grubbs, 2007; Litvinov, 2007). There is a strong link between deep-sea benthic communities at submarine elevations with local bottom current and substrate types (Van Rooij et al., 2010). In areas with strong bottom currents, erosion and sediment transport are promoted and, in some cases, hard substrata are exhumed and colonized by suspension feeders (Van Rooij et al., 2010; Gasser et al., 2011). In those areas, associated benthic communities are usually dominated and structured by slow-growing and long-living organisms, mainly suspension feeders (e.g. colonial scleractinians such as the so called white corals, gorgonians and sponges), which benefit from a local high productivity derived from mound-induced upwelling and the enhanced currents around them (Genin et al., 1986; Roden, 1986; Rogers, 1994; Richer de Forges et al., 2000; Samadi et al., 2007). These organisms provide three-dimensionally complex habitats (sometimes known as "marine animal forests"; Rossi et al., 2017; Wienberg and Titschack 2017) for a large number of vagile invertebrates and demersal fish, and they only occur in specific locations (Richer de Forges et al., 2000; Samadi et al., 2007; Altuna, 2013). These habitat-forming organisms are important features of the deep sea, recently classified as vulnerable marine ecosystems (VMEs hereinafter), and are very sensitive and vulnerable to fishing activities, particularly to bottom contact gears (Koslow et al., 2001; Clark and Koslow, 2007).

Ecosystems on submarine elevations are at the forefront of international concerns and negotiations, and discussed by worldwide organizations, policy makers and scientific researchers in order to improve the sustainable use of resources as well as the protection of the associated biodiversity in VMEs in the high seas (Gjerde and Breide, 2003; WWF/IUCN, 2004; United Nation, 2007; FAO, 2009). Nevertheless, the level of scientific knowledge of deep-sea habitats is still limited (Koslow et al., 2015). Scientific data regarding the description of VMEs and associated communities are crucial for establishing management strategies in order to protect ecologically important deep-sea areas. Regarding deep hard bottoms, which are difficult to study using classical extractive methods without destroying ecosystem components, the development of non-invasive techniques (e.g. underwater cameras, remotely operated vehicles (ROVs hereinafter), multibeam echosounder systems) has enabled the direct visual inspection of the seafloor characteristics and the megafauna, allowing the identification,

mapping and quantitative study of different habitats (e.g. Orejas et al., 2009; Howell et al., 2010; Bo et al., 2011; Sánchez et al., 2014; Taviani et al., 2015; Ramos et al., 2016; Lim et al., 2017; van den Beld et al., 2017; de la Torriente et al., 2018; Price et al., 2019). Underwater images and videos have largely increased our knowledge on deep-sea VMEs, fostering management and conservation plans (WWF/IUCN, 2004; Ramirez Llodra and Billett, 2006), and providing precise information for the assessment of the environmental status for several indicators of the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) concerning the conservation of natural habitats (Kazanidis et al., 2020).

Over the last few decades, commercial fisheries shifted effort and expanded into the deep-sea following fisheries overexploitation on global continental shelves (Morato et al., 2006; Norse et al., 2011; Costello et al., 2012; FAO, 2018). This shift in exploitable fishing depths is leading to potentially long-term impacts including biodiversity loss in VMEs (Pitcher et al., 2010). Within southern Europe, there is detailed and extended information regarding deep-sea VMEs for the western and central Mediterranean basin (e.g. D'Onghia, 2019; Puig and Gili, 2019; Rueda et al., 2019; Gulf of Lions: Orejas et al., 2009; Gori et al., 2013; Aymà et al., 2019; off Cape Santa Maria di Leuca: Tursi et al., 2004; Taviani et al., 2005; Mastrototaro et al., 2010; D'Onghia et al., 2011; Strait of Sicily: Zibrowius and Taviani, 2005; Schembri et al., 2007; Freiwald et al., 2009; Taviani et al., 2009), whereas other areas are less studied, as for instance the southern Iberian continental margin (Díaz-del-Río, 2014; de la Torriente et al., 2018; Corbera et al., 2019; Rueda et al., accepted).

The European LIFE+ INDEMARES Project was carried out in Spanish waters with the main aim of providing the necessary scientific information to establish a network of deep-sea areas of biological interest for conservation purposes. One of the study cases was the Shallow Field of Fluid Expulsion (SFFE hereinafter) (Díaz-del-Río, 2014), which is located on the upper and middle slope of the Gulf of Cádiz (GoC hereinafter) continental margin, between 300 and 1200 m water depth. This area presents an important number of mud diapirs and mud volcanoes resulting from massive plastic material movements and actively extruding material, respectively, from sub-seafloor layers to the surface due to density differences (Díaz-del-Río et al., 2003; Pinheiro et al., 2003; Medialdea et al., 2009), which is why the area is also known as the mud volcanoes of the GoC (MVGoC hereinafter). This geomorphological diversity is enriched by the presence of fields of methane-derived authigenic carbonates (MDACs hereinafter) exhumed by bottom currents erosive processes, which have triggered a diversification of habitat types and biological communities (Greinert et al., 2001).

111   Traditionally, soft bottoms across the MVGoC have been exploited by multispecific
112 bottom trawl fleets, with the Norway lobster *Nephrops norvegicus* (Linnaeus, 1758) as one of
113 the main target species due to its high economic value (Jiménez et al., 2004; Vila et al., 2015).
114 The MVGoC were integrated into the European Natura 2000 network as a Site of Community
115 Importance (SCI-ESZ 12002 "*Volcanes de fango del Golfo de Cádiz*") due to the presence of (1)
116 five habitat subtypes within "1180 Submarine structures made by leaking gases", and (2) nine
117 habitat subtypes within "1170 Reefs", both categories included within Annex I of the Habitats
118 Directive of the European Union (Council Directive 92/43/EEC) (Díaz-del-Río, 2014).
119 Furthermore, highly fragile keystone epibenthic species related to the OSPAR (Oslo and Paris
120 Commissions) habitats list (https://www.ospar.org/work-areas/bdc/species-habitats) such as
121 "coral gardens" and "deep-sea sponge aggregations" are also present in the MVGoC (Rueda et
122 al., 2016). Nevertheless, despite the increasing interest on deep-sea ecosystems, few studies
123 have been focused on the associated benthic fauna of MVGoC (Delgado et al., 2013; Rueda et
124 al., 2016; Lozano et al., 2020a, b), most of them studying the distinct fauna associated with
125 fluid migration and seepage (Oliver et al., 2011; Rueda et al., 2012; Cunha et al., 2013;
126 Rodrigues et al., 2013), while some others analyzed the spatial and temporal distribution of
127 cold-water corals (Taviani et al., 1991; Wienberg et al., 2009).

128   The aims of the present study were: (i) to identify and describe the main habitats and
129 megabenthic assemblages occurring on Gazul MV and surrounding areas, (ii) to map their
130 distribution using a backscatter raster in order to get an interpretative habitat map, and (iii) to
131 analyze the potential influence of seafloor characteristics (obtained using acoustic systems) on
132 the distribution of these habitats. This information will improve the knowledge on the
133 biological and ecological characteristics of this specific area of the GoC, as well as of a recently
134 declared SCI.

135

2. Materials and Methods

2.1. Study area

The geomorphology of the GoC is largely shaped by tectonics and diapiric processes related to a complex geodynamic evolution of the continental margin (Medialdea et al., 2009). These processes provide escape pathways for over-pressured sediments and fluids from deeper layers to the seafloor surface, and favor the formation of characteristics seafloor structures such as MVs (Pinheiro et al., 2006; Fernández-Puga et. al., 2007). On the upper and middle slope of the Spanish continental margin (300-730 m depth), the SFFE is characterized by the presence of two main diapiric ridges (DR hereinafter), the Guadalquivir DR and the Cádiz DR (Somoza et al., 2003; Fernández-Puga et al., 2007); two main contourite channels with sinuous morphology, the Gusano and Huelva channels (García et al., 2009); and several MVs and mud diapirs (Díaz-del-Río, 2014; Palomino et al., 2016).

Gazul is one of the four MVs that have been confirmed in the SFFE (Palomino et al., 2016). It is located in the northeastern part of the SFFE and to the north of the Cádiz DR (Fig. 1). This MV has its summit at 363 m depth (relief: 107 m) and a diameter of 1200 m. According to Palomino et al. (2016), this MV has a subcircular base and an asymmetrical bathymetric profile, with flanks of different lengths and oriented NE–SW. It presents two prolongations running NW–SE that are interpreted as 20 to 40 m height outcrops of muddy materials, surrounded by two depressions (depth: 15 and 20 m below adjacent bottoms; length: 2.1 and 2.3 km, respectively) located north and northwest of the MV main edifice (Fig. 1C). There are also isolated and grouped mounds about 55 m wide occurring to the west of the western depression, at depths between 460 and 480 m and oriented NW–SE (Fig. 1C). The summit of Gazul MV is characterized by a thin veneer of hemipelagic muddy sediments overlying greenish grey-mud breccia facies with abundant bioclasts and MDACs; the area of the mounds presents MDACs, mainly slabs and chimneys; finally, sediments of the depressions are coarser and composed of sand and bioclastic gravel (Palomino et al., 2016).

The pattern of oceanographic circulation in the GoC is controlled by the exchange of water masses through the Strait of Gibraltar, with the surficial North Atlantic Central Water flowing into the Alboran Sea and the deeper Mediterranean Outflow Water (MOW hereinafter) flowing out to the Atlantic Ocean (Lacombe and Lizeray, 1959; Ochoa and Bray, 1991; Sánchez-Leal et al., 2017) (Fig. 1A). The MOW, which shows high salinity (38.45 psu) and temperature (12.9 °C), sweeps along the southwestern Iberian margin as a seafloor bottom current between 300 m and 1200 m water depth, flowing to the north and west due to the

169 Coriolis deflection, and splitting into two main branches, the Mediterranean Upper Core and
170 the Mediterranean Lower Core (Madelain, 1970; Ambar and Howe, 1979; Sánchez-Leal et al.,
171 2017). The present study area is under the influence of the Mediterranean Upper Core (Fig.
172 1A), with bottom currents reaching a maximum speed of 0.3–0.5 m·s^{-1} along the contourite
173 channels, in contrast to the minimum speeds of between 0.01–0.1 m·s^{-1} observed between the
174 diapiric ridges (Díaz-del-Río, 2014; Sánchez-Leal et al., 2017). This MOW branch exerts a great
175 influence on the bottoms of this area as it circulates in contact with the friction surface of the
176 seabed, resulting in diverse morphological features, both depositional and erosional
177 (Hernández-Molina et al., 2003; García et al., 2009; Sánchez-Leal et al., 2017; Lozano et al.,
178 2020b).

179 *2.2. Video sampling design and video data collection*

180 Underwater video transects have been recorded in three expeditions conducted at 3
181 sites on Gazul MV (the summit, northern flank and southern flank) and also at 4 sites from the
182 surrounding areas (the eastern and western adjacent areas, and the western and central
183 depressions) between 2012 and 2016 (Fig. 1C). The first expedition was carried out within the
184 LIFE+ INDEMARES/CHICA project on board the Research Vessel (RV) Ramón Margalef (CHICA-
185 0412 expedition); during this expedition three ROV video transects (total recording time of 6h
186 20min) were performed using the ROV LIROPUS 2000 (model Super Mohawk II; equipped with
187 a high definition Kongsberg video camera, a Kongsberg tooling camera and three frontal flash
188 LED Matrix). The second survey was carried out within the ISUNEPCA project on board the RV
189 Ángeles Alvariño (ISUNEPCA-0616 expedition); during this expedition three Remotely Operated
190 Towed Vehicle (ROTV) video transects (2h 55min) were performed using the ROTV TST-HORUS
191 (equipped with two Full HD video cameras which have an angle of inclination of 45° in relation
192 to the ground, and a unique frontal flash LED Matrix). The third survey was carried out within
193 the H2020 ATLAS project on board the RV Sarmiento de Gamboa (MEDWAVES expedition);
194 during this expedition two ROV video transects (13h 31min) were performed using the ROV
195 LIROPUS 2000. Underwater transects of all three expeditions were georeferenced with a
196 transponder that allowed the position of the images to be precisely determined relative to the
197 RV vessel along each transect. Additionally, both the ROV and the ROTV were equipped with
198 two parallel laser beams providing either a 10 cm (ROV) or a 7.5 cm spatial scale (ROTV).

199 The bathymetric data of Gazul MV (and surrounding areas) used in this study were
200 acquired during the ISUNEPCA project using a Kongsberg Simrad EM 710 multibeam
201 echosounder (from 70 to 100 kHz) with a lower velocity, and processed with CARIS HIPS & SIPS

202 data processing software to produce a 5×5 m bathymetric grid model. Backscatter values and
203 other seafloor predictors were also processed from swath bathymetry using the Geocoder
204 algorithm of CARIS HIPS & SIPS software. In addition, a backscatter mosaic was created after
205 the processing of bathymetric data with CARIS HIPS & SIPS software with a 3×3 m of spatial
206 resolution and it was analyzed with the ArcGis v10.7.

207   The video footage (22h 46min of recording) was visually analyzed and split into one-
208 minute video track units (N_t= 1366 video track units) for the geological and biological data
209 acquisition, and named as samples hereinafter. These 1-min samples were treated as different
210 samples and those with different substrate types were removed in order to avoid ambiguous
211 classifications with species from different habitats. The video tracks that corresponded to
212 sampling events (when the ROV is not moving), zooms or indistinct images were removed from
213 the analysis, and only those 1-min video samples displaying continuous movement ROV tracks
214 at similar low speeds (ROV: 12 m·min^{-1}; ROTV: 16 m·min^{-1}) and distance from the bottom
215 (generally between 0.5 and 2.0 m) were included in the analyses. This methodology has been
216 recently used in similar studies for identifying epibenthic habitats and spatial patterns of
217 associated benthic assemblages (e.g. Beaman et al., 2016; de la Torriente et al., 2018). The
218 interpretation of soft bottoms at Gazul MV in the video footage has been carried out using
219 information regarding the nature and sediment texture obtained from previous works carried
220 out in the LIFE+ INDEMARES project and MEDWAVES expedition (Díaz-del-Río, 2014; Palomino
221 et al., 2016; Orejas, 2017). Finally, a total of 505 out of 1366 1-min video samples
222 corresponding to a unique substrate type and covering similar characteristics (ROV speed and
223 distance from the bottom) were included for the habitat identification analysis.

2.3. Biological and geological data sets

225   The abundance of identifiable and conspicuous epibenthic and demersal species was
226 evaluated in each one of the 505 1-min video samples according to a semi-quantitative index
227 coded as 1 (1 observation [i.e. individual/colony] per 1-min video sample), 2 (2-5
228 observations), 3 (5-30 observations), 4 (30-100 observations) and 5 (>100 observations).
229 Several groups of morphologically similar species were used instead when species
230 identification using video imagery was not possible in order to avoid taxonomic inconsistencies
231 (see Table 1). This approach was applied mainly to sponges, which were very diverse and
232 abundant in the area, but scarcely distinguishable from each other in the underwater images,
233 being grouped as "large sponges", "small and digitate sponges" and "encrusting sponges".
234 Other groups included small gorgonians and were referred to the "*Bebryce* group",

alcyonaceans and hydrozoans. Despite these taxonomic limitations, this approach gives an idea of the range of organisms that form part of the faunal communities identified in the samples. In addition, the density (in terms of individuals or colonies m^{-2}) of these species (or species groups) was evaluated on specific video frames obtained from different 1-minute video samples by measuring the areas of the frames with the help of the scale provided by the laser beams. Some video-taxonomic determinations of epibenthic taxa were confirmed with specimens collected with benthic dredge and beam-trawl (sampling area ca. 300 m^2 and 2000 m^2, respectively, and targeting epifaunal and demersal organisms from sedimentary and non-sedimentary habitats) in previous LIFE+ INDEMARES/CHICA expeditions carried out before obtaining underwater imagery in Gazul MV (Díaz-del-Río, 2014; Palomino et al., 2016; Rueda et al., 2016; Sitjà et al., 2019).

Six different bottom types were defined in order to avoid uncertainties and to facilitate interpretation, including (1) coarse sand and bioclastic bottoms (CSBB); (2) sandy ripple bottoms (SRB); (3) sandy bottoms (SB); (4) hard bottoms comprising MDACs (i.e. bottoms dominated by large crusts or slabs partly covered by a thin layer of sediment) (HB); (5) coral-rubble bottoms (CRB); and (6) mixed bottoms (i.e. soft sediments covered by scattered MDACs) (MXB). Substrate types and seafloor micro-morphologies (e.g. ripples) as well as fluid venting related features (e.g. carbonate chimneys) were annotated in each 1-min video sample and, whenever possible, ground truthing by samples and available sedimentological and backscatter data obtained in different LIFE+ INDEMARES/CHICA expeditions at Gazul MV (Díaz-del-Río, 2014; Palomino et al., 2016).

Data based on first-order derived statistics of bathymetric data were obtained using different extensions within ArcGIS v10.7. These seafloor predictors included slope (degrees of inclination), aspect (orientation of the seabed), backscatter (where high values correspond to hard substrates), profile curvature (topographic unevenness) and Bathymetric Position Index (BPI; it measures whether the area is on a topographic high (crest) or low (depression) relative to the surrounding area), as well as water depth as a position variable.

2.4. Anthropogenic activity indicators

Bottom trawling activity in Gazul MV and adjacent areas was obtained from Vessel Monitoring System (VMS) datasets for the period between 2006 and 2012, which were supplied by the *Secretaría General del Mar* of the Spanish government. These datasets included date, time, vessel registration number, vessel position and speed, and type of fishing gear (e.g. trawl, purse seine, etc.). Annual and average fishing efforts (as total trawled hours)

268   were calculated for a grid of the study area with 1 km^2 cell size. These analyses were carried

269   out using the package VMStools in R software (Hintzen et al., 2012). Interpolation between

270   positional signals was calculated in VMStools. Positional signals corresponding to fishing

271   activity were defined by a speed range of 2 to 5 knots, as this is the usual speed for trawling

272   vessels operating in the area. The results obtained were expressed in trawling hours and

273   represented in a map with the software ArcGIS v10.7.

274   Additionally, the abundance and distribution of marine litter was analyzed by

275   annotating its presence on each 1-min video sample. Litter was classified following the Master

276   List of Categories of Litter Items given by the MSFD Technical Subgroup on Marine Litter

277   (2013), which divided the marine litter into five main categories of material (plastics, metal,

278   rubber, glass/ceramics, natural products). Additionally, marine litter was analyzed considering

279   the type of item (e.g. fishing lines, cans, drink bottles), and their presence was evaluated

280   through the relative frequency of occurrence of each type, estimated as the percentage of

281   samples in which the litter was present. The potential impact of marine litter on benthic fauna

282   was also evaluated following the classification of Angiolillo et al. (2015) (i.e. covering, abrasion,

283   hanging, lying).

284   *2.5. Data analyses*

285   The total frequency of occurrence of each taxa and assemblage identified in the

286   analyzed underwater imagery has been determined as the percentage of samples in which a

287   particular taxa/assemblage is present, and it was expressed as a frequency index (%F). In the

288   case of those taxa included in further analysis, the relative frequency of occurrence per

289   bottom type was also considered.

290   Multivariate methods such as group-average sorting classification (CLUSTER) with the

291   UPGMA agglomeration algorithm (Sneath and Sokal, 1973) and non-metric multidimensional

292   scaling ordination (nMDS) using the Bray-Curtis similarity index were carried out

293   independently on the same matrix of abundance values (i.e. as semi-quantitative ranks above

294   mentioned). For these multivariate analyses, only those characteristic epibenthic taxa that

295   provided a biological structure (potential habitat-forming species) and displayed a total

296   frequency of occurrence in samples of more than 1% were considered, and referred to as

297   habitat-typifying species (Table 1). These multivariate analyses were done for detecting spatial

298   patterns and identifying epibenthic assemblages forming habitats on Gazul MV. To test for

299   differences between the identified assemblages, a distance-based permutational multivariate

300   analysis of variance (PERMANOVA) (Anderson, 2001; McArdle and Anderson, 2001) was

301 performed. This design included 2 fixed and orthogonal factors: substrate type (6 levels: coarse
302 sand and bioclastic bottoms, sandy ripples bottoms, sandy and muddy bottoms, hard bottoms,
303 coral-rubble bottoms, mixed bottoms) and sites (7 levels, 3 in the MV: summit, northern flank,
304 southern flank; and 4 in the surrounding area: central depression, western depression, eastern
305 adjacent area, western adjacent area). The PERMANOVA analysis was based on Bray-Curtis
306 similarity on semi-quantitative data, using 999 random permutations. The identification of the
307 main taxa characterizing each group (i.e. epibenthic assemblages) in the CLUSTER analysis was
308 performed through a similarity percentage analysis (SIMPER) with a 90% cut-off for low
309 contributions. All statistical analyses were carried out using PRIMER 6+ software (Clarke and
310 Warwick, 2001).

311 Information regarding the bottom type observed along the video tracks and the
312 epibenthic assemblages identified from multivariate analyses was superimposed on the
313 backscatter mosaic, resulting in an interpretative habitat map obtained with the ArcGIS
314 desktop software.

315 Finally, the potential effect of seafloor variables in the spatial distribution of
316 assemblages was determined using canonical correspondence analysis (CCA), previously
317 applied in other works using underwater imagery (e.g. Sánchez et al., 2014; Gunton et al.,
318 2015; de la Torriente et al. 2018; Grinyó et al., 2018). The set of variables used in the CCA
319 analysis included backscatter, slope, aspect, BPI and profile curvature, as well as the location of
320 sites in terms of depth (m). The statistical significance of the effect of each variable was tested
321 by a Monte Carlo permutation test. Prior to this, the seafloor variables were screened for
322 correlations in order to avoid collinearity using a Spearman correlation analysis. These
323 multivariate analyses were executed using the software CANOCO 4.5.

324

3. Results

3.1. Bottom types

Two major substratum types were identified at Gazul MV. Hard substrates showed higher backscatter values (mean values ranging between -16.72 and -18.73 dB) and are located in areas with greater slopes (mean slope: 9.13±0.4 degrees), whereas soft substrates showed lower backscatter values (between -20.64 and -23.33 dB) and were located in generally flat surfaces (mean slope: 3.04±0.2 degrees).

CSBB were observed in 23.6% of the samples (n= 119 samples), mainly located in the western depression with many shell remains (mostly belonging to the pectinid bivalve *Pseudamussium peslutrae* and to the brachiopod *Gryphus vitreus*) and echinoid spines (*Cidaris cidaris*), with the eastern mounds containing similar bioclasts (Fig. 2). Sinusoidal and partly bifurcated SRB were locally restricted to a flat surface in the western adjacent area (17.2 % of the samples) with the lowest backscatter values, whereas homogeneous SMB were observed in the central depression (6.8 %) (Fig. 2). SB were also detected close to the summit area of the MV and along the southwestern flank, in the latter displaying some bioturbation (6.7 %) (Fig. 2). HB dominated by MDACs, mainly slabs, was mainly found on the eastern mounds as well as on the southwestern flank (17.2%) and displayed the highest backscatter values (Fig. 2). In HB located close to the eastern mounds, a chimney forest was observed with some chimneys still showing an erected position (Fig. 2). These chimneys displayed lengths ranging between 50 and 100 cm and maximum diameters between 10 and 20 cm, and some of them were colonized by large sponges. CRB mostly composed of *Madrepora oculata* remains were usually found on the northern flank of the MV (16.8%), a steep area with steep slopes and high BPI values (Fig. 2). Finally, MXB (16 %) were widespread throughout the study area (Fig. 2).

3.2. Epibenthic assemblages and habitats

A total of 51 taxa (42 epibenthic taxa and 9 fishes) were identified in the samples (Table 1) including the actinarians *Actinauge richardi* and *Peachia* sp., the scleractinians *Flabellum chunii*, *Dendrophyllia cornigera*, *Madrepora oculata* and *Lophelia pertusa*, the gorgonians *Acanthogorgia hirsuta* and *Callogorgia verticillata*, the antipatharians *Antipathella subpinnata* and *Leiopathes glaberrima*, a styelid ascidian (probably belonging to the genus *Polycarpa*), the poriferan *Asconema setubalense* (hexactinellid) and the echinoderm *Cidaris cidaris* (echinoid). Small gorgonians (*Bebryce* group) were mostly represented by *Bebryce mollis* and *Swiftia dubia*; large sponges included *Poecillastra compressa*, *Petrosia crassa*,

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357   *Phakellia robusta* and *Pachastrella* sp.; *Axinella vellerea* was among the small and digitate

358   sponges; encrusting sponges would include *Jaspis* sp. (likely *J. incrustans*) whereas

359   alcyonaceans were mainly represented by *Paralcyonium spinulosum*; finally, *Polyplumaria*

360   *flabellata* was one of the most frequently observed hydrozoans.

361   The best represented groups characterizing epibenthic assemblages forming habitats

362   were cnidarians (17 taxa) and echinoderms (12 taxa) (Table 1) as well as sponges, but in the

363   latter case they were aggregated into groups of morphologically similar species. Large sponges

364   and the echinoid *C. cidaris*, followed by the gorgonian *A. hirsuta* and the scleractinians *F. chunii*

365   and *M. oculata*, were the most frequent habitat-typifying species observed in the study area

366   (Table 1). Finally, a total of 9 ichthyofauna taxa were also identified, with the blackbelly

367   rosefish *Helicolenus dactylopterus* being the most representative fish species identified in

368   Gazul MV and surrounding areas and observed mostly on MXB, HB and CRB.

369   CLUSTER analyses split the samples into two main clusters at a level of 95.93% of

370   dissimilarity (Fig. 3A) and in a similar way of Fig. 2E. Bottom type seems to have a role in the

371   clustering, since the first cluster grouped samples mainly located on soft bottoms

372   (corresponding to soft bottom assemblages), whereas the second cluster was characterized by

373   samples mainly located on hard and mixed bottoms (corresponding to hard and mixed bottom

374   assemblages). The first cluster was further divided into three groups: Group IA (57% similarity

375   within the group) with samples collected on SRB, group IB (50% similarity) comprised mainly

376   samples of CSBB but also of SB, and group IC (40% similarity) grouped mainly samples of CSBB

377   but also of MXB (Fig. 3A). The second cluster grouped samples of MXB and hard bottoms that

378   included rocky and CRB, which formed one large group clustering at 24% similarity that was

379   divided into group IIA (36% similarity) with samples mainly located on bottoms with MDACs

380   but also on MXB, and group IIB (37% similarity) comprising samples mostly located on CRB, and

381   one small group (IIC) that corresponded to samples mostly located on MXB (Fig. 3A).

382   Assemblages obtained by means of CLUSTER analysis are also consistent in the two-

383   dimensional MDS plot. This revealed a good data fit in the ordination of all samples since raw

384   stress (a measure of the goodness-of-fit of the representation of the true similarity matrix

385   values by the ordination according to Clarke (1993)) was 0.08, with a segregation of samples

386   according to faunal composition and structure, which also responded to bottom type (Fig. 3B).

387   Table 2 shows faunal differences between clusters (interpreted as different assemblages

388   conforming habitats) highlighted by the SIMPER analysis. This analysis revealed that

389   differences between assemblages on soft and hard-mixed bottoms were mostly due to the

390   presence and/or higher abundance of *F. chunii*, *A. richardi*, *C. cidaris* and *Peachia* sp. on soft

391   bottoms, and of large and small-digitate sponges, *A. hirsuta*, *M. oculata*, hydrozoans and *A.*

392   *setubalense* on hard-mixed bottoms (Average dissimilarity= 94.99%).

393   Differences in the composition and structure of faunal assemblages between bottom

394   types and sites were detected by the PERMANOVA analysis (Table 3). Pairwise comparisons

395   revealed that differences were consistently significant among all bottom types ($p< 0.001$, for

396   all cases) and sites ($p< 0.001$, for all cases). The largest differences among bottom types were

397   detected between assemblages of CRB and those of SRB (Pairwise test: t= 20.802; Average

398   dissimilarity: 1.79%), and among sites, between assemblages at the northern flank of the MV

399   and those located at the western adjacent area (Pairwise test: t= 13.578; Average dissimilarity:

400   94.53%). Overall, soft bottoms presented a significantly lower number of taxa than hard and

401   mixed bottoms (Mann-Whitney: U= 6725.5; $p< 0.001$), with the lowest value observed in SB

402   (12 taxa) and the highest one in MXB (32 taxa); on the other hand, CRB displayed the highest

403   mean number of taxa per sample (5.3±0.2 taxa; mean±SE), whereas the lowest values was

404   observed in CSBB (1.5±01 taxa).

405   PERMANOVA also showed, for some assemblages, significant differences regarding

406   different bottom types and/or sites. For instance, hard bottom assemblage IIB (corresponding

407   to CRB with colonial scleractinians, see below) displayed a significantly different structure

408   considering both factors, being more distinct for site than for bottom-type (PERMANOVA:

409   factor bottom type, Pseudo-F: 6.186, $p< 0.001$; factor site, Pseudo-F: 18.641, $p< 0.001$). In this

410   case, pairwise comparisons after PERMANOVA revealed that the largest average dissimilarity

411   was detected between the MV summit and the northern flank (SIMPER: 63%) due to higher

412   abundances of *A. subpinnata*, *L. glaberrima*, *M. oculata* and large sponges in the northern

413   flank. In the case of the widely distributed soft bottom assemblage IB (corresponding to a *F.*

414   *chunii* assemblage, see below), differences were only significant for site (PERMANOVA: factor

415   bottom type, Pseudo-F: 0.634, $p= 0.499$; factor site, Pseudo-F: 15.626, $p< 0.001$), with the

416   highest average dissimilarity (SIMPER: 82.37%) observed between the western depression and

417   the southern flank of the MV due to the higher abundance of *F. chunii* and the presence of *C.*

418   *cidaris* in the western depression, and the presence of *Peachia* sp. in the southern flank.

419   Regarding multivariate analyses based on both biological and seafloor characteristics,

420   six different assemblages were detected (Fig. 3), with three main soft bottom assemblages

421   identified as:

i) Soft bottoms dominated by the actiniarian *Actinauge richardi* (group IA): this assemblage was found on SRB of the western adjacent area, where it was observed in 85 samples (17.6 %F). It is characterized by *A. richardi* (semi-quantitative index [SQI] values: 2-4), which reached densities up to 25 individuals per square meter (indiv. m^{-2}) (Fig. 4A-C); secondary characteristic species included *Peachia*-like actinarians (SQI values: 1-2), which were observed in high densities in some samples, the echinoid *C. cidaris* (SQI values: 1-2) and isolated individuals of the solitary scleractinian *F. chunii*.

ii) Soft bottoms dominated by the scleractinian *Flabellum chunii* (group IB): this assemblage was mainly found on CSBB, being recorded in 128 samples (25.3 %F), and at a lower extent on SMB. This is the most frequent assemblage found on soft bottoms of Gazul MV and surrounding areas (50.2 %F). Its characteristic species is the solitary coral *F. chunii* (Fig. 4D-G), which showed densities between 1 and 3 indiv. m^{-2} (SQI values: 2-3). Nevertheless, a highly dense aggregation was observed at the western depression, with densities up to 10 indiv. m^{-2} (SQI values: 4-5) (Fig. 4F). Characteristic species include *Peachia*-like actinarians, which were observed on SMB of the central depression, and were locally very abundant (SQI values: 3) (up to 4 indiv.·m^{-2}), with *C. cidaris* mainly occurring at the western depression (SQI values: 1-2), and with isolated individuals of the polychaete *Hyalinoecia tubicola* (Fig. 4H).

iii) Soft bottoms dominated by the echinoid *Cidaris cidaris* (group IC): the sea urchin *C. cidaris* was widely distributed (SQI values: 1-2), mainly observed on soft bottoms (52.7%), but also on hard (27.3%) and mixed (20%) ones. It was found to be a locally dominant species on several soft bottoms of the study area, characterizing this assemblage in 7.5% of the samples. Density of *C. cidaris* did not usually exceed 2 indiv. m^{-2} (Fig. 4I-J), and it was accompanied by *F. chunii* in CSBB, isolated pennatulaceans (e.g. *Funiculina quadrangularis*) in SMB, and by the decapod *Munida intermedia* in MXB.

Three main assemblages were identified on CRB and on hard bottoms (Fig. 3), mainly conformed by MDACs and sometimes intermixed with soft bottoms:

iv) Hard and mixed bottoms dominated by sponges and gorgonians aggregations (group IIA): this assemblage included (1) **aggregations of sponges**, which were observed colonizing MXB and hard substrates in 84 samples (16.6 %F). Characteristic species, such as the demospongians *Phakellia* spp. and *Poecillastra compressa* among others, constitute the large sponges group (SQI values: 2-3) (Fig. 5A), recorded in 127 samples and reaching densities up to 12 colonies per square meter (col. m^{-2}), together with large individuals of the hexactinellid *Asconema setubalense* (SQI values: 2-3) (40 samples; Fig. 5C), and encrusting and digitate

455   sponges (SQI values: 2) (22 samples; up to 23 col. m^{-2}). The (2) **gorgonian aggregations** (<1 %F)

456   were observed on MXB and dominated mainly by *Acanthogorgia hirsuta* (SQI values: 2) (up to

457   15 col. m^{-2}; Fig. 5D) and the *Bebryce*-group (SQI values: 1), which were sometimes

458   accompanied by other gorgonians such as the large *Callogorgia verticillata* (Fig. 5E), as well as

459   by isolated large sponges and *C. cidaris*. The (3) **mixed sponge-gorgonian aggregations** were

460   observed in 79 samples (15.6 %F), mainly on hard bottoms of the mounds located in the

461   eastern adjacent area. A mixed and dense aggregation of *A. setubalense* (up to 4 col. m^{-2}) and

462   *A. hirsuta* (up to 10 col. m^{-2}) was found in those mounds. Sponge aggregations and mixed

463   sponge-gorgonian aggregations also included other typifying species such as *C. verticillata* (SQI

464   values: 1)*, small gorgonians (mostly *Bebryce mollis* and *Swiftia dubia*; Fig. 5B) (SQI values: 2-3),

465   different echinoderms such asteroids (e.g. *Chaetaster longipes*), crinoids (e.g. *Leptometra

466   phalangium*) and echinoids (e.g. *C. cidaris*, *Gracilechinus acutus*) (SQI values: 1, respectively),

467   the decapod *M. intermedia* (SQI values: 2) and the octopus *Eledone cirrhosa* (SQI values: 1).

468   **v) Coral-rubble bottoms dominated by colonial scleractinians** (group IIB): this assemblage is

469   associated with CRB occurring at the northern flank and close to the summit of Gazul MV. It is

470   characterized by the white coral species *Madrepora oculata* (SQI values: 2-4) (96 samples;

471   density up to 10 col. m^{-2})*, Lophelia pertusa* (SQI values: 1-2) (16 samples; up to 1 col. m^{-2}) and

472   *Dendrophyllia cornigera* (SQI values: 1-2) (14 samples; up to 3 col. m^{-2}), representing 16.8% of

473   the samples (Fig 5F-H). In addition, other typical species include the antipatharians (black

474   corals) *Antipathella subpinnata* (up to 6 col. m^{-2}) and *Leiopathes glaberrima* (up to 4 col. m^{-2}),

475   highly branched hydrozoans (e.g. *Polyplumaria flabellata*), large sponges (up to 6 ind. m^{-2}) (SQI

476   values: 2-3, respectively), encrusting and small-digitate sponges (SQI values: 2-3), gorgonians

477   (e.g. *A. hirsuta, B. mollis*), as well as abundant bright-orange ophiurids (*Ophiothrix*), the

478   echinoids *G. acutus*, *Echinus melo* and *C. cidaris*, and the decapod *M. intermedia* (SQI values: 1-

479   2, respectively).

480   **vi) Mixed bottoms dominated by styelid ascidian aggregations** (group IIC): this assemblage is

481   strongly associated with slabs located on bottoms with sand ripples of the western adjacent

482   area of the Gazul MV. This assemblage showed a low frequency of occurrence (<1 %F), and

483   was characterized by the presence of a dominant styelid ascidian (probably belonging to the

484   genus *Polycarpa*) (SQI values: 4-5), which reached densities up to 50-70 ind. m^{-2} (Fig. 5I-J).

485   These ascidians were accompanied by *B. mollis* colonies (SQI values: 2-3), crinoids, the

486   decapods *M. intermedia* and *Bathynectes maravigna*, yellowish encrusting sponges and large

487   colonies of the polychaete *Filograna implexa* (SQI values: 1-2, respectively). Ascidians were

488   also observed on hard substrates slightly covered by sediments of the mounds located in the

489   western adjacent area, intermixed with aggregations of *A. hirsuta* (up to 15 col. m^{-2}) and large

490   white sponges (up to 3 ind. m^{-2}).

491   *3.3. Effects of seafloor variables on the epibenthic assemblages*

492   The multivariate CCA ordination analysis of the characteristic species generated an ordination

493   biplot with the first two axes explaining 16.4% of variance of the species data, and which

494   accounted for 84.4% of the variation of the species and the seafloor variables relationship

495   (Table 4). A Monte Carlo test indicates that all canonical axes together were highly significant

496   (p <0.001; 999 permutations under full model). Marginal effects (fit of the first CCA axis with

497   each variable entered separately) determined by the forward selection procedure of CANOCO

498   were highest for slope, depth and backscatter. Regarding conditional effects (additional fit as

499   each variable is added to the model), the analysis highlighted slope, backscatter and BPI.

500   Figure 6 shows the CCA biplot based on CCA axes 1 and 2, with slope and depth negatively

501   correlated with axis 1, whereas axis 2 was positively correlated with backscatter (Table 4).

502   Seafloor profile curvature made the lowest contribution to axis building, showing low

503   discriminatory power. CCA sample discrimination and grouping were consistent with the

504   groups obtained from the cluster and ordination analysis (Fig. 3).

505   *3.4. Anthropogenic activity indicators at Gazul MV and surrounding areas*

506   Bottom trawling represented the main type of commercial fishing technique in the area;

507   however, it must be considered that the authors could not obtain information on recreational

508   or artisanal fishing that could occasionally occur at Gazul MV. Bottom trawling effort (total

509   number of hours of trawling per km^2 for the period 2006-2012) showed the highest values in

510   the upper slope of the continental margin (depths ranging between 130-530 m). Trawling

511   effort decreased in intensity between 400-500 m depth, with the lowest effort values observed

512   around Gazul MV. No signs of bottom trawling were observed on the seabed. Effort increased

513   towards the westernmost part of the SCI "*Volcanes de fango del Golfo de Cádiz*" (depths

514   ranging between 500-600 m) and around Anastasya MV, where trawling activity is focused on

515   the Norway lobster (*Nephrops norvegicus*) (Fig. 7).

516   A total of 28 marine litter items were recorded in the samples, including mostly

517   artificial polymer materials (85.2 %), but also glass (14.8 %). Overall and regarding type of item,

518   fishing gears represented the dominant source of debris (63.0 %) (Fig. 8A-F), including fishing

519   lines and nets. Ropes were occasionally found, representing 3.7 % of the samples. Finally,

520   plastic and glass were observed in 18.5 % and 14.8 % of the samples, mostly as bottles (Fig.

16

521 8G). The highest occurrence of marine litter, mostly fishing lines, was observed in the western

522 adjacent area (42.9% of the total observed) followed by the western depression (25%) and the

523 northern flank (14.3%).

524 More than half of marine litter items (61.5%) were observed in contact with sessile

525 invertebrates, probably causing potential abrasion on large sponges, gorgonians and/or

526 ascidians on mixed bottoms (56.2%) (Fig. 8A); on colonial scleractinians, black corals and large

527 sponges on coral-rubble bottoms (25%) (Fig. 8B-C); and on *Actinauge* individuals on soft

528 bottoms (18.8%). A small piece of net was observed snagged on a MDAC covering partly a

529 *Madrepora* colony (Fig. 8F). The remaining portion of debris (plastic, bottles) was recorded

530 lying on soft bottoms (60%) (Fig. 8G), and up to three lost fishing lines were observed hanging

531 in hard substrates on mixed bottoms (40%), in both cases without producing any apparent

532 injury to sessile organisms.

533 **Discussion**

534 ***Substrate and habitat heterogeneity***

535 Based on the new observations made in this study, Gazul is an example of a MV with

536 latent/dormant conditions (León et al. 2007). Gazul MV presents a high availability of MDACs

537 (e.g. tabular-shape chimneys, slab-shaped pavements and crusts) on the seafloor (Palomino et

538 al., 2016; this study). MDACs were formed within the sediments during past seepage activity,

539 and exhumed and exposed to seawater as a consequence of erosive processes by strong

540 bottom currents, resulting in a high structural complexity of the seabed (Cunha et al., 2002;

541 León et al., 2007; Magalhães et al., 2012; Viola et al., 2014; Sánchez-Leal et al., 2017). The

542 chimney forest reported in this study for Gazul MV represents one of the very few examples of

543 columnar carbonates fields in vertical position found in European waters (Angeletti et al.,

544 2015), and to the best of our knowledge, it is the first reported for the GoC, which

545 complements other observations on chimney fields of the GoC (Díaz-del-Rio et al., 2003;

546 Somoza et al., 2003; Magalhães et al., 2012).

547 The identified epibenthic assemblages forming habitats associated with soft and hard bottoms

548 of Gazul MV and surrounding areas showed a patchy mosaic distribution with spatial

549 differences, with hard bottoms of the MV edifice containing the most biodiverse assemblages.

550 Several authors have observed that the existence of different habitat types in submarine

551 elevations (e.g. seamounts) are promoted by the presence of diverse substrate types and

552 geomorphological structures occurring at different depths (McClain and Lundsten, 2015; Du

Preez et al., 2016; de la Torriente et al., 2018). In a similar way, the high geomorphological variability and diversity of bottom types of Gazul MV, as well as the different exposition to bottom currents (Palomino et al., 2016), promotes the existence of biodiverse and vulnerable faunal communities dominated by sessile slow growing suspension and filter feeding macro-organisms such as deep-water corals and sponges, which potentially benefit from moderate-strong bottom currents (Fernández-Salas et al., 2012) and from an enrichment process promoted by land-based runoff of important rivers such as the Guadalquivir (García-Isarch et al., 2006). On the other hand, the diversity of soft bottoms around Gazul MV promotes a colonization by a variety of species, some of them with a high commercial value (e.g. Norway lobster), enriching the associated benthic communities when compared to other soft bottoms within the GoC (Fernández-Zambrano, 2010; Lozano et al., 2020a).

Each assemblage at Gazul was preferentially associated with a specific bottom type and a combination of seafloor characteristics, with slope, backscatter and depth as the most important factors determining the distribution of habitats and assemblages. These results are similar to the observations made by de la Torriente et al. (2018) when studying the distribution of epibenthic communities at the Seco de los Olivos Seamount (also known as Chella Bank) (western Mediterranean Sea), as well as by other authors at different submarine elevations and depth ranges (McClain and Lundsten, 2015; Bernardino et al., 2016; Du Preez et al., 2016). The presence of hard structures (e.g. MDACs) increase the habitat complexity of the MV edifice and those of the central and western depressions, when compared to the adjacent bottoms, representing a major factor influencing the distribution of the benthic communities (Cunha et al., 2002, 2009; Rueda et al., 2016). Similar patterns of spatial differentiation have been found in coral mounds and adjacent bottoms without colonial scleractinians that are generally composed by a lower number of species (Henry and Roberts, 2007), as well as in those communities of seamounts when compared to the impoverished adjacent bottoms (Danovaro et al., 2010).

Bottom complexity further increases once MDACs on the seafloor are colonized by organisms usually presenting complex three-dimensional structures (e.g. colonial scleractinians, gorgonians, sponges) (Jensen et al., 1992; Díaz-del-Río et al., 2003; León et al., 2007; Buhl-Mortensen et al., 2010; Levin et al., 2015; Wienberg and Titschack, 2017), promoting a diversification of microhabitat types that are used by numerous species, enriching the associated faunal communities. These habitat-forming organisms are in some cases also responsible for generating the substrate, shelter and food for other benthic species (Buhl-Mortensen et al., 2010; Rossi et al., 2017), thus increasing the differences with the adjacent

18

soft bottoms, as it has been observed in the present study. In this line, for instance Henry and Roberts (2007), as well as Buhl-Mortensen et al. (2016), proposed that coral communities offer high vertical habitat heterogeneity (living/dead coral, rubble, sediment-clogged framework, etc.) and thus high biodiversity, which foster a characteristic reef fauna. At Gazul MV, the species previously reported that may benefit from habitat-forming species included the polychaete *Eunice norvegica* (Linnaeus, 1767) (associated with the scleractinian *Madrepora oculata*), the gastropods *Emarginula* spp. and triphorids that feed on sponges, and solenogastres, epitonids and ovulids that are generally associated with gorgonians, actinaria and scleractinians of Gazul MV (Rueda et al., 2016; Utrilla et al., 2020).

Soft bottom assemblages

Three main epibenthic assemblages were identified in the soft bottoms of Gazul MV and surrounding areas, being characterized by deposit feeders such as solitary hard (*Flabellum chunii*) and soft cnidarians (*Actinauge richardi*), as well as by cidarid echinoids (*Cidaris cidaris*). Similar species were reported by Fernández-Zambrano (2010) as dominant ones in adjacent sedimentary habitats around Gazul MV from samples collected with a combination of gears (beam-trawl, box-core and shipek grab), mostly contributing to differences between faunal assemblages inhabiting adjacent bottoms in comparison to those of the MV.

Trophic and oceanographic drivers control the spatial distribution of *A. richardi* populations, which were observed in the western adjacent area of Gazul MV, an area with strong bottom currents reflected by the presence of a sandy ripples field. This sea anemone is a passive suspension feeder that inhabits muddy or sandy bottoms, always offshore (BIOTIC, 2019). Hormathiid actinarians (Hexacorallia) such as *A. richardi* have been observed dominating faunal communities on circalittoral and bathyal sedimentary bottoms of the Cantabrian Sea (e.g. Avilés canyon), GoC and Mediterranean Sea (e.g. Llanes canyon) (Aguilar et al., 2009; Ruiz-Pico et al., 2010; Rueda et al., 2016; Lozano et al., 2020a), and represents a key taxa typifying deep-sea sedimentary assemblages.

In contrast, the solitary scleractinian *F. chunii* presents a certain structuring character in sedimentary habitats, being locally abundant in specific soft bottoms of the GoC, as well as of the Galicia Bank (NW Spain) and of the Conception Bank (Canary Islands) (Almón et al., 2010; de la Torriente et al., 2014; Díaz-del-Río, 2014).

Finally, the dominant echinoderm *C. cidaris* showed a patchy distribution in Gazul MV; it occurs mainly in soft bottoms, but also in hard and mixed bottoms. Similar observations were made by Delgado et al. (2013) in soft bottoms of the SFFE of the GoC from otter-trawl samples,

620 where *C. cidaris* represented one of the dominant species throughout the year, relating its
621 patchy distribution to sediment characteristics.

622 Faunal assemblages inhabiting soft bottoms around MVs are not as biodiverse as those
623 associated with MVs themselves due to the lower structural complexity of habitats (Fisher et
624 al., 2007; Cunha et al., 2009; Levin et al., 2015; Rueda et al., 2016). Nevertheless, according to
625 Delgado et al. (2013), soft bottoms of the MVGoC presents species richness values that are
626 higher to those reported in northern Spain and the Alboran Sea at similar depths, and this
627 could be related to the geographical location of the GoC, in the Atlantic-Mediterranean and
628 subtropical-template transition (i.e. confluence of fauna). Indeed, the oceanographic context
629 of the GoC is complex and characterized by a surficial Atlantic Inflow Water (AIW) current
630 towards the Alboran Sea and a deep Mediterranean Outflow Water (MOW) current towards
631 the Atlantic Ocean (Sánchez-Leal et al., 2017). These water masses may transport larvae and
632 organisms from the Mediterranean and the Atlantic, promoting a biological confluence in the
633 GoC that could result in high biodiversity in those areas with a high benthic complexity that
634 can harbor species associated with different substrates as detected at the Gazul MV.

635 ***Hard bottom assemblages***

636 Hard bottoms of Gazul MV showed a heterogeneous distribution, being represented by MDAC
637 formations and by coral-rubble, in both cases increasing the complexity of soft bottoms and
638 promoting a mixture of hard- and soft-bottoms fauna. The exhumation of MDACs are favored
639 by moderate-strong bottom currents that at the same time promotes a continuous availability
640 of food particles, which supports complex faunal communities mainly composed of filter and
641 suspension feeders (Hovland, 2008). Live colonies of the white coral *Madrepora oculata*,
642 intermixed with some dispersed colonies of other colonial scleractinians such as *Dendrophyllia*
643 *cornigera* and the less frequent *Lophelia pertusa*, were observed associated with coral-rubble
644 bottoms of the northern flank and close the summit of Gazul MV. This represents one of the
645 few records of live colonies of these colonial scleractinians in the GoC (Rueda et al., 2016),
646 which seems to represent an unsuitable area for these species after the past glacial periods
647 (Wienberg et al., 2009; Van Rooij et al., 2011). Nevertheless, densities of *M. oculata* colonies in
648 Gazul MV are occasionally as high as in other areas of the Mediterranean Sea (up to 10
649 colonies m^{-2}) (Orejas et al., 2009). In several studies dealing with scleractinians of the GoC and
650 adjacent areas, abundant coral graveyards related to massive declines after glacial periods
651 have been found but no live colonies could be detected (Wienberg et al., 2009; Wienberg and
652 Titschack, 2017; Hebbeln et al., 2019). Recently, carbonate mounds with abundant remains of

653 *M. oculata* have also been found in the Pen Duick Escarpment in the Moroccan margin, but no
654 living colonies of this coral could also be detected (Van Rooij et al., 2011). In the Strait of
655 Gibraltar, remains of this species were found between 33 and 443 m depth, especially in one
656 particular area with mounds, but no clear indication was given on the presence of live colonies
657 by the authors (Álvarez-Pérez et al., 2005). In the Mediterranean Sea, live scleractinian
658 colonies (mainly of *L. pertusa* and *M. oculata*, but also *Dendrophyllia* spp. and *Desmophyllum*
659 *dianthus*) have been found in specific areas such as the southern Adriatic Sea, Santa Maria di
660 Leuca, the Corsica Channel and the Strait of Sicily in the central Mediterranean (Schembri et
661 al., 2007; Vertino et al., 2010; Rossi et al., 2017; Angeletti et al., 2019; D'Onghia, 2019; Lo
662 Iacono et al., 2019; Rueda et al., 2019; Angeletti et al., 2020), and Cap de Creus canyon and
663 some Alboran Sea seamounts and banks in the western Mediterranean (Orejas et al., 2009;
664 Pardo et al., 2011; Gori et al., 2013; Lo Iacono et al., 2014; de la Torriente et al., 2018; Aymà et
665 al., 2019; Corbera et al., 2019; Puig and Gili, 2019; Rueda et al., 2019). Further deep-sea
666 exploration with the use of non-invasive methods such as the ones used here (e.g. ROV, ROTV)
667 will allow the discovery and documentation of new white coral sites, as well as to increase the
668 information about their associated communities with the combination of sampling methods
669 targetting endofauna, epifauna and demersal fauna.

670 The widespread presence of colonial scleractinians and antipatharians in the northern flank
671 and close to the summit of the MV is related to the characteristics of the substrate (i.e. the
672 presence of coral-rubble bottoms, which gives them a preferable elevated position), as well as
673 potentially to the enhanced availability of food. This could be linked to the high-speed flow
674 promoted by the interaction between bottom currents and topography (Palomino et al., 2016),
675 which benefit these and other organisms (White et al., 2005, Dorschel et al., 2007, Mienis et
676 al., 2007, Orejas et al., 2009, Sánchez et al., 2014), as observed for other filter-feeding
677 assemblages inhabiting similar mud volcanoes of the GoC (Fernández-Salas et al., 2012; Lozano
678 et al., 2020a, b). On the other hand, although high reflectivity values may indicate the
679 presence of hard substrates (e.g. coral-rubble) on the southern-southeastern flank of the MV
680 (see Fig. 2), potential lateral sedimentation by dragging along the slope would cause the
681 sediment to be deposited on this flank of the MV, resulting in the scarce occurrence of hard
682 formations on the seafloor. A high sediment supply is necessary to guarantee the fast infilling
683 of the coral framework, being entrapped within it and providing a stabilizing effect, but it also
684 increases sediment accumulation (Wienberg and Titschack, 2017; Hebbeln et al., 2019). This is
685 probably the cause of the scarce presence of colonial scleractinians on this flank of the MV,
686 which is characterized by sandy and muddy bottoms colonized by solitary corals and cidaroid

687 echinoids. Similar observations were made by Orejas et al. (2009) in the Cap de Creus canyon,

688 linking the scarcity of colonial scleractinians on the northern flank of the canyon to a prevailing

689 depositional regime with high sediment accumulation rates.

690 Besides colonial scleractinians, many suspension-feeding species are also favored by the

691 environmental conditions at Gazul MV, including large deep-sea sponges (90% of the biomass

692 collected with different sampling gears; see Rueda et al., 2016, Sitjà et al., 2019; e.g. *Asconema*

693 *setubalense*, *Pachastrella* sp., *Poecillastra compressa*, *Petrosia crassa*), several species of

694 gorgonians (e.g. *Swiftia dubia, Bebryce mollis, Acanthogorgia hirsuta*) and black corals

695 (*Antipathella subpinnata* and *Leiopathes glaberrima*), among other macro-organisms. These

696 species have been observed colonizing both exposed MDACs and those with moderate charges

697 of fine sediments located in the MV and adjacent mounds. Regarding this, Gazul MV

698 represents a conical edifice that reaches 100 meters above adjacent bottoms, which may

699 induce turbulent hydrodynamics due to the interaction between the predominant

700 northwestern wards current and the MV that provides organic particles and removes

701 sediments that may smother sessile organisms as those abovementioned. Moreover, these

702 organisms are probably benefited by productive local upwellings and mass and energy inputs

703 from land-based runoff (e.g. Guadalquivir river) that occur in this area as also found along the

704 Portuguese coasts of the GoC (García-Isarch et al., 2006; García-Lafuente and Ruiz, 2007;

705 Echevarría et al., 2009). In addition, Vázquez et al. (2009) and Bruno et al. (2013) explained

706 how large-amplitude internal waves generated on the lee side of Camarinal sill induce a

707 suction of chlorophyll-rich water masses from the coastal margins (e.g. Cape Trafalgar, see Sala

708 et al., 2018) toward the central zones of the channel (i.e. towards the pathway of the MOW).

709 Deep-sea sponges are one of the dominant taxa at Gazul MV, with some species capable of

710 forming dense local aggregations, e.g. the sponges *A. setubalense*, *P. compressa* and *P. crassa*.

711 This was also observed by Sitjà et al. (2019), who studied the sponge fauna of the whole MV

712 field of the northern GoC from samples collected using a 2 m-wide beam trawl. These authors

713 highlighted the presence of a 'micro-aggregation' of 71 individuals of the carnivorous sponge

714 *Lycopodina hypogea* (Vacelet and Boury-Esnault, 1996) on a flattened carbonate boulder of 35

715 cm^2 collected from Gazul MV, this species being rarely found in such high densities. The

716 sponge faunal list provided by Sitjà et al. (2019) for the MVGoC, with three sponge species

717 previously documented in the Mediterranean Sea and recorded in the Atlantic Ocean for the

718 first time (*Geodia anceps* (Vosmaer, 1894), *Coelosphaera (Histodermion) cryosi* (Boury-Esnault,

719 Pansini and Uriz, 1994) and *Petrosia (Petrosia) raphida* (Boury-Esnault, Pansini and Uriz, 1994)),

720 would support the idea that the natural export of Mediterranean deep-sea benthos by the

22

721 MOW might be more important than previously believed. Moreover, Sitjà et al. (under review)
722 found that the deep-sea sponge fauna of the GoC showed closer affinity with that of the
723 western Mediterranean than with the fauna of the northeastern Atlantic. According to the
724 authors, this pattern clearly illustrates the importance of the MOW in transporting
725 components of the Mediterranean deep-sea sponge communities towards the bathyal
726 communities of the GoC.

Anthropogenic impact

728 The most active commercial fishing fleet operating around Gazul MV is the trawling fleet,
729 which represents a multi-species fishery spanning a wide geographic area, with the main target
730 species including the Norway lobster and the deep-water rose shrimp, as well as other
731 accompanying species such as the European hake (*Merluccius merluccius* (Linnaeus, 1758)) and
732 the monkfish (*Lophius* spp.), among others (González-García et al., 2020). The greatest fishing
733 effort throughout the historical dataset is located where the fishing grounds for the Norway
734 lobster and for the deep-water rose shrimp overlap, matching spatially with the geographical
735 location of these fishing grounds according to Ramos et al. (1996). Shallow areas of the upper
736 continental shelf of the GoC are suitable for some commercial species that prefer muddy
737 bottoms, such as in the case of the Norway lobster, concentrating a great part of the fishing
738 activity carried out in the GoC. Contrary to this, the trawling activity around Gazul MV is low
739 mostly due to the presence of MDACs and moderate and high near-bottom current speed that
740 may promote the presence of coarser sediments that are not ideal for the Norway lobster and
741 that may make the trawling operations very difficult (González-García et al., 2020). Another
742 important commercial fishing fleet operating in the area, but with a low impact on benthic
743 habitats, are represented by that using purse seine nets along the continental shelf down to
744 100 m depth and targeting mainly the European anchovy *Engraulis encrasicolus* (Linnaeus,
745 1758) and the European pilchard *Sardina pilchardus* (Walbaum, 1792) (Silva et al., 2012).
746 Finally, commercial bottom longline fishing is carried out mostly in the Strait of Gibraltar area
747 targeting mainly the blackspot seabream *Pagellus bogaraveo* (Brünnich, 1768) (Silva et al.,
748 2012).

749 In this study, the occurrence of marine litter is mainly caused by fishing gears such as lost
750 nylon long lines, representing more than half of all debris found at Gazul MV. Bottom longline
751 fishing activity obtained from VMS datasets for the evaluation of the Marine Strategy
752 Framework Directive shows that this fleet operates mostly off Trafalgar Cape, but also at some
753 isolated locations of the northern Gulf between Cádiz and Matalascañas, in all cases on the

continental shelf (Silva et al., 2012). These areas are geographically distant from Gazul MV, and thus the longlines observed in the images would come from remote locations, being swept away by strong bottom currents in this area of the GoC. Another explanation could be that these lost longlines come from recreational fishing taking place around Gazul MV, where longlines get stuck in hard substrates. Boats engaged in recreational fishing are not required to carry any location system or to track their catches in fishing logbooks, so it is very difficult to track their fishing activity within the GoC. Similar observations have been made in other deep-sea areas of southern Europe characterized by intense fishing activities, such as those in the Tyrrhenian Sea (NW Mediterranean Sea) (Bo et al., 2014; Angiolillo et al., 2015). Although the abundance of marine litter recorded at Gazul MV is relatively low, a nylon line takes up to six hundred years to decompose (Bollmann et al., 2010). Therefore, lost or abandoned fishing gears such as lines and nets can potentially have a high impact on benthic communities dominated by large and branched scleractinians, gorgonians, black corals and sponges, which are easily snagged, covered and/or abraded by derelict gears as they can move laterally across the seabed by the action of strong bottom currents (Ragnarsson et al., 2017). Besides this direct damage, injured specimens can suffer epibiotic colonization by opportunistic fast-growing species (e.g. hydroids, or polychaetes) that can lead to the death of colony portions or even the entire colony (Mistri, 1994). In those areas heavily impacted by fishing and lost fishing lines, potential effects include the decrease of the coverage of habitat-forming species and lastly the diversity and abundance of associated invertebrates (Bo et al., 2014; Fabri et al., 2014), which could modify the structure and functioning of deep-sea ecosystems. Future adequate management actions to be developed within the Site of Community Importance "*Volcanes de fango del Golfo de Cádiz*" could take advantage of the results presented here, as they provide a quantitative assessment of marine litter and its distribution at Gazul MV, as well as a baseline for future monitoring efforts. Similarly, this information can be used as a first step for setting the targets of Descriptor 10 (marine litter) within the Marine Strategy Framework Directive. Further monitoring of potential recreational fishing activity should be implemented in the area together with trawling restrictions for the commercial trawling fleet.

Habitat & Biodiversity Conservation

Gazul MV, as well as other fluid venting submarine structures of the GoC, represents a clear example of Habitat 1180 (Submarine structures made by leaking gases) under the Habitat Directive 92/43/EEC (European Commission DG Environment, 2013) considering its geological past and the presence of mud breccia and MDACs (Palomino et al., 2016). Regarding the composition and structure of the faunal assemblages identified in this and other more general

788   studies (Rueda et al., 2016; Lozano et al., 2020a), Gazul MV may also represent an example of

789   Habitat 1170 (Reefs) due to the presence of large quantities of MDACs colonized by deep-sea

790   sponges (e.g. *A. setubalense, P. crasa, Phakellia* spp., among others) with some colonial

791   scleractinians (e.g. *M. oculata*), black corals (*A. subpinnata*, *L. glaberrima*) and gorgonian

792   species (e.g. *A. hirsuta, S. pallida*, among others). Habitats found in Gazul MV are also similar

793   to those included in other conventions such as OSPAR (Convention for the protection of the

794   Marine Environment of the North-East Atlantic) under the names "Coral gardens" or "Deep-

795   sea sponge aggregations" (OSPAR Commission, 2008); furthermore, the VMEs documented in

796   Gazul   MV   have   been   recently   included   in   the   VME   database   from   ICES

797   (https://www.ices.dk/marine-data/data-portals/Pages/vulnerable-marine-ecosystems.aspx).

798   Gazul MV is located close to the coast at shallower depths than other MVs of the northern

799   GoC, and is therefore one of the most vulnerable MVs in Spanish waters to human activities

800   (Palomino et al., 2016). Bottom-trawl fisheries may have already caused significant impacts to

801   benthic communities, as detected in the abundant remains of nets, ropes and wires

802   documented in the underwater images. Taking into account the Marine Strategy Framework

803   Directive (adopted in June 2008) that aims to more effectively protect the marine environment

804   across Europe, bottom trawl fisheries should be banned in the vicinity of the Gazul MV as this

805   ecosystem represents a small but locally significant area within the GoC with high ecological

806   values due to the presence of several ecologically important VMEs (three species of reef

807   framework-forming corals, coral gardens including solitary scleractinians, gorgonians and black

808   corals, as well as deep-sea sponge aggregations) that seem to be rare in other areas of the GoC

809   (Cunha et al., 2009; Rueda et al., 2016). Moreover, trawling activity in Gazul MV is already

810   relatively low compared to that around other MVs and adjacent bottoms as documented in

811   this study, and this surely has benefited the establishment and persistence of populations of

812   very   slow-growing   and   structurally   complex   organisms.   In   this   sense,   the   potential

813   socioeconomic impact to bottom trawling after closuring this area to fisheries is expected to

814   be   low   according   to   González-García et al. (2020).   As   commented   previously,   other

815   fisheries operating in the northern GoC are concentrated on areas far from Gazul MV such as

816   along the continental shelf (down to 100 m depth) (e.g. purse seine nets) and close to the

817   Strait of Gibraltar (e.g. longlines), and also would not be compromised by closure of the Gazul

818   area. Finally, some biological and ecological attributes of Gazul MV (e.g. presence of MDACs

819   colonized by colonial scleractinians and antipatharians, sponges and black corals, among other

820   fauna; high biodiversity, including endemism species, for some faunal groups such as molluscs

821   (Utrilla et al. 2020) fit several criteria under the Convention on Biological Diversity for an

822　Ecologically or Biologically Significant marine Area (EBSA) (e.g. uniqueness or rarity;

823　importance for threatened, endangered or declining species and/or habitats; vulnerability,

824　fragility, sensitivity or slow recovery; biological diversity). In addition to Gazul MV, other areas

825　of the GoC also have high diversity of benthic habitats including carbonate mounds, submarine

826　canyons, channels and escarpments shaped by tectonic activity and erosion, MVs) (Díaz-del-

827　Río et al., 2006; Medialdea et al., 2009; Palomino et al., 2016), which could contribute to the

828　future potential nomination of a wider EBSA in the southern Iberian Peninsula that would

829　include the connected areas of the Alboran Sea, the Strait of Gibraltar and the GoC.

830

849   **Conflict of Interest**

850   The authors declare that the research was conducted in the absence of any commercial or

851   financial relationships that could be construed as a potential conflict of interest.

852   **Authors Contributions**

853   JU and JLR designed the structure of the manuscript. JU and DP coordinated and wrote the

854   manuscript. All authors were substantially involved in the literature search and/or writing of

855   the different sections of the manuscript, contributed to the final product in significant ways,

856   and/or provided approval for publication. Oceanographic expeditions´ chiefs were LMFS

857   (CHICA-0412), YV (ISUNEPCA-0616) and CO (MEDWAVES).

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