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Habitat mapping of Cabo Girão Marine Park (Madeira island): a tool for conservation and management

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Abstract
At the time Cabo Girão natural marine park was proposed (2016) and later when it was established, (2017), its effective conservation and marine spatial planning goals were hampered by the scarce knowledge on the sea floor habitats and biotic patterns inside the area. In the present work, a combination of different datasets and underwater surveys was used to produce the first habitat map of the Natural Marine Park of Cabo Girão, which is also the first habitat map for Madeira island. Five major habitats were identified, including two previously unknown for Madeira — *Avrainvillea canariensis* meadows and maërl beds. 132 marine taxa (macroflora, macrofauna and fishes) were identified, including 18 commercially important species and three vulnerable fish species. The results show that the methods used are useful to produce reliable information with limited resources. The information obtained is a tool for conservation and marine spatial planning, which allows for improved policy-making and better management. This study provides a baseline for the benthic habitats of this MPA against which future marine biodiversity changes can be recognised.

Keywords Habitat mapping · MPA · Madeira · Conservation · Marine spatial planning · Management

Introduction

Conservation of marine and coastal environments and their associated biodiversity is a global priority and the need for effective marine conservation, integrating a more holistic ocean management regime, has never been greater (Spalding et al. 2007). In fact, these areas represent some of the most productive environments of the ocean, inhabited by a wide array of species and complex benthic habitats (Eyre and Maher 2011).

Despite their importance, the biological resources of coastal zones are under extensive pressure worldwide, with habitats being altered and impacted in ways that only recently began to be understood, measured and monitored (Cogan et al. 2009; Knutsen et al. 2010). The impacts in coastal areas can be inflicted by pollution, habitat destruction, climate change, invasive species and overfishing, producing serious and irreversible damage on marine biodiversity. This has been documented in coastal areas throughout Europe and elsewhere (Knutsen et al. 2010) and it is also a problem in Madeira (Friedlander et al. 2017; Gestoso et al. 2017; Alves et al. 2018), where their direct destruction is the most important threat on marine habitats (Petit and Prudent 2010).

The archipelago of Madeira is located in the eastern North Atlantic Ocean about 700 km NW Africa and comprises the islands of Madeira (742 km^2), Porto Santo (43 km^2) and Desertas (14 km^2) — Fig. 1. The former two are inhabited islands, whereas Desertas remains uninhabited and legally protected since 1990 (SPNM 2004). The two inhabited islands are home to nearly 268.000 people, with a population density of more than 300 inhabitants/km^2, the highest in the Macaronesian region (Petit and Prudent 2010).

Madeira island's coastal marine ecosystems are under high pressure due to numerous human activities. The south, encompassing a coastline of about 100 km, is the most populated of the archipelago and therefore faces even higher human-induced pressures (Whittaker and Fernández-Palacios 2007). Tourism is the most important industry for the economy of the archipelago, with more than one million tourists visiting the islands annually (Oliveira and Pereira

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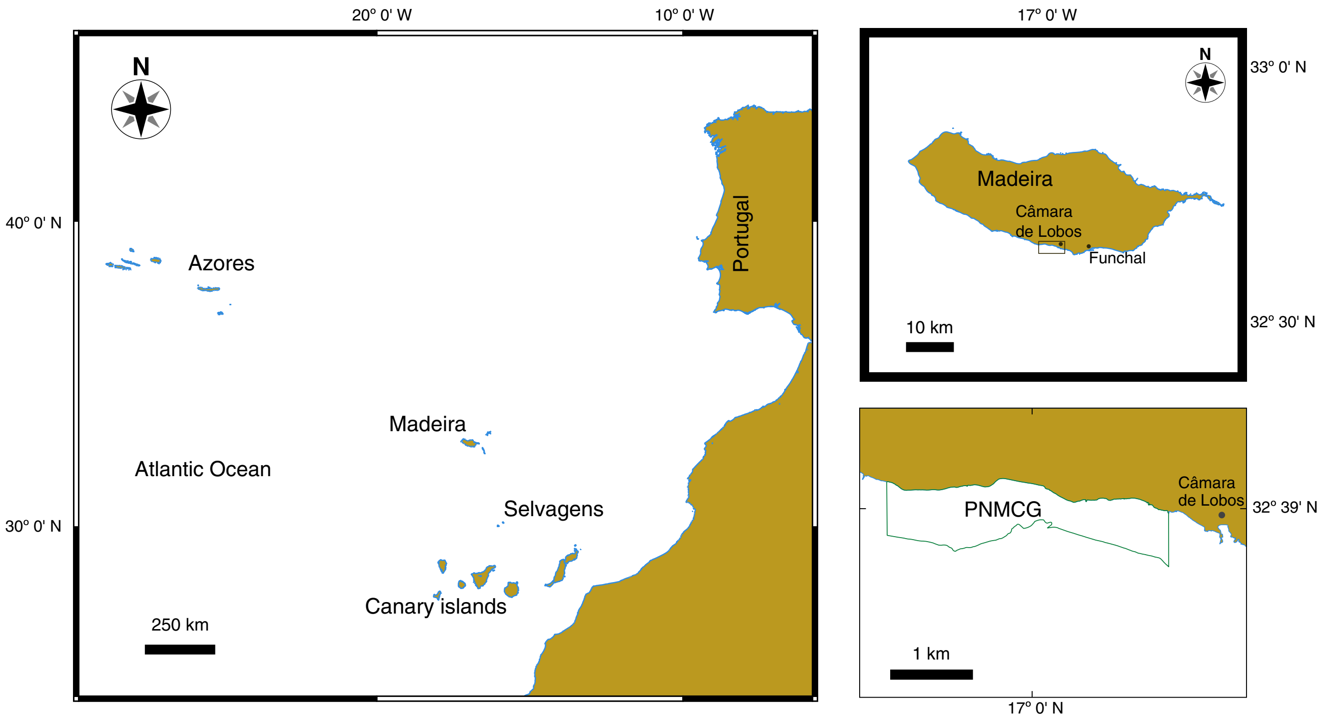

Fig. 1 Location of Madeira archipelago and of the Natural Marine Park of Cabo Girão

2008). To meet the constant demands of this activity, many infrastructures were built along coastal areas (e.g. harbours and marinas, hotels, etc.), that pose ever-growing pressures on marine habitats. Besides tourism, activities such as fisheries and aquaculture are also sources of impact on the coastal marine environments (Santos 2010; Hermida and Delgado 2016; Friedlander et al. 2017) of the island.

Recently, as a result of the European Union (EU) Blue Growth strategy and Horizon2020 financial framework, aquaculture has received an important boost with local production, supported by off-coast fish farms, expected to grow from 450 ton/year to approximately 5.000 ton/year by 2020. Within this scenario, and considering examples from other regions in the world, increasing impacts in coastal water quality, sediment conditions and benthic fauna and/or flora are expected to occur (Holmer 2010).

There are several examples of irreversible damage inflicted to Madeira's marine biodiversity in the last decades, but here the following two are highlighted: 1) the disappearance of a dense seagrass meadow of *Cymodocea nodosa,* that occurred over an area of about 200 × 400 m, between depths of 7 to 16 m in Machico Bay (SE coast of Madeira) — (Wirtz 1995); and 2) the massive decline of the *Cystoseira abies-marina*, which was referred by Levring (1974) as the most abundant alga in Madeira, forming dense populations in exposed locations from the lower littoral zone down to several meters. This species is undergoing a decline in Madeira, particularly on the south coast (C. Ribeiro and P. Neves pers. obs.), where higher habitat destruction and occupation of the coast are more visible. Furthermore, this decline of the species has also been reported to the neighbour archipelagos of the Canaries and Azores and based on that, it was proposed that the species classification under the IUCN criteria CR A2ac was changed to "Critically Endangered" (Valdazo et al. 2017).

Minimizing impacts and balancing different (and many times conflicting) interests and pressures on the marine ecosystems has been a concern for European countries and institutions over the years (e.g. the Habitats Directive — 92/43/EEC, the EU Marine Strategy Framework Directive — MSFD, 2008/56/EC and the EU Directive on Marine Spatial Planning — MSP 2014/89/EU). However, both economic development and conservation policies and measures need to be supported by scientific knowledge on the habitats and associated biota (Bax and Williams 2001; de Jonge and Giebels 2015). Hitherto, the expanded use of the coastal zone in Madeira is being carried out with little or no consideration for the local biological values and coastal dynamics due the fact that they have been poorly studied (Caldeira et al. 2002; Campuzano et al. 2010; SRA 2014). In effect, knowledge gaps were identified in the initial assessment report from the MSFD for the Madeira sub-area of the Exclusive Economic Zone (EEZ) of Portugal (SRA 2014). A number of weaknesses were then listed, which could hamper the achievement of good environmental status (GES) and the directive's strategy goals, namely (1) the paucity of georeferenced data on species and habitats and their narrow spatial coverage; (2)

short time-series datasets; and (3) the lack of baseline information on habitats, biotopes and niches of ecological and economical importance occurring in coastal and deeper environments.

In view of these limitations, knowledge on the spatial distribution, nature and quantity of Madeira's marine coastal habitats is essential to underpin conservation, ecosystem-based management (EBM), sustainable use and regional economic development (particularly fisheries, aquaculture and coastal marine ecotourism). This is of paramount importance for MSP, with habitat maps being a major tool in the assessment and monitoring of coastal marine systems, including GES evaluation (Baker and Harris 2012; Micallef et al. 2012).

Besides supporting MSP directly, marine habitat mapping (MHM) provides the spatial structure of ecosystems that is fundamental to understand biodiversity (Costello 2001; Cogan et al. 2009; Appeltans et al. 2012), to identify the sites that incorporate the ecological processes supporting biodiversity (Roberts et al. 2001), and to provide the context for biodiversity management (Lundblad et al. 2006; Smale et al. 2012). Furthermore, MHM is vital for planning Marine Protected Areas (MPA) and its networks, being a powerful approach to support modelling and management of marine ecosystems (Cogan et al. 2009) and to assist sustainable multiple-uses and development of coastal zones (Beech et al. 2008).

The aims of this study were (1) to collect data on diversity and abundance of marine flora and fauna, gathering baseline scientific knowledge that promotes conservation and management of Natural Marine Park of Cabo Girão (NMPCG), (2) identify the marine habitats present and (3) show that using a feasible approach and low-cost method of underwater data collection, combined with bathymetry and substratum data, it is possible to obtain useful and reliable information that can contribute to the management of this small, multiple-uses MPA.

The new information, can be used by managers to improve the capacity of effective MSP, defining protective measures for habitat sensitive areas and species that may warrant protection in the NMPCG. Ultimately, we provide a baseline against which future marine biodiversity changes can be recognised.

Material and methods

Local setting

The NMPCG designated under regional law (Decreto Legislativo Regional no 4/2017/M) was the first marine park created in the archipelago of Madeira. It is a small MPA, occupying an area of about 2.4 km^2 and located in the south-west coast of Madeira, that extends from 10 m above the coastline (defined by mean tidal range), seaward down to the 50 m isobath (Fig. 1). This park is the marine component of the Protected Area of Cabo Girão (PACG), that also comprises a terrestrial dimension — the Natural Monument of Cabo Girão and the Protected Landscape of Cabo Girão.

According to Decreto Legislativo Regional no 4/2017/M, the establishment of the NMPCG was considered a pilot experiment that intends to evaluate the application of this type of conservation measures to Madeira's specificities (e.g. oceanic island, within the macaronesian region, with no continental shelf, and with a high population density and coastal occupation).

Based on the current International Union for Conservation of Nature (IUCN) classification system of protected areas (that encompasses six categories), the NMPCG is a category VI or, as reported by Spalding et al. (2016), an extractive MPA, which has somewhat less protection of its ecosystems than the categories above. It is a multiple-uses MPA that intends to be a managed resource protected area, yet allowing for some level of human activities which can potentially impact species or ecosystems. Among those activities are: professional and recreational fishing, the harvesting of molluscs and crustaceans (such as limpets, snails, octopus and lobsters — *Scyllarides* spp.), boat traffic and anchoring.

The main management goals established for this small marine park are the good conservation status and the protection of Cabo Girão marine habitats and species, the maintenance of vital biologic processes, as well as the promotion of the ecosystems' recovery. Additionally, the management of this MPA aims to balance conservation issues with the economic benefits that will be obtained from the activities occurring inside it (e.g. SCUBA diving, surf, boat-trips).

Although NMPCG has been established recently, no baseline study or dedicated surveys were carried out on the area before the MPA creation. This situation creates an ambiguity and constrains effective conservation, since the goal of marine spatial management, the scope under which the marine park was created, is to promote a sustainable use of resources while not risking marine biodiversity and habitats (Buhl-Mortensen et al. 2015).

Management of the NMPCG

The management of this protected area is the responsibility of the Instituto das Florestas e Conservação da Natureza (IFCN IP-RAM) — the official managing agency for all MPAs in Madeira, that will implement a special management plan for the area. The process is conducted by IFCN IP-RAM, for the entire PACG and the plan is being currently built in close collaboration with a consultants' committee covering key government agencies (e.g. Direcção Regional das Pescas, Secretaria Regional do Turismo, Marinha, etc.), and including researchers and stakeholders. This commission was appointed by the Regional Government in order to ensure that the cross-disciplinarian nature of the initiative is addressed effectively, with proper rules and effective implementation.

An opportunity for conducting surveys and habitat mapping on the Cabo Girão Marine Park arose due the lack of information on the area and the need to promote/potentiate scientific studies (one of the management goals of the park), and this study was carried out.

Methods

In order to map the existing habitats and identify the main biological communities inside the study area, different datasets were used. Data on the characterization of the seabed environment were collected by the Portuguese Hydrographic Institute (IH) between 2000 and 2001 and in 2007. Qualitative and quantitative data of benthic macrofauna and flora were collected between 2016 and 2018 by Friedlander et al. (2017) and by the authors using SCUBA diving surveys.

Habitat mapping

Available bathymetry data from surveys performed with Multi-beam Echo-sounder (MBES) by IH in the South coast of the island of Madeira was used to produce the bathymetric map of Cabo Girão Marine Park. Similarly, the sediment composition was processed from data obtained by the IH (project GM52OP02). Raster datasets were imported into the Madeira Marine Geographical Information System (SIGMa — a GIS platform developed in QGIS (QGIS Development Team, 2020)) and vectorized. Two layers were created; 1) substrate type (rock and unconsolidated sediment) that was inferred from the MBES data and 2) particle grain size, according to the Udden/Wentworth (Wentworth 1922) scale.

To identify the benthic habitats inside the new MPA, and considering the existing logistical constrains, the chosen approach was based on SCUBA-diving surveys. This type of survey provides a detailed and quantitative observation of seabed habitats, from about 30 m depth up to the shore level. The sampling locations were chosen based on the seabed maps previously created, in order to maximize survey efforts. The first phase involved dives on different substrate types (rock vs sand) in order to identify the major habitats. A second phase, with more detailed surveys, was implemented in areas with greater habitat diversity (e.g. rocky reefs, maërl beds).

Diver-propulsion vehicles (DPV Suex X-Joy 7) allowed the divers to cover greater areas on each dive and a range of fairly inexpensive equipment were used to maximize data collection. A handheld GPS unit (Garmin Montana 600) was placed on a surface marker buoy and towed by the divers in order to record the underwater route for each dive. Using different digital cameras, several pictures were taken along the tracks, particularly when transitions on the substrata occurred or when different habitats were found. The obtained data were downloaded and the pictures were georeferenced by correlation with the recorded GPS track, using Digikam (Digikam Development Team 2020). Image depth was obtained by correlating each image with the dive profile, using Subsurface Divelog software (Subsurface Development Team 2020). In order to ensure an adequate correlation among all datasets, equipment clocks (digital cameras, GPS unit and dive computers) were either pre-synchronized or a picture was taken of their screen in order to correct for small-time differences. The processed data was then imported into SIGMa and habitat types plotted.

Over the different habitat types identified (e.g. maërl, algae meadows, etc.) a more detailed sampling was carried out using underwater visual census, according to standard procedures previously used in Madeira (Ribeiro et al. 2005, 2006). Belt transects to estimate: i) fish (25 × 2 m) and ii) macrobenthos (25 × 1 m) densities and in situ records of all species seen outside transect area, were done. Video and photograph records were analysed in order to obtain a more complete and comprehensive information of species composition (incidence data). Lists of species were obtained from all type of records: in situ, video and photographs. The species nomenclature follows Algaebase (Guiry and Guiry 2019), Catalogue of Fishes (Fricke et al. 2020), World Porifera database (Van Soest et al. 2019) and the World Register of Marine Species (WoRMS Editorial Board 2020).

The information provided by the underwater surveys was superimposed on the seabed environmental data in SIGMa, and used to identify and map the distribution of seabed habitats. These habitats were classified according to the European Nature Information System (EUNIS), which is considered a reference tool within the European context (Vasquez et al. 2015), providing a common reference set of habitat types that allows reporting habitat data in a comparable form, to use in nature conservation, habitat mapping and environmental management.

Data analysis

All data analysis was carried out using R Software (R Core Team 2020) and the Vegan package (Oksanen et al. 2019). Multivariate and univariate statistics were used to determine whether or not biological communities were compositionally different among the major habitat types in the study area.

Species diversity (Shannon index — H) and richness (S) were calculated for all samples and then averaged for each habitat. Nonmetric Multidimensional Scaling was used to visualize variation in communities among the different habitats. Species abundances were square-root transformed prior to analysis and the Bray-Curtis dissimilarity index was used to calculate the distance matrix for the abundance data.

Results

The NMPCG comprises, within its 2.4 km^2 area, an array of biological assets in the south coastal area of the island of Madeira. Two natural substrate types (rock and sand) and one artificial, 5 major different habitat types, belonging to three EUNIS categories (A2, A3 and A5) and a total of 132 taxa were identified within the marine park boundaries during this study (Table 1).

The intertidal area of the NMPCG, which is directly linked to the subtidal environment, is almost entirely formed by pebble beaches and rubble (A2.11). Rocks (A3) dominate the shallow waters (depths beween 5–10 m) of the entire marine park and sublittoral sediment (A5) becomes more common with increasing depth, interspersed by occasional rocks. In terms of area, rocky substrates account for 50.3% of the NMPCG, while sediments occupy 49.7% of the area. On average, the 30 m depth isobath (maximum depth surveyed by SCUBA) is 515 m away from the shoreline (Fig. 2). From the analysis of the surveys completed so far inside the reserve, it is clear that the distribution of substrates differ longitudinally along the area of the park (Fig. 2). Rocky substrate prevails from the intertidal down to approximately 30 m depth in the western area, while soft sediments prevail in the eastern side of the park. Beyond the 30 m depth contour, the particle grain size decreased considerably from the west to the east side of the study area; coarse sand (phi 0–0.5) dominating the west, medium sand (phi 1.0–1.5) on the central area and fine sand (phi 2.0–2.5) on the east. Very fine sand (phi 3.0–3.5) is present also on the eastern area of the MPA, mainly beyond the 30 m isobath. However, no ground-truthing using SCUBA was performed beyond this depth.

The non-destructive quantitative surveys carried out inside the NMPCG comprised a total of 37 fish transects and 34 focusing on benthic macrofauna. Additionally, 25 samples for presence-absence of flora and fauna were also analysed in order to identify and characterize the various communities present.

Major habitats identified within the marine park are: 1) rocky reefs (A3), 2) mäerl beds (A5.51), 3) vegetated sand (S) with *Avrainvillea canariensis* meadows, *Caulerpa prolifera* and garden eel colonies — *Heteroconger longissimus* (A5.25), 4) very small patches of *C. nodosa* (A5.5311) and 5) an artificial habitat (currently without EUNIS correspondence) created by the wreck of the "NRP Afonso Cerqueira", an old Portuguese Navy ship that was intentionally sunk on the 4th September 2018, over a sand bottom at 30 m depth on the east area of the park with the aim of creating an artificial reef (Fig. 2).

From the 132 taxa recorded inside the NMPCG, 72 belong to the benthic macrofauna, 17 are marine plants and 43 are fish (Table 1). Fish apart, the most diverse phyla recorded within the boundaries of the marine park were Arthropoda and Porifera (13 taxa), followed by Cnidaria (10 taxa), Mollusca and Annelida (9 taxa) — (Table 1).

Rocky reefs (RR) are the dominant habitat inside the park (50.3% of the MPA area), formed mostly by rock boulders, (generally >1 m). The shallower reefs (less than 5 m depth), are characterized by encrusting algal communities (A3.14), found associated with some mobile invertebrates such as the echinoderms *Arbacia lixula and Sphaerechinus granularis*, the crustacean *Percnon gibbesi*, the mollusc *Stramonita haemastoma* and the fish species *Ophioblennius atlanticus*. Other macroalgae were scarce and mainly formed by turf and erect algae (e.g. *Dasycladus vermicularis*, *Padina pavonica*, *Halopteris* — A3.15), occurring especially between the depths of 5 and 10 m. Deeper rocks (>10 m) are mainly covered by sessile invertebrates (primarily barnacles and bryozoans) and some crustose coralline algae (*Lithophylum* sp.) or consist of barren rocks, where the long spine sea-urchin *Diadema africanum* is abundant (maximum abundance recorded 13.4 ind/m^2) — A3.24. In this deeper RR, the dominant benthic macrofaunal species are the barnacles (*Balanus trigonus*), occupying the majority of the rock surface (Fig. 3e, f). The bryozoans *Reptadonella violacea* and *Schizoporella dunkeri* and two species of sponges: *Batzella inops* and *Phorbas fictius* are also among the most abundant. The mobile benthic fauna is almost dominated by the sea-urchin *D. africanum*, responsible for the erect macroalgae-deprived rock surface (barren reefs) — Fig. 3f. Moreover, on the RR habitats also important are the maërl beds (the occurrence of this habitat over rock substrate currently has no EUNIS habitat code) that occur interspersed between the rocks and that are home to a diverse community (e.g. molluscs — *Bittium* sp., *Jujubinus exasperatus*, bryozoans — *R. violacea*, *S. dunkeri*, polychaetes — *Hermodice carunculata*, *Lygdamis wirtzi* and hydrozoans).

Soft substrates comprised five distinct communities: 1) garden eel (*H. longissimus*) colonies associated with *C. prolifera* meadows 2) *A. canariensis* meadow, 3) *C. nodosa* patches, 4) maërl beds and 5) the artificial reef. On these, and in addition to the dominant species which characterize each of the communities (*A. canariensis*, *C. prolifera* and *H. longissimus*), invertebrates are also common. Among them, the polychaetes were the dominant group, with *Ditrupa* sp. being the most abundant, while the species *Acromegalomma vesiculosum, Myxicola infundibulum, H. carunculata* and *Sabellaria* sp. were much less abundant (less than 1 ind/m^2). Also present are the phoronid *Phoronopsis californica* and the hermit-crabs (Table 1). Moreover, the sighting of the fish *Lesueurigobius heterofasciatus* inside the NMPCG on a sandy substrate at 30 m depth (Fig. 4), is of importance, considering this is the first time the species is seen and photographed (despite some specimens deposited at Funchal Natural History Museum, occasionally collected in bottom traps at greater depths) in Madeira after its description by Maul (1971).

Table 1 Taxa identified on the habitats of NMPCG. Species marked with * have not been sighted elsewhere in Madeira; species with bold typeface are commercially important and species with underlined typeface are vulnerable species according to IUCN

Phylum/Class	Order	Family	Species	RR	M	S
Macrofauna						
Annelida						
Polychaeta	Amphinomida	Amphinomidae	*Hermodice carunculata* (Pallas, 1766)	+	+	+
	Eunicida	Onuphidae	*Diopatra* sp.			+
	Sabellida	Sabellidae	*Acromegalomma vesiculosum* (Montagu, 1813)			+
			Myxicola infundibulum (Montagu, 1808)		+	+
		Sabellariidae	*Lygdamis wirtzi* Nishi & Nunez, 1999	+	+	
			Sabellaria sp.			+
		Serpulidae	*Ditrupa* sp.			+
			Indet.	+	+	
	Terebellida	Terebellidae	*Lanice conchilega* (Pallas, 1766)		+	+
Arthropoda						
Hexanauplia	Sessilia	Balanidae	*Balanus trigonus* Darwin, 1854	+	+	
Malacostraca	Decapoda	Diogenidae	*Calcinus tubularis* (Linnaeus, 1767)	+	+	
			Dardanus calidus (Risso, 1827)	+		
		Galatheidae	Indet.		+	
		Inachoididae	*Stenorhynchus lanceolatus* (Brullé, 1837)	+		
		Lysmatidae	*Lysmata grabhami* (Gordon, 1935)	+	+	
		Paguridae	Indet.	+	+	+
			Pagurus anachoretus Risso, 1827	+		
		Palaemonidae	*Tuleariocaris neglecta* Chace, 1969	+		
		Percnidae	*Percnon gibbesi* (H. Milne Edwards, 1853)	+		
		Thoridae	*Thor amboinensis* (de Man, 1888)	+	+	
		Brachyura	Indet.		+	
	Mysida		Indet.	+	+	
Brachiopoda			Indet.	+	+	
Bryozoa						
Gymnolaemata	Cheilostomatida	Adeonidae	*Reptadeonella violacea* (Johnston, 1847)	+	+	
		Phidoloporidae	*Rhynchozoon papuliferum* Souto, Kaufmann & Canning-Clode, 2015	+	+	
		Schizoporellidae	*Schizoporella dunkeri* (Reuss, 1848)	+	+	
		Candidae	*Scrupocellaria* sp	+	+	
Stenolaemata	Cyclostomatida	Densiporidae	*Favosipora purpurea* Souto, Kaufmann & Canning-Clode, 2015		+	
Cnidaria						
Anthozoa	Actiniaria	Andvakiidae	*Telmatactis cricoides* (Duchassaing, 1850)	+	+	
	Pennatulacea	Veretillidae	*Veretillum cynomorium* (Pallas, 1766)			+
	Scleractinia	Caryophylliidae	Indet.	+		
		Pocilloporidae	*Madracis* sp.	+	+	
	Spirularia	Cerianthidae	Indet.	+	+	+
Hydrozoa	Anthoathecata	Tubulariidae	*Ectopleura crocea* (Agassiz, 1862)		+	
		Pennariidae	*Pennaria disticha* Goldfuss, 1820			+
	Leptothecata	Aglaopheniidae	*Aglaophenia pluma* (Linnaeus, 1758)	+	+	
			Macrorhynchia philippina Kirchenpauer, 1872		+	
		Halopterididae	*Antennella* sp.	+	+	+
Chordata						
Thaliacea	Pyrosomatida	Pyrosomatidae	*Pyrosoma* sp		+	
	Salpida	Salpidae	*Salpa* sp.	+		
Echinodermata						
Asteroidea	Forcipulatida	Asteriidae	*Coscinasterias tenuispina* (Lamarck, 1816)		+	+

Table 1 (continued)

Phylum/Class	Order	Family	Species	RR	M	S
	Paxillosida	Astropectinidae	*Astropecten aranciacus* (Linnaeus, 1758)			+
	Spinulosida	Echinasteridae	*Echinaster (Echinaster) sepositus* (Retzius, 1783)	+	+	
Crinoidea	Comatulida	Antedonidae	*Antedon bifida* (Pennant, 1777)	+		
Echinoidea	Arbacioida	Arbaciidae	*Arbacia lixula* (Linnaeus, 1758)	+		
	Diadematoida	Diadematidae	*Diadema africanum* Rodríguez, Hernández, Clemente & Coppard, 2013	+	+	
	Camarodonta	Toxopneustidae	*Sphaerechinus granularis* (Lamarck, 1816)	+		
Holothuroidea	Holothuriida	Holothuriidae	*Holothuria (Platyperona) sanctori* Delle Chiaje, 1823	+	+	
Foraminifera						
Globothalamea	Rotaliida	Homotrematidae	*Miniacina miniacea* (Pallas, 1766)	+		
Mollusca						
Cephalopoda	Octopoda	Octopodidae	***Octopus vulgaris*** Cuvier, 1797		+	
	Sepiida	Sepiidae	***Sepia officinalis*** Linnaeus, 1758			+
Gastropoda		Cerithiidae	*Bittium* sp.	+	+	
	Littorinimorpha	Vermetidae	*Vermetus* sp.		+	
	Neogastropoda	Columbellidae	*Columbella adansoni* Menke, 1853	+	+	
	Nudibranchia	Proctonotidae	*Janolus* sp. *			+
	Trochida	Trochidae	*Jujubinus exasperatus* (Pennant, 1777)	+	+	
	Neogastropoda	Muricidae	*Ocenebra* sp.		+	
			Stramonita haemastoma (Linnaeus, 1767)	+	+	
Phoronida		Phoronidae	*Phoronopsis californica* Hilton, 1930			+
Porifera						
			Indet. 1	+	+	
			Indet. 2	+		
			Indet. 3	+		
Calcarea	Leucosolenida	Sycettidae	*Sycon* sp.	+		
Demospongiae	Axinellida	Axinellidae	*Axinella* sp.	+	+	
	Chondrosiida	Chondrosiidae	*Chondrosia reniformis* Nardo, 1847	+		
	Dictyoceratida	Irciniidae	*Ircinia* sp.	+		
	Haplosclerida	Petrosiidae	*Petrosia (petrosia)* ficiformis (Poiret, 1789)		+	
	Poecilosclerida	Chondropsidae	*Batzella inops* (Topsent, 1891)	+	+	
			Indet.		+	
		Hymedesmiidae	*Phorbas fictitius* (Bowerbank, 1866)	+	+	
	Suberitida	Suberitidae	*Aaptos aaptos* (Schimdt, 1864)	+	+	
	Verongiida	Aplysinidae	*Aplysina aerophoba* (Nardo, 1833)	+		
Marine plants						
Chlorophyta						
			Indet.		+	+
Ulvophyceae	Bryopsidales	Dichotomosiphonaceae	*Avrainvillea canariensis* A. Gepp & E.S.Gepp*			+
		Caulerpaceae	*Caulerpa prolifera* (Forsskål) J.V.Lamouroux			+
			Caulerpa webbiana Montagne		+	
	Dasycladales	Dasycladaceae	*Dasycladus vermicularis* (Scopoli) Krasser	+		
Ochrophyta						
			Indet.			+
Phaeophyceae	Sphacelariales	Stypocaulaceae	*Halopteris filicina* (Grateloup) Kützing	+		
	Dictyotales	Dictyotaceae	*Lobophora* sp	+		
			Dictyota sp.	+	+	+
			Padina pavonica (Linnaeus) Thivy	+		
			Stypopodium zonale (J.V.Lamouroux) Papenfuss	+		

Table 1 (continued)

Phylum/Class	Order	Family	Species	RR	M	S
	Sporochnales	Sporochnaceae	*Sporochnus pedunculatus* (Hudson) C.Agardh			+
Rhodophyta						
			Indet. 1	+	+	+
Florideophyceae			Indet. 2	+	+	
	Bonnemaisoniales	Bonnemaisoniaceae	*Asparagopsis taxiformis* (Delile) Trevisan	+	+	
	Corallinales	Lithophyllaceae	*Lithophyllum* sp	+	+	
Tracheophyta						
Monocots	Alismatales	Cymodoceaceae	*Cymodocea nodosa* (Ucria) Ascherson			+
Fishes						
Actinopteri	Anguilliformes	Congridae	*Heteroconger longissimus* Günther 1870			+
		Muraenidae	*Enchelycore anatina* (Lowe 1838)	+		
			Gymnothorax unicolor (Delaroche 1809)	+		
			Muraena augusti (Kaup 1856)	+		
	Aulopiformes	Synodontidae	*Synodus synodus* (Linnaeus 1758)	+	+	
	Blenniiformes	Blenniidae	*Ophioblennius atlanticus* (Valenciennes 1836)	+		
		Tripterygiidae	*Tripterygion delaisi* Cadenat & Blache 1970	+		
	Centrarchiformes	Kyphosidae	***Kyphosus sectatrix*** (Linnaeus 1758	+		
	Gobiiformes	Gobiidae	*Gnatholepis thompsoni* Jordan 1904	+		
			Gobius gasteveni Miller 1974		+	+
			Lesueurigobius heterofasciatus Maul 1971*			+
	Perciformes	Apogonidae	*Apogon imberbis* (Linnaeus 1758	+		
		Carangidae	***Pseudocaranx dentex*** (Bloch & Schneider 1801)	+	+	
			Seriola rivoliana Valenciennes 1833	+		
		Haemulidae	*Parapristipoma octolineatum* (Valenciennes 1833)		+	
			Pomadasys incisus (Bowdich 1825)	+		
		Labridae	<u>***Bodianus scrofa***</u> (Valenciennes 1839)	+	+	
			Coris julis (Linnaeus 1758)	+		
			Thalassoma pavo (Linnaeus 1758)	+	+	
			Xyrichtys novacula (Linnaeus 1758)			+
		Mullidae	***Mullus surmuletus*** Linnaeus 1758			
		Pomacentridae	***Chromis limbata*** (Valenciennes 1833)	+	+	
			Similiparma lurida (Cuvier 1830)	+	+	
		Priacanthidae	*Heteropriacanthus fulgens* (Lowe 1838)	+		
		Scaridae	***Sparisoma cretense*** (Linnaeus 1758)	+	+	
		Serranidae	<u>***Mycteroperca fusca***</u> (Lowe 1838)	+	+	
			Serranus atricauda Günther 1874	+	+	
		Sparidae	***Boops boops*** (Linnaeus 1758)	+	+	
			Dentex gibbosus (Rafinesque 1810		+	
			Diplodus cervinus (Lowe 1838)	+		
			Diplodus sargus (Linnaeus 1758)	+	+	
			Diplodus vulgaris (Geoffroy St. Hilaire 1817)	+	+	
			Oblada melanura (Linnaeus 1758)	+	+	
			Pagellus erythrinus (Linnaeus 1758)	+		
			Sarpa salpa (Linnaeus 1758)	+		
	Scorpaeniformes	Scorpaenidae	*Scorpaena maderensis* Valenciennes 1833	+	+	
	Syngnathiformes	Aulostomidae	*Aulostomus strigosus* Wheeler 1955	+		
		Syngnathidae	*Hippocampus hippocampus* (Linnaeus 1758)			+
	Tetraodontiformes	Balistidae	***Balistes capriscus*** Gmelin 1789	+		+

Table 1 (continued)

Phylum/Class	Order	Family	Species	RR	M	S
		Tetraodontidae	*Canthigaster capistrata* (Lowe 1839)	+	+	+
			Sphoeroides marmoratus (Lowe 1838)	+	+	+
Elasmobranchii	Myliobatiformes	Dasyatidae	*Dasyatis pastinaca* (Linnaeus 1758)		+	+
		Gymnuridae	***Gymnura altavela*** (Linnaeus 1758)			+
			Total n° of taxa	91	72	35

In terms of fish diversity, a total of 43 species were recorded inside the NMPCG, 33 of which were recorded over RR, 20 in maërl beds and 10 over sand habitats. On average, maërl beds and rocky reefs showed higher fish and macrobenthic (fauna and flora) diversity and richness when compared to the sandy habitats (both for quantitative and qualitative data) — Table 2.

The results for the fish data (Fig. 5a) show a clear distinction between the RR/maërl and the sandy substrates. Furthermore, there is a separation that shows differences in the assemblage composition between *A. canariensis* meadows and the remaining sand communities, mainly due to the higher abundance of *H. longissimus* on the later. Although showing a similar fish assemblage composition, fish diversity was much higher on these two former habitats than in sand, as it would be expected, (Table 1). Nonetheless, in terms of abundance and due to the presence of large colonies of garden eels, *H. longissimus*, the sand habitat show higher fish abundance.

For benthic communities (invertebrates and algae for incidence data and invertebrates for abundance data) there was also distinct differences between RR/maërl and sand habitats in assemblage composition (Figs. 5b and 6), that was largely driven by the species *C. prolifera* and *Ditrupa* sp., both very abundant over sand substrates within the NMPCG intermediate and deep depth strata (15–30 m). Among the sand substrates there is also a distinct separation between *C. prolifera* and *A. canariensis* meadows, which was mostly due to the presence and higher abundance of hermit-crabs (Paguroidea) and the sea-star *Coscinasterias tenuispina* in the *A. canariensis* meadow.

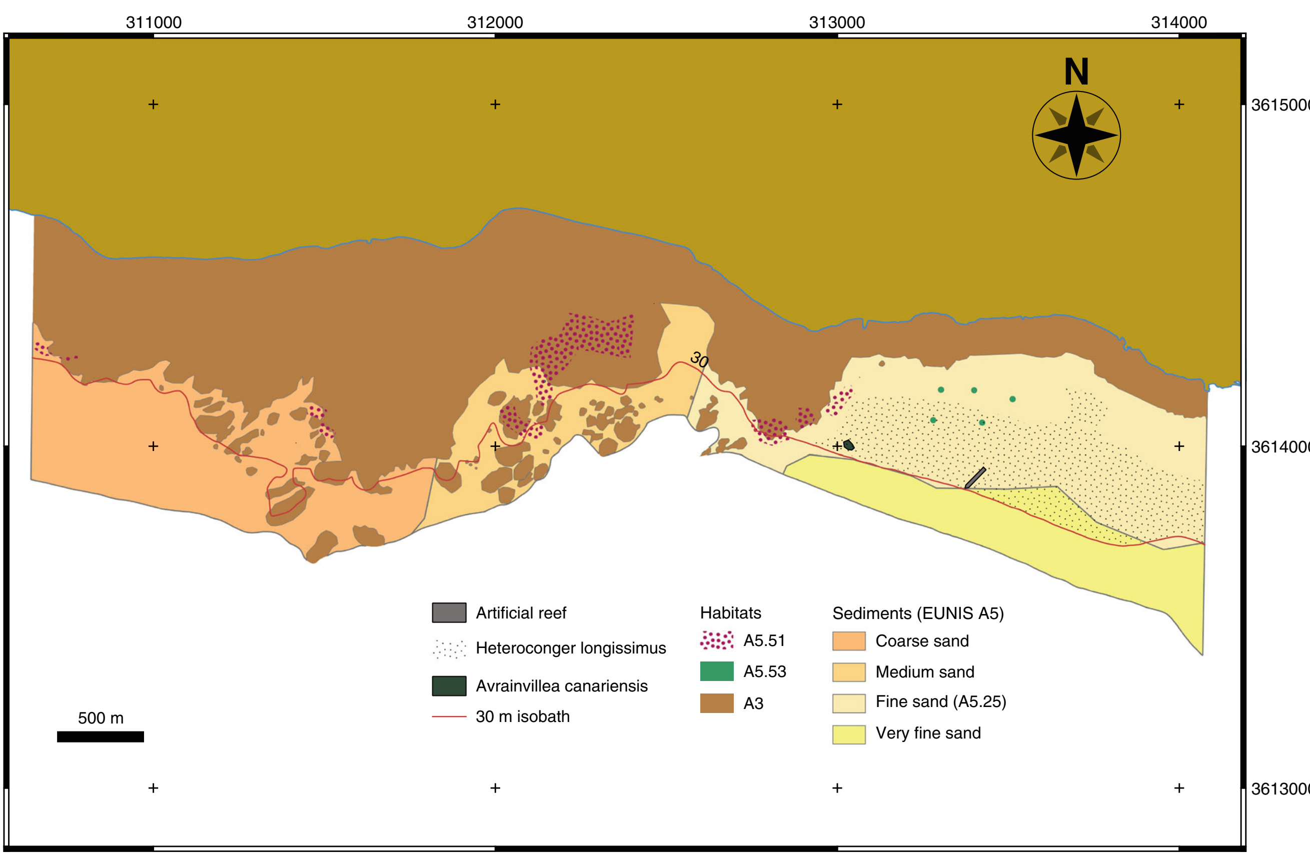

Fig. 2 Subtidal habitats of the Natural Marine Park of Cabo Girão. CRS:EPSG5016

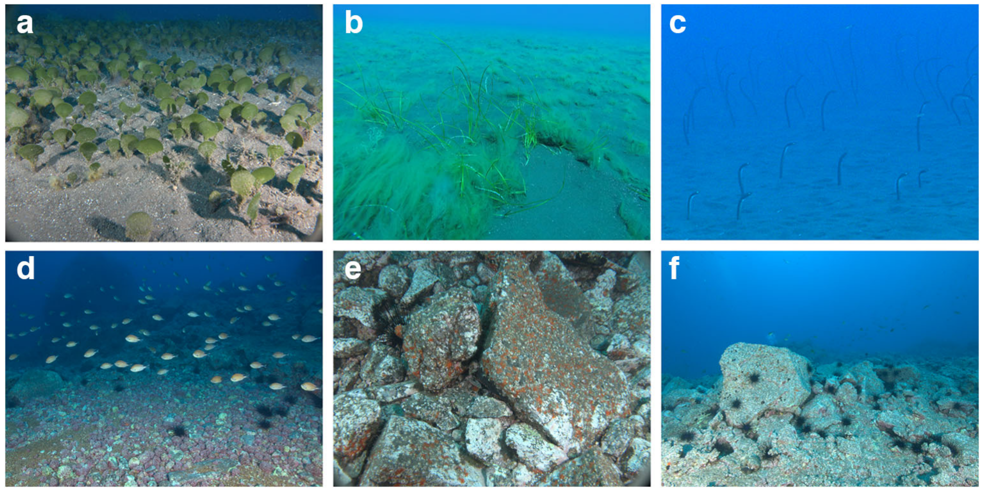

Fig. 3 Some of the main habitats found inside the study area. **a**: *Avrainvillea canariensis* meadow; **b**: *Cymodocea nodosa* patch; **c**: Garden eel colony; **d**: maërl bed; **e**: rocky reef; **f**: "barren" rocky reef

Discussion

During this study, the results obtained were suitable to identify the different major types of marine habitats in the NMPCG, as well as for mapping the subtidal habitats within the 2.4 km^2 area of the marine park on an appropriate scale for coastal zone management. Located in the south coast of the Island of Madeira, this small MPA includes a rocky intertidal made up of pebble beaches, subtidal rocky reefs, an artificial reef (shipwreck "Afonso Cerqueira") and unconsolidated substrate that extends 70 to 750 m from shore to the outer limits of the park.

This study, using non-destructive methods, reported the presence of 132 taxa of marine flora and fauna, belonging to 15 phyla. The marine park is an important area for several fish species, among them, 18 fisheries-valued and three vulnerable species included in the IUCN red list of threatened species: the barred hogfish (*Bodianus scrofa),* the island grouper (*Mycteroperca fusca),* and the spiny butterfly ray *Gymnura altavela* (Table 1). The former two species, besides having a restricted range (only occurring in the four archipelagos of Macaronesia) face a decreasing population trend (Russel et al. 2010; Pollard et al. 2018). Within the NMPCG rocky reefs and maërl beds, both species were observed more frequently than in other similar coastal areas of the South coast of Madeira (Ribeiro et al. 2005, 2006). For this reason, the management plan that is under preparation should consider the prohibition of fishing both species inside the marine park

Fig. 4 *Lesueurigobius heterofasciatus* on the NMPCG

Table 2 Diversity indexes for some of the habitats in NMPCG according to type of collected data

Habitat	Diversity (H)	Richness (S)
Ictiofauna abundance		
Rock	1.280	12
Sand	0.033	3
Maërl	1.425	13
Avrainvillea canariensis	0.328	4
Ictiofauna incidence		
Rock	2.142	17
Sand	0.858	5
Maërl	2.012	14
Avrainvillea canariensis	0.693	4
Macrobentos abundance		
Rock	0.513	8
Sand	0.125	6
Maërl	0.946	9
Avrainvillea canariensis	0.593	3
Macrobentos incidence		
Rock	2.641	28
Sand	1.525	8
Maërl	2.938	34
Avrainvillea canariensis	2.252	13

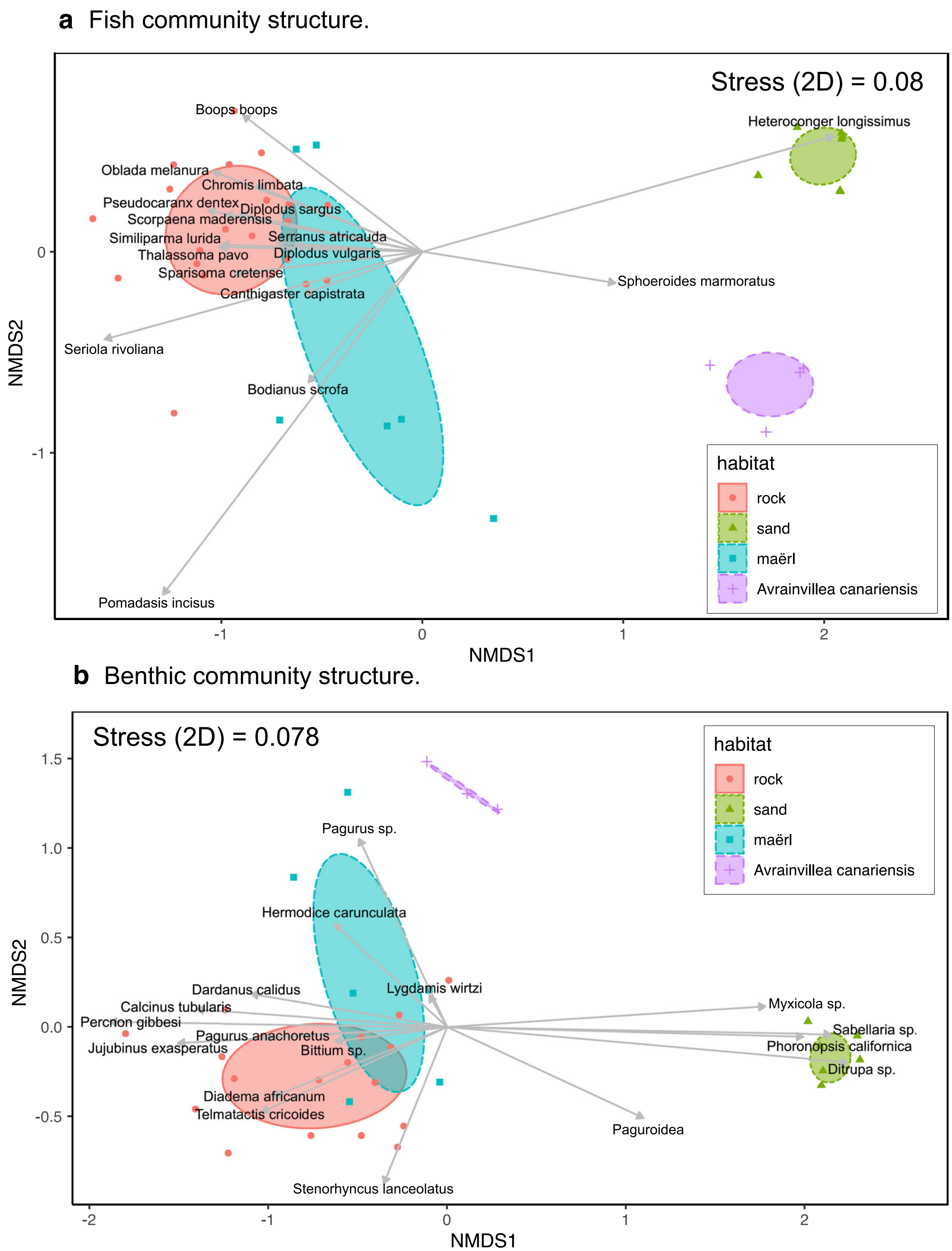

Fig. 5 Nonmetric Multidimensional Scaling ordination based on abundance data. **a**: Fish community structure and **b**: Benthic community stricture. Ellipses drawn using point's Standard Error, with a confidence limit of 0.95. Species included are only the 50% most abundant. Ordination using 3 dimensions

and should include an assessment to estimate the actual fish catches inside the MPA. The spiny butterfly ray is commonly seen by divers in soft bottoms in Madeira and is not targeted by fisheries (Biscoito et al. 2018).

Apart from fish species, invertebrates have a noticeable presence on the RR of the marine park, in particular, the barnacle *B. trigonus,* which is also very common on other RR in Madeira (Alves et al. 2018). Among the bryozoans,

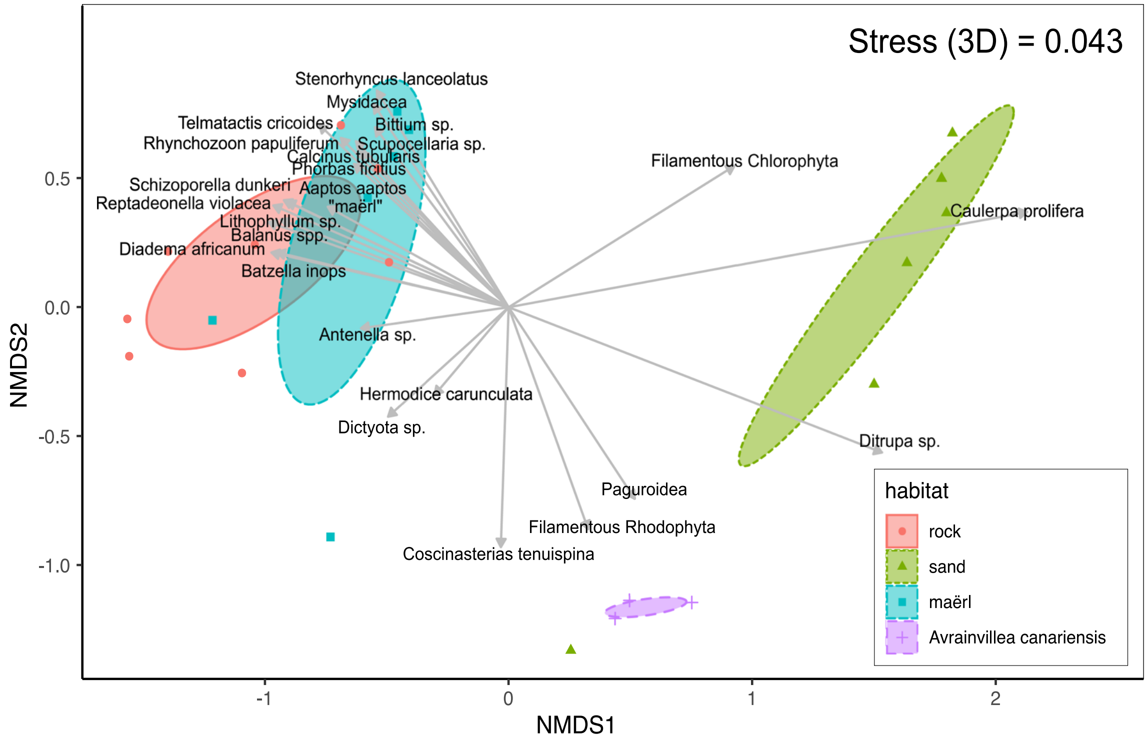

Fig. 6 Nonmetric Multidimensional Scaling ordination based on incidence (presence/absence) data for the benthic community. Ellipses drawn using point's Standard Error, with a confidence limit of 0.95. Species included are only the 30% most frequent. Ordination using 3 dimens

R. violacea and S. dunkerii are the dominant species, both occurring in RR and in maërl beds of the NMPCG. The former, has also been referred as common over RR in the archipelago (Bianchi et al. 1998) and the latter was only recently recorded from Madeira (Souto et al. 2015). Among mobile invertebrates, the sea-urchin *D. africanum* was the most abundant species. This species has been pointed out as being able to effectively reduce algal abundance and determine the algal community structure of rocky substrates in Madeira archipelago (Alves et al. 2003).

The major types of habitats identified within the NMPCG are similar to other coastal areas of the archipelago of Madeira, namely RR and *C. prolifera* meadow with large colonies of garden eels. However, two other habitats were also identified, both found on sublitoral sediment: one unique, *A. canariensis* meadows and the other rare and sensitive, *C. nodosa* plants. *A. canariensis* is a mesophotic green algae, firstly recorded from Madeira archipelago by Ribeiro et al. (2019). This species was considered endemic from the Canaries (Gallardo et al. 2016), until it was found forming dense patches inside the NMPCG. To this date, the species has not been found elsewhere in Madeira (Ribeiro et al. 2019). Also, in the Canaries, this species is considered of "Interest for the Canarian marine ecosystems" (Annex III of the Canarian Catalogue of Protected Species — Ley 4/2010, del 4 de junio, del Catálogo Canario de Especies Protegidas. BOC 117, de 09/6/2010), under the category "sensitive to habitat changes". *C. nodosa* is a seagrass, known worldwide as a key habitat occurring in near-shore soft-bottoms. This species, exert influence over physical, chemical and biological environments, acting as "ecological engineers" and thus providing many goods and ecological services to humans (York et al. 2017). The only species of seagrass known to Madeira archipelago, is the species found inside the NMPCG, *C. nodosa,* which has markedly declined in the archipelago of Madeira (Araújo et al. 2012) and according to Tuya et al. (2018) it is particularly vulnerable to local impacts in these oceanic archipelagos (Madeira and Canaries). Although, seagrasses have been recognized as one of the priority habitats in the EU Habitat Directive as well as in several other conservation legislative frameworks, with special protection rules, *C. nodosa* particularly, integrates the category "Of Interest for Canarian Ecosystems' in the neighbouring archipelago of the Canaries (Riera et al. 2014); in Madeira the knowledge about the species is very limited, with no possibility to evaluate the biological and ecological importance of this habitat. From our personal observations, the habitat could be considered vestigial in Madeira archipelago, including inside the NMPCG where it was represented only by a few plants in a soft bottom around 14 m depth. However, further studies are needed to evaluate if there will be a chance of recovery and if this habitat should be targeted by conservation measures.

Due to the fragility of both species *A. canariensis* and *C. nodosa*, their area of occupation should entail the zoning plan with prohibition for anchoring, recreational diving and nutrient enrichment (agricultural effluents should be assessed). Moreover, aquaculture infrastructures should be avoided in the boundaries of this marine park.

Besides the previous marine plants habitats identified within the NMPCG boundaries, maërl beds are also a significant habitat, occurring either on rocky and sandy substrates. Until recently, the knowledge about this habitat in Madeira was limited to a few references to its occurrence and species composition (Saldanha 1968; Cabioch 1974; Levring 1974), but new observations resulting from an ongoing habitat-mapping project suggest the possibility of maërl beds being more common and extensive than previously supposed (Ribeiro et al. in prep). Accordingly, the current results obtained in the small area of NMPCG, where maërl was found from 15 down to 35 m (probably down to 50 m in the west area of the park) suggest this is a common subtidal habitat in Madeira.

Several studies have shown that specific subaquatic habitats, as seagrasses, *Avrainvillea* sp. meadows and maërl beds can form complex three-dimensional habitats in an otherwise two-dimensional environment, thus providing habitat and shelter for numerous species, supporting a high degree of species and trophic group diversity, as well as important feeding and reproduction areas for marine life (e.g. Jackson et al. 2001; Barbera et al. 2003; Langston and Spalding 2017). For this reason, they should be the focus of interest/research initiatives as well as of protection measures in order coastal development be carried out in a way that minimizes the damage over the most sensitive and valued aspects of nature (Sahla et al. 2016). Moreover, spatial distribution and size of habitats in seascape play an important role in the functioning and structuring marine communities (Hewitt et al. 2004), which can even be more important in a small MPA such as NMPCG (2.4 km^2). Ultimately, the larger the number of habitats within an area, the larger the number of species found there (Thrush et al. 2006), suggesting habitat as an effective and efficient surrogate of biodiversity, especially in a region for which few data on species are available and time for decision is restricted (Fraschetti 2012), which is the case of Madeira.

Hence, this work shows the importance of having consistent spatial data on marine habitats in order to prevent licensing of activities that disturb the sea-floor benthic communities in biologically sensitive areas, as it is the case of *A. canariensis, C. nodosa* meadows and maërl beds.

While marine research studies have been done in Madeira archipelago since the nineteenth century, they have predominantly focused on taxonomy and species listing (e.g. Lowe, Günther, etc.), or specific biological studies (e.g. Vasconcelos et al. (2012), rather than habitat mapping (Augier 1985; Alves et al. 2001). Moreover, and despite accounting for the highest proportion of the European North Atlantic EEZ, the mapped area of the Macaronesia region, to which Madeira archipelago belongs, is substantially less than other sub-regions of the European North Atlantic, having more than 80% of their seabed area without cartographic information and habitat maps still not available (Galparsoro et al. 2014; SRA 2014)). Therefore, and considering the pressing need for seabed inventory mapping (Strong et al. 2019) and using data previously obtained with remote sensing techniques, sedimentary analysis and undertaking marine field surveys and ground-truthing, this study produces the first maps of marine habitats for the island of Madeira.

MHM brings new focus to the power of marine habitat maps and provides a pathway for the biological and ecological sciences to support the urgently needed advances in management. Indeed, as a logical sequence within EBM, MHM can address specific objectives from one research project to another and should be in the early stages of the management process, followed by evaluations of biodiversity, functional processes, and the development of management procedures (Cogan et al. 2009). Discussing issues of holistic ocean and coastal management, (Spalding et al. 2016) suggested that conservation community needs to encourage and engage the growth of MSP as a way of increase marine conservation and to ensure that a broader array of sea uses and impacts (e.g. fisheries, coastal development, agricultural run-off) are effectively planned and managed, so that they do not undermine marine conservation.

In this sense, the map produced for the NMPCG and the baseline data gathered will aid managers and researchers to manage, monitor, plan and conduct further biological studies inside the marine park. Additionally, maps allow detection of changes in habitat cover, as well as boundary demarcation of multiple-use zoning schemes (Fraschetti 2012). Being a manageable unit, the marine habitat map of the NMPCG is suitable for managers to visualise the spatial distribution of habitats inside this MPA as well as to help in future planning of MPAs' networks and will allow habitat fragmentation monitoring (Gray 1997). More detailed studies on the marine biodiversity of this area are needed and will promote ecological awareness of population and stakeholders about the unique flora and fauna of the NMPCG (e.g. the green alga *A. canariensis*).

Environmental management and conservation requires standardised classifications and terminologies for habitats to enable consistent mapping and storage of information on the environment across all possible habitats (Fraschetti 2012). For this reason, the hierarchical EUNIS habitat classification system (HCS) was applied. However, this HCS, does not reflect many of the marine communities occurring in Macaronesia (see Tempera et al. 2013) and for that reason the following comments are added about the composition of the habitats we found in the present study: 1) The barren reefs and facies of the sea urchin *D. africanum* (Fig. 3f) should be listed in a further level of A3.35 ("Faunal communities on low energy infralittoral rock"); 2) The description of A5.2 "sublittoral sand" is not sufficiently precise for the habitats found within

Macaronesia and should include the *C. prolifera* and *A. canariensis* meadows and the extensive garden eel colonies (*H. longissimus*). Moreover, and as referred by Strong et al. (2019) despite the benefits associated with the consistent classification of habitats during mapping, it must be recognized that the use of an HCS also imposes certain constraints and limitations, which are inherent within the fundamental concepts of habitat classification. The same authors pointed that many HCS assume individual habitats as discrete classes and when used in mapping, those classes usually form mutually exclusive patches when shown spatially, failing to capture the natural continuities (biocoenoses) and environmental gradients (ecotones), perhaps better reflecting the natural configuration and gradients between different habitat types.

Although MHM can be done using an array of techniques, which vary in cost, resolution capabilities, and on the need for data processing and expertise (Buhl-Mortensen et al. 2015), the approach applied in this study was mostly based on SCUBA-diving. In effect, and despite all the new remote sensing techniques for MHM and their several advantages (e.g. covering extensive areas, more suitable for spatially complex areas), mapping marine biodiversity remain operationally complicated and expensive (Martin et al. 2015), a reason for SCUBA diving and video not to be undervalued. In cases where SCUBA use is practical, which was the case with the present work, it is the best non-destructive method, allowing the observation of habitats up close and assessing the community's species composition — thus a ground-validation method (Lee et al. 2015). Further investigation to collect more spatial data on the subtidal habitats of this MPA within 30–50 m depth is needed. The acquisition of new information on the mesophotic habitats (~ 30–120 m depth), combining the methodology here described with other methodologies (e.g. deeper SCUBA-diving, underwater drop camera, ROV's) will provide a wider picture of the importance of this small, multiple uses MPA within Madeira's network of protected areas.

The findings presently obtained add knew knowledge to Madeiran nearshore marine environments, and support evidence of a diverse and regionally significant marine fauna. Besides providing for the first time, a marine habitat map for Madeira, with baseline information crucial for the conservation, protection and management of the MPA area.

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