Template for Submission of Scientific Information
to Describe Areas Meeting Scientific Criteria for
Ecologically or Biologically Significant Marine Areas

Name of the area: North Mid-Atlantic Ridge

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Abstract

The North Mid-Atlantic Ridge (North MAR), is a linear feature of 7,700 km and an area of 4,4 million km^2 (200 to 5,000 m depth). The North MAR contains 72 true seamounts, 9 major fracture zones, 64 known and inferred hydrothermal vent fields, and many canyons, guyots, rift valleys, and small ridges. The presence of the North MAR alters the water circulation creating regions of high productivity and enhanced biological biomass and diversity. It supports rich communities of vulnerable and fragile cold-water corals, sponge aggregations, and deep-water vulnerable fish. Additionally, hydrothermal vent fields and transform faults support unique fauna; many of which are endemic to the MAR. The level of human impacts is relatively low but concerns have arisen from the potential developments of deep-sea mining on the North MAR. Here, we present scientific information that suggest the North MAR meet the scientific criteria for being described as an EBSMA.

Introduction

Mid-ocean ridges are highly complex and dynamic geological systems, which develop at the juncture of different tectonic plates (UNESCO, 2017). They are important geological features, extending 50,000–60,000 km across the floor of ocean basins, which increase the environmental heterogeneity and influence biological communities (Alt et al., 2019). Mid-ocean ridges hold a large variety of habitats such as small ridges, hills and seamounts, axial valleys, and fracture zones, spreading from shallow waters to bathyal depth of more than 3,500 m (Harris et al., 2014). In addition, hydrothermal vents where first discovered along mid-ocean ridges in the late 1970s. About 90% of the known and predicted hydrothermal vents are contained within the rift valleys of spreading ridge features (Harris et al., 2014). This diversity of habitats supports multiple forms of life, from hydrothermal vent fauna to benthic filter feeders taking advantage of the hydrographic conditions created by the mid-ocean ridges (Holland et al., 2005; Vinogradov, 2005), and affect the distribution, biodiversity and biogeography of both pelagic and benthic organisms. The productivity over mid-ocean ridges has been described as a major factor influencing patterns of fauna abundance and distribution (King et al., 2006; Bergstad et al., 2008).

The Mid-Atlantic Ridge (MAR) began to form 200 million years ago but was only discovered in the mid-19th century, when the first submarine cables linking the North America and Europe were deployed.

The MAR is a volcanic mountain range that rises from the Atlantic abyssal plain, extending within the OSPAR Maritime Area from the Arctic at the Gakkel Ridge to the Antarctic at the Bouvet Triple Junction, ranging more than 16,000 km (UNESCO, 2017). It is the major topographic feature of the Atlantic Ocean and the longest mountain range in the world, dominating the seafloor topography in the High Seas of the OSPAR region.

As the Atlantic Ocean slowly expands, new oceanic floor is formed in the central valley of the MAR on the boundaries of the Nubia, American and Eurasian tectonic plates, at a speed of 28-33mm·year^{-1} (Dinter, 2001; Heger et al., 2008; Hosia et al., 2008). In this process massive volcanic events give rise to large ridge- and seamount-like structures, and in some cases even to islands such as those of the Azores (Portugal) or St. Peter and St. Paul's Archipelago (Brazil). Noticeably, the MAR is a hotspot of seamounts but also of hydrothermal vents which are formed when seawater circulates into the crust through cracks and porous rocks, heated by underlying magma, and rise back through openings in the seafloor. There are about 85 known and inferred distinct and unique deep-sea hydrothermal vent fields at the MAR; with only 28 being confirmed as active vents (InterRidge Vents Database v3.4). The topography of the MAR is highly differentiated with depths ranging from about 200m on the top of some seamounts around the Azores to about 4,500 m in adjacent abyssal plain.

The Mid-Atlantic Ridge has a profound role in the circulation of the water masses in the North Atlantic Ocean (Rossby, 1999; Bower et al., 2002; Heger et al., 2008; Søiland et al., 2008). The complex hydrographic setting around the Mid-Atlantic Ridge in general and the presence of the ridge itself leads to enhanced vertical mixing and turbulence that results in areas of increased productivity over the MAR (Falkowski et al., 1998; Heger et al., 2008).

Mid-ocean ridges in general and the MAR in particular are fundamentally different from both isolated seamounts surrounded by deep ocean and from continental slopes where effects of coastal processes are pronounced. The MAR increases the availability of suitable habitats for benthic species but also strongly shapes the habitat characteristics in the water column through modification of currents and production patterns (Opdal et al., 2008). Therefore, many areas of the MAR support extremely rich communities of cold-water corals reefs and gardens, sponge aggregations, and demersal fish. Additionally, hydrothermal vent fields of the MAR support unique fauna dominated by the blind shrimp *Rimicaris exoculata*, the mussel *Bathymodiolus azoricus*, or by an undescribed amphipod species. Many species are endemic to the MAR hydrothermal vents, which forms a consistent and distinctive biogeographic unit (Desbruyères et al., 2001). Large portions of the MAR fit the FAO criteria for defining Vulnerable Marine Ecosystems (VME) (Morato et al., 2018) while others are considered priority habitats in need of protection by the OSPAR convention for the protection and conservation of the North-East Atlantic. These include seamounts (OSPAR, 2010a), ocean ridges with hydrothermal vents (OSPAR, 2010b), coral reefs (OSPAR, 2009) and coral gardens (OSPAR, 2010c) and deep-sea sponge aggregations (OSPAR, 2010d).

With the exception of a small fraction, the MAR remains poorly studied. However, several international research projects (e.g. MAR-ECO, ECOMAR, ATLAS, SPONGES) have shed some light on the geology, oceanography and ecology of the MAR. But more recently both the EU H2020 ATLAS and SPONGES projects have revealed some important aspects of the benthic communities inhabiting different habitats of the northern part of the MAR, highlighting the biological diversity, uniqueness, vulnerability, and the ecological importance of the MAR. Here, we present scientific information that suggest the North Mid-Atlantic Ridge meet the scientific criteria for being described as an Ecologically or Biologically Significant Marine Area.

Location of the North Mid-Atlantic Ridge area

The area/feature under consideration, the North Mid-Atlantic Ridge (North MAR), it's located in the North Atlantic Ocean extending from the Reykjanes Ridge at 63.5°N, close to the Steinahóll hydrothermal vent, south to the Vema Fracture Zone at around 10° N. For the purpose of producing a submission of scientific information to describe areas meeting scientific criteria for Ecologically or Biologically Significant Marine Areas the North Mid-Atlantic Ridge was defined by the Mid-Ocean spreading ridges polygon produced by Harris et al., (2014) and creating a 250km buffer around the spreading MAR to include the range of representative benthic habitats and include sufficient area relevant for population connectivity through larval dispersal (Figure 1). The resulting proposed feature has a linear length of about 7,700 km and a total area of about 4,4 million km^2 with a variety of habitats ranging from 200 to 5,000 m depth. The average depth of the North MAR area is 2,600m. The benthic portion of North Mid-Atlantic Ridge area is encompassed by the lower bathyal (800 to 3500 m) North Atlantic and Northern Atlantic Boreal biogeographic provinces, and the abyssal (3501 to 6500 m) North Atlantic biogeographic province (Watling et al., 2013).
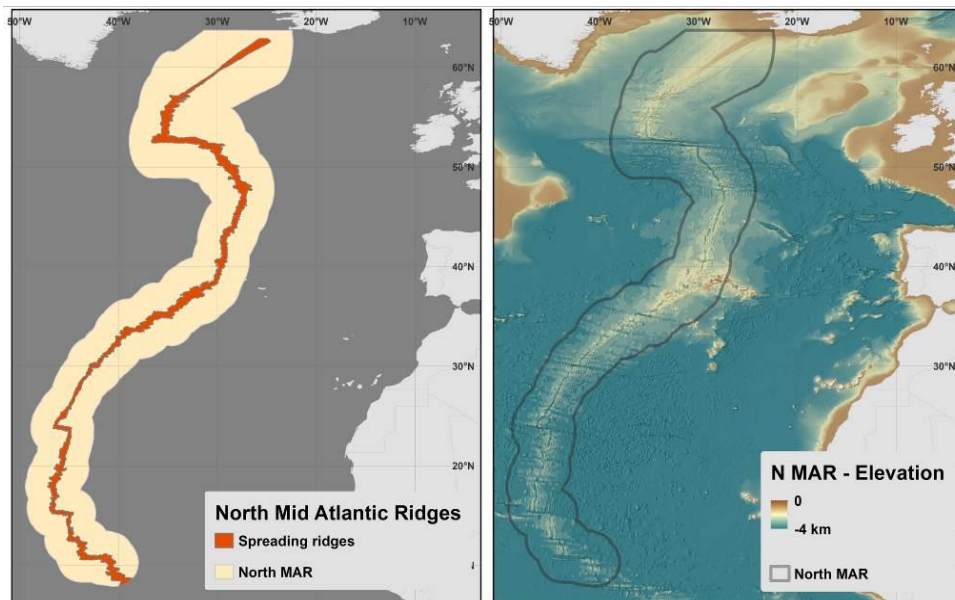

Figure 1- The area/feature under consideration, the North Mid-Atlantic Ridge (North MAR).

Feature description of the proposed area

A comprehensive revision of the available scientific literature for the Mid Atlantic Ridge was carried out as part of the SEMPIA workshop in 2016. Although some published information may have been overlooked, a total of 138 scientific cruises, 306 articles and 410 unique sampling sites were identified. With the exception of a fraction of the North MAR, the area remains poorly described in the literature. Of the 306 articles that could be geo-referenced greater scientific efforts were spent on the northern portion of the MAR, but they were generally limited to very specific areas. In fact, in recent decades most of deep-sea research on the North MAR mirrored the location of hydrothermal vents, focusing therefore on very peculiar ecosystems and spatially limited areas. Several international projects conducted scientific cruises in the North MAR. The MAR-ECO (Patterns and processes of the ecosystems of the northern Mid-Atlantic) (Bergstad & Godø, 2002) and its spin-off project ECOMAR (Ecosystem of the Mid-Atlantic Ridge at the sub-polar front and Charlie-Gibbs Fracture Zone) (Priede et al., 2013) led to the many scientific papers published in the recent years. Noticeably, many new species were described, other were taxonomically revised, and in many cases the known distribution

was expanded species that were not known to exist in this region have been uncovered (e.g., Gebruk et al., 2008 ; Cardenas & Tore Rapp, 2015; Tabachnick & Collins, 2008; Molotsova et al., 2008). More recently, the H2020 ATLAS project conducted several scientific expeditions, in particular around the Azores and in the Reykjanes Ridge.

Brief physical and oceanography description

The North Mid-Atlantic Ridge feature contain a range of underwater ridges, mountains, transform faults, and valleys, that separates the Eurasian from the American plate as an active seafloor spreading centre (Dinter 2001; Heger *et al* 2008). Data from Harris et al., (2014), from the InterRidge Vents Database v3.4, and GEBCO Undersea Feature Names Gazetteer show that the North Mid-Atlantic Ridge area contains many different geomorphological features, namely:

- 72 true seamounts with depths of the summits ranging from 200 to 3000 m (Figure 2);
- 9 major fracture zones (from South to North, Vema, Fifteen-Twenty, Kane, Atlantic, Hayes, Oceanographer, Pico, Kurchatov, Faraday, Charlie-Gibbs, and Bight)
- 64 known and inferred hydrothermal vent fields; with 22 being confirmed as active vents, 28 being inferred active vents, and 14 being inactive sites (InterRidge Vents Database v3.4). Some of the most well-known vents in this region are the Broken Spur, Logatchev, Lost City, Lucky Strike, Menez Gwen, Moytirra, Rainbow, Saldanha, Snake Pit, Steinahóll, and TAG.
- Many different canyons, guyots, rift valleys, and small ridges.

Seamounts and hydrothermal vent areas on the North MAR exhibit a wide range of environmental conditions, including great variation in depth and associated physical parameters, and different geologic setting and underlying rocks. These factors can affect the composition of hydrothermal vent communities.

The dominant water masses over the Mid-Atlantic Ridge between Iceland and the Azores show three different hydrographic regimes, dividing the water column environment into: i) cold, sub-polar conditions north of the Sub-Polar Front; ii) warm, sub-tropical conditions south of the Sub-Polar Front; and iii) the frontal region itself which blends the characteristics of both areas (Pierrot-Bults, 2008; Søiland et al., 2008). Shallower portions of the MAR (e.g. Reykjanes Ridge) act like a barrier to water movements, while deep west-to-east fracture zones (e.g., Charlie-Gibbs or Vema Fracture Zone) seemed to guide the spatial and temporal distribution of thermal fronts and water masses (Belkin et al., 2009).
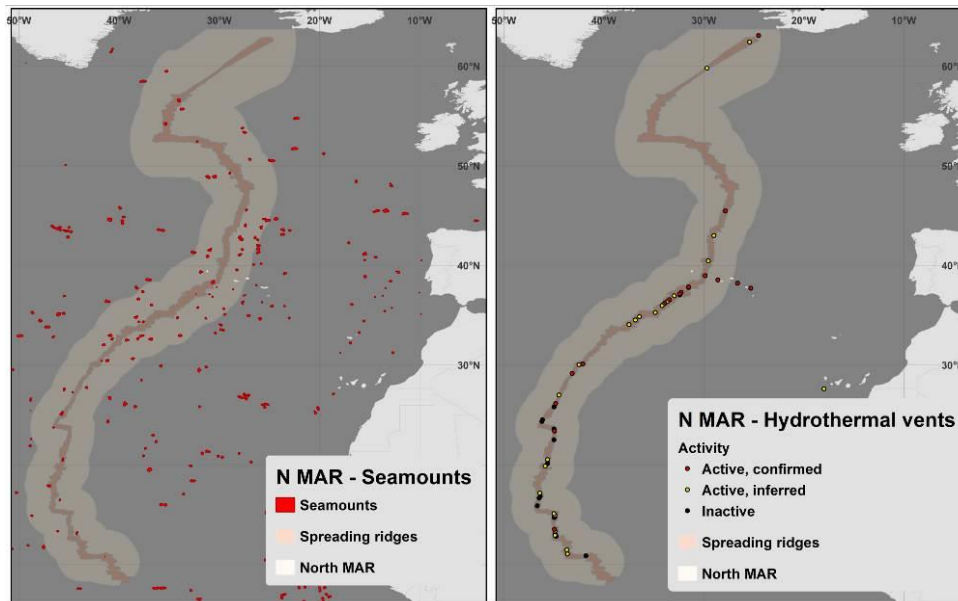
Figure 2- Location of seamounts in the North Mid-Atlantic Ridge (North MAR) and of hydrothermal vent fields from Harris et al., (2014) and the InterRidge Vents Database v3.4, respectively.

Linking physical and oceanography properties to biological productivity

The presence of the North MAR disrupts the ocean circulation creating regions of high biomass that may arise from topographic influences on water circulation (St Laurent & Thurnherr 2007), bathymetrically-induced frontal (Scales et al., 2014; Morato et al., 2018), upwelling nutrient-rich deep water, as well as concentrating biomass over summits creating mid ocean regions of high productivity (Priede et al., 2013). Therefore, the North MAR greatly alters the water circulation and the biology of the north Atlantic Ocean providing habitat for bathyal organisms that would not otherwise survive in mid ocean (Priede et al., 2013). The benthic biomass on the North MAR is enhanced (Priede et al., 2013) and the biodiversity is increased compared with an abyssal plain but the demersal fish species richness and abundance is equal to that on the ocean margins at the similar depths. The North MAR constitutes an important habitat for benthic species otherwise confined to narrow strips of appropriate depth around the Atlantic Ocean margins (Bergstad et al., 2012; Cousins et al 2013) and play an important role in deep-sea populations' connectivity. Applying species-area theory (Storch et al., 2012) this suggests that the MAR is more important for sustaining bathyal benthic diversity in the Atlantic basin as a whole rather than supporting a rich endemic fauna of its own (Priede et al., 2013).

The North MAR also provides a significant amount of hard substrate in the open ocean (Dinter, 2001), which in addition to the hydrographic conditions over the Mid-Atlantic Ridge, are favourable for sessile suspension feeders such as cold-water corals (Mortensen et al., 2008). Enhanced cold-water corals diversity are therefore found along the MAR. During ROV dives North of the Azores, Mortensen et al., (2008) observed 28 different coral taxa (including *Lophelia pertusa*). Of those, seven were unique to the area (*Madrepora oculata, Solenosmilia variabilis, Stephanocyathus moseleyanus, Scleroptilum grandiflorum,* and three *Radicipes* species), as compared to sample sites around and north of the Charlie-Gibbs Fracture Zone (Mortensen et al., 2008). The MAR region of the Azores is considered a cold-water coral hotspot in the North Eastern Atlantic, with 184 species identified to date (Braga-Henriques et al., 2013; Sampaio et al., 2019) and with more than twenty different types of coral gardens (Tempera et al., 2013). A large proportion of CWCs belongs to the subclass Octocorallia with 98 species identified (Sampaio et al., 2019), representing the highest octocoral diversity given for European waters (Costello et al., 2001). Cold-water coral reefs have also a positive effect on fish diversity and/or abundance, with

data indicating higher fish abundance within the coral areas (Linley et al., 2017). The number of megafaunal taxa is also higher in areas with coral than those without, a finding common to other regions (Mortensen *et al* 2008). The number of associated species to cold-water corals is large with a high potential for the discovery of new species to science (e.g. Carreiro-Silva et al 2011; 2017). Furthermore, recent H2020 ATLAS scientific surveys in seamounts along the MAR reveal many more types of undescribed habitats and species that may be new to science.

Biological diversity and uniqueness of the North MAR

Hydrothermal vents

Deep-sea vents represent one of the most physically and chemically unusual biomes on Earth (Takai & Nakamura, 2011). Hydrothermal processes control the transfer of energy and matter from the earth core to its crust, hydrosphere and biosphere (Pirajno & Kranendonk, 2005). The vent circulation accounts for approximately one third of the global geothermal heat flux to the oceans and strongly affects the chemical composition of the water (Elderfield & Schultz, 1996).

The North MAR is a hotspot of hydrothermal vents, with 64 known and inferred hydrothermal vent fields; with 22 being confirmed as active vents, 28 being inferred active vents, and 14 being inactive sites (InterRidge Vents Database v3.4). Some of the most well-known vents in this region are the Broken Spur, Logatchev, Lost City, Lucky Strike, Menez Gwen, Moytirra, Rainbow, Saldanha, Snake Pit, Steinahóll, and TAG. Some of these vent fields present unique characteristics. For example, the Lost City vent field is estimated to have been active for more than 30,000 years and has unique characteristics, being a low temperature vent with high alkalinity. The MAR also hosts the hottest vent reported to date, with temperatures of up to 407°C.

Deep-sea hydrothermal fields are biological oasis compared to the surrounding abyssal environments. Chemosynthetic microorganisms serve as food for mussels, shrimps and other species that are densely aggregated around hydrothermal vents, with biomass at deep-sea hydrothermal fields that can reach value of 20 kg·m^{-2}. Hydrothermal communities have a complex spatial structure due to the high variability of conditions near hydrothermal emissions (Copley et al., 1997; Desbruyeres et al., 2001; Colaco et al., 2002; Cuvelier et al., 2009).

Different species occur in different zones within hydrothermal fields according to local conditions. As a result, hydrothermal communities consist of a mosaic of species assemblages. The most common hydrothermal foundation species in the North MAR are mytilid and vesicomyid mollusks, alvinellid and siboglinid polychaetes, and alvinocaridid shrimps (Rybakova & Galkin, 2015). There are two species of *Bathymodiolus* spp. on the North MAR: *Bathymodiolus azoricus* (distributed from 700–2300 m depth) and *Bathymodiolus puteoserpentis* (distributed from 3000–3510 m depth) (Desbruyeres et al., 2006). The Broken Spur vent field (3000 m) is a hybrid zone between the two species (Won et al., 2003). The foundation species in shrimp assemblages on the North MAR is *Rimicaris exoculata* (Rybakova & Galkin, 2015). The endemic rate of hydrothermal fields in this region is very high, thereby increasing its intrinsic natural value. The organic matter produced at vents complex with metals like iron or copper released from vents with organic ligands (Bennett et al., 2008; Hoffman et al., 2018), is also spread with the buoyant plume, contributing to the global ocean micronutrient budgets (Tagliabue et al., 2010; Resing et al., 2015). The chemosynthetic productivity from vents is therefore exchanged with the nearby deep-sea environments, providing labile organic resources to benthic and pelagic ecosystems that rare otherwise food limited (Levin et al., 2016). Vent-derived organic carbon flux supplements the metazoan food web beyond the areas where hydrothermal venting occurs (Bell et al., 2017).

Cold-water coral gardens and reefs, and sponge aggregations

The North MAR provides ideal conditions for the colonization of deep-sea suspension-feeding fauna such as cold-water corals (CWC) and sponges. Cold-water coral diversity is particularly high in the North MAR with more than 200 species identified to date (Braga-Henriques et al., 2013; Sampaio et al., 2019). Octocorals together with Antipatharia (black corals) and Stylasteridae (hydrocorals) form tri-dimensional complex habitats, referred to as coral gardens (OSPAR, 2010c), that are used by a large number of associated sessile (e.g. zoantharians, anemones, hydroids) and vagile (e.g. polychaetes, echinoderms, crustaceans, fish) species (Buhl-Mortensen et al., 2010). Many of these species are slow growing, long-lived and have low reproductive outputs, which makes them extremely vulnerable to fisheries or other human impacts, with recovery times of individual coral colonies and communities requiring decades to centuries. These characteristics have resulted in coral habitats being listed as Vulnerable Marine Ecosystems (VME) (UNGA, 2007; OSPAR 2009, 2010c,d).

After the first expeditions to the deep sea in the late 19th century, extensive scientific research based in the Azores region of the North MAR has revealed many coral gardens and sponges aggregations, however, the North MAR ecosystems are still poorly known. The H2020 expeditions mapped the deep-sea benthic habitats inhabiting previously unexplored areas of the MAR and discovered one new hydrothermal vent field, new species of cold-water corals, and new areas that may fit the FAO vulnerable marine ecosystems (VME) definition (Figure 3). These exciting discoveries, close to the shores of the Azores islands, highlight once again how little we know about the deep-sea of the MAR but also the ecological and biological importance of the area.
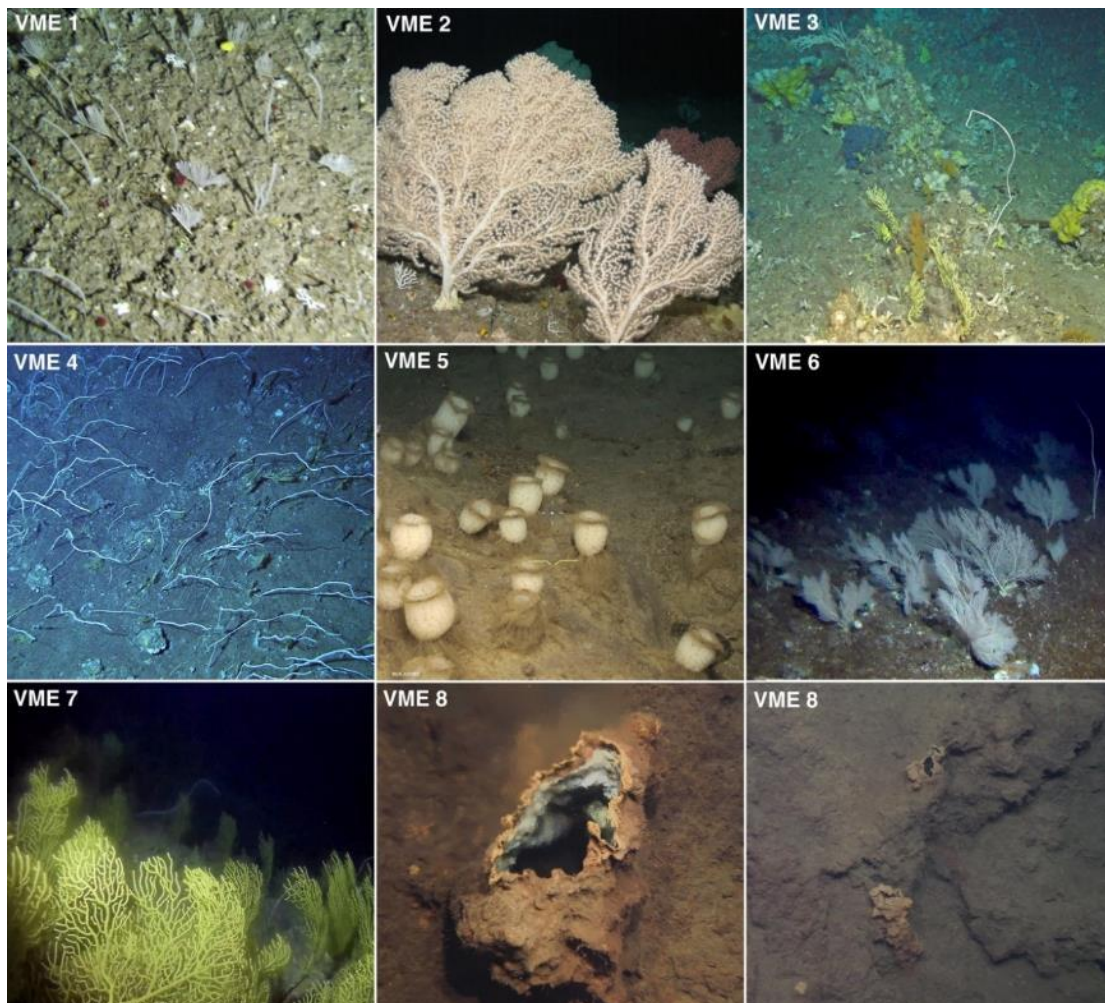
Figure 3. Examples of the different VMEs identified in the deep-sea areas of the North MAR during the H2020 project ATLAS.

Here we also provide two examples of CWC gardens and sponge aggregations found in the North MAR. The **Gigante Complex Area** (39°N) is a ridge-like seamount that sits over the Mid-Atlantic Ridge, extremely close to the triple junction of the African, European and North American plates. A preliminary characterization of predominant sessile fauna and of fish and shark aggregations was based on seven video transects recorded in 2018. To date about 200 morphospecies were identified, mostly belonging to the taxonomic groups Cnidaria (80), Porifera (60) and Actinopterygii (34). Overall, the dives performed in GCA revealed a series of benthic habitats of ecological significance: (1) The summits of the 3 seamounts hosted very dense and diverse coral gardens, where large octocorals (*Viminella flagellum*, *Dentomuricea* aff. *meteor* and *Acanthogorgia* cf. *hirsuta*) and large sponges generate complex three-dimensional structures that provide a suitable habitat for a wide range of associated species (Figure 4); (2) Areas of large basaltic lava ballons located on the deep slopes where a specific association of the sponge *Poecillastra compressa* and the octocoral *Pleurocorallium* cf. *johnsoni* can be observed; (3) The northern flank of Gigante Seamount, which hosts dense patches of various coral species, as well as aggregations of large tubular, flabellate and massive sponges; (4) Areas of the 127 Seamount, which are home to deep-sea sharks, and its soft-bottom areas on the deepest slope, which hosts very dense aggregations of the Silver roughy *Hoplostethus mediterraneus*; (5) The slopes of the western ridge are colonized by large specimens of the gorgonian coral *Paragorgia johnsoni*, creating the one of the best-preserved aggregations of this species identified in the Azores EEZ so far, with colonies reaching heights of over 1.5 m (Figure 4). Although some colonies on the summit showed signs of fishing impact, a large number of colonies on the flanks remain in a very good conservation status, with all their branches still intact.
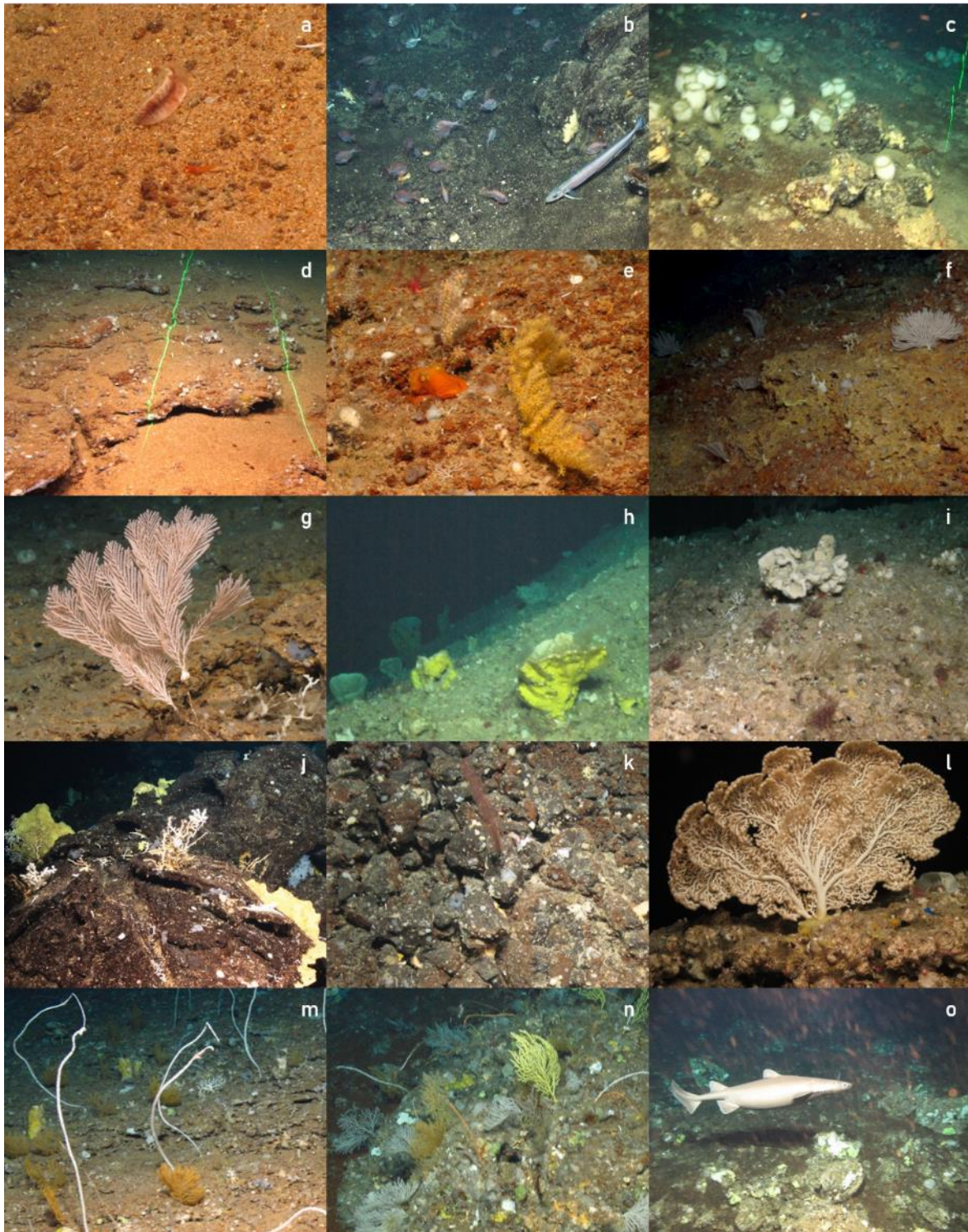
Figure 4. Some of the benthic assemblages of the GCA. (a) *Flabellum* cf. *chuni*. (b) *Molva macrophthalma* and aggregation of *Hoplostethus mediterraneus*. (c) *Pheronema carpenteri*. (d) Encrusting and small globular sponges on rocky outcrops in high sedimentation areas. (e) *Acanthogorgia armata*, another species of Acanthogorgiidae and the cephalopoda *Pteroctopus tetracirrhus*. (f) cf. *Narella bellissima* aggregation. (g) *Callogorgia verticillata*. (h) tubular sponge aggregation (cf. *Characella pachastrelloides*). (i) *Anthothela* dominated facies with cf. *Neophrissospongia nolitangere*, Coralliidae and Plumulariidae species. (j) cf. *Poecillastra compressa* and *Pleurocorallium* cf. *johnsoni*. (k) *Parantipathes hirondelle* on crumbled basaltic rock. (l) *Paragorgia johnsoni*, dead cirripeds, Alcyoniidae and Dendrophylliidae species. (m) *Viminella flagellum*, *Acanthogorgia* cf. *hirsuta*, cf. *Characella pachastrelloides*, cf. *Hemicorallium* sp. (n) *V. flagellum*, *Candidella* cf. *imbricata*; *Dentomuricea* cf. *meteor* and encrusting sponges. (o) Deep water shark *Dalatias licha*.

At the **Cavalo ridge** (37°N), the hard substrates on the flanks of the seamount, at depths of 600-700 meters, are dominated by the octocoral species *Narella bellissima* and *Narella versluysi*, both found in very high densities along a considerably large area (Figure 5). Those two species were accompanied by a wide range of other large coral species, such as the octocorals *Paragorgia johnsoni*, *Corallium* cf. *johnsoni* and *Callogorgia verticillate,* as well as some laminate sponges.

Figure 5. Images recorded on Cavalo seamount. (a) Very dense aggregation of the octocorals *Narella verluysi* and *Narella bellissima*, accompanied by a wide variety of other coral and sponge species. (b) Large specimen of the coral *Paragorgia johnsoni*.

Vulnerable Marine Ecosystem (VME) indicator taxa

Taking advantage of existing institutional databases as well as from public databases such as the Ocean Biogeographic Information System portal (OBIS), the NOAA Deep Sea Coral Data Portal, and the ICES Vulnerable Marine Ecosystems data portal, the H2020 ATLAS project compiled the best available information on Vulnerable Marine Ecosystem indicator taxa for the North Atlantic and developed a multi-criterion assessment (MCA) to evaluate how likely an area represents a VME. The ATLAS VME database is currently comprised of approximately 455,000 records distributed in both sides of the north Atlantic, but only 79,000 are located in the North MAR (Figure 6). Thirteen VME indicator types were agreed for inclusion in the ATLAS database and followed the ICES advice (ICES, 2016), reflecting the main taxonomic groups of VME indicators occurring in the North Atlantic.

Based on the ATLAS VME database and multi-criterion assessment (Morato et al., 2018.), a VME index and associated Confidence Index were produced for the North MAR estimated at the scale of the North Atlantic Ocean. The MCA identified areas with high values of VME index mostly located in Reykjanes Ridge and southern Iceland, and the Azores (Figure 6). Unfortunately, most of the North MAR south of the Azores have been scientific sampled mostly in hydrothermal vent fields; which are defined as bona fide VME habitats. Nevertheless, it is clear that when studied and sampled every region of the North MAR reveals important habitats, namely cold-water coral gardens and sponges' aggregations.
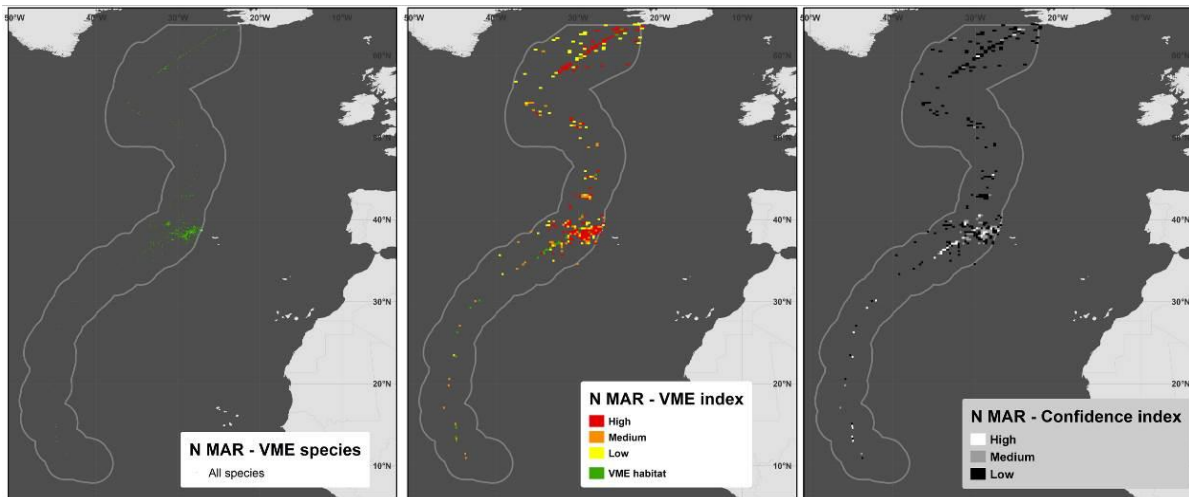
Figure 6. Distribution of VME indicator records in the North MAR contained within the H2020 ATLAS VME database (left), and applying the VME Index and Confidence Index to the H2020 ATLAS VME database for the North MAR. a) VME index; b) Confidence Index.

Available models for cold-water corals

The H2020 ATLAS project developed habitat suitability models for six VME indicator taxa in the deep waters of the North-Atlantic basin (from 18°N to 76°N and 36E° to 98W). The VME indicator taxa selected included three scleractinian corals forming aragonitic skeletons (*Lophelia pertusa, Madrepora oculata*, and *Desmophyllum dianthus*), and three gorgonians forming calcitic skeletons (*Acanella arbuscula, Acanthogorgia armata*, and *Paragorgia arborea*). Scleractinian corals under present day conditions showed a higher suitability in the Eastern North Atlantic and the Mid-Atlantic Ridge including the Azores, but also in the Gulf of Mexico and the Mediterranean Sea, whilst gorgonian showed higher suitability in the Western North Atlantic and south of Greenland (Figure 7).
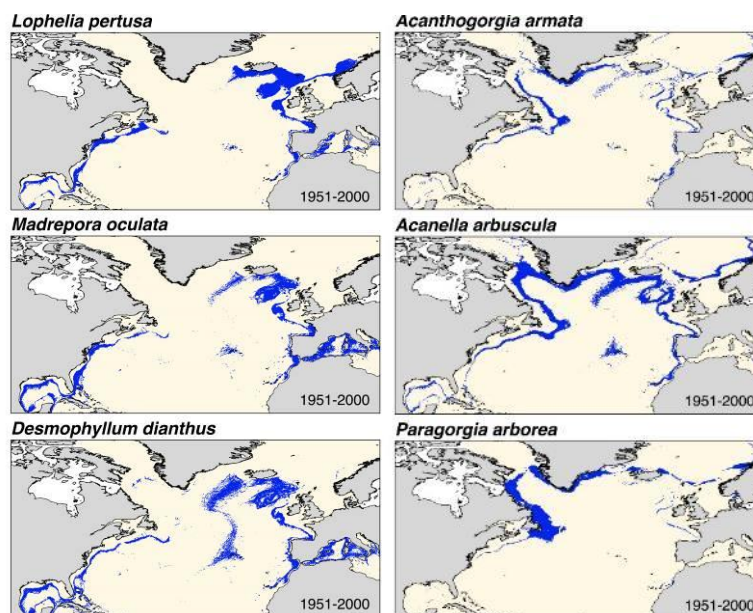

Figure 7. Suitable habitat of cold-water corals in North Atlantic Ocean, as determined by binary maps built with an ensemble modelling approach and the maximum sensitivity and specificity (MSS) threshold.

Global habitat suitability models and distribution maps are also available for areas including the North MAR. Yesson et al. (2012) modelled the distribution of seven suborders of Octocorallia while Davies & Guinotte (2011) modelled five species of framework-forming scleractinian corals (Figure 8). In both studies, the area of the North MAR was revealed as containing important suitable habitats for these taxa.

Habitat Suitability of Cold-Water Octocorals (Yesson et al. 2012)
Habitat Suitability (# of Octocoral Species)
1 2 3 4 5 6 7

Habitat Suitability of Scleractinia (Davies and Guinotte 2011)
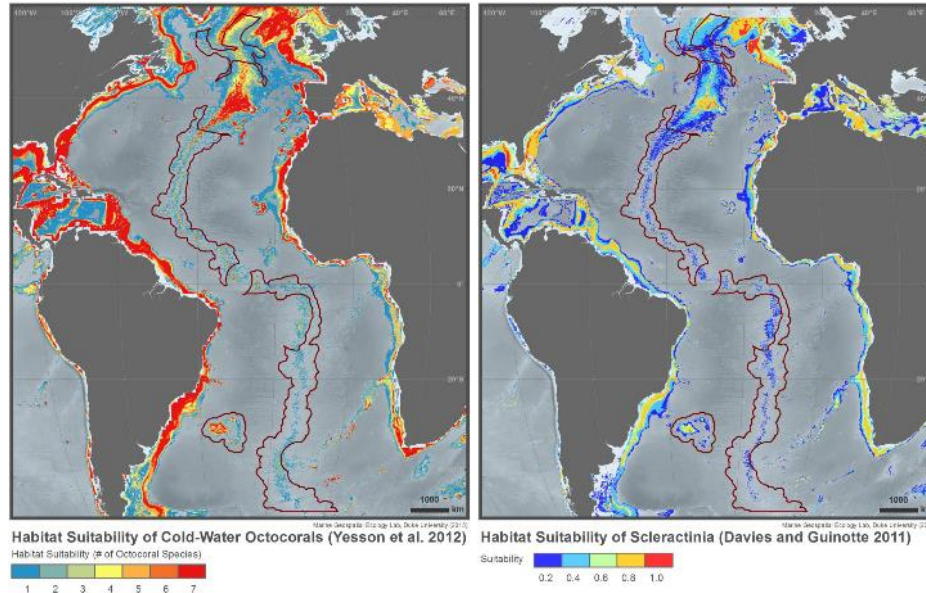Suitability
0.2 0.4 0.6 0.8 1.0

Figure 8. Global habitat suitability models for seven suborders of Octocorallia (left, Yesson et al., 2012) and five species of scleractinian corals (right, Davies & Guinotte, 2011).

Rare and threatened species on the North MAR

The North Mid-Atlantic Ridge is home for rare and threatened species, including a large diversity of deep-sea fish and cold-water corals (Fossen et al., 2008; Das & Afonso 2016). Longlines catches on the North MAR between Iceland and the Azores resulted in large numbers of deep-sea sharks including the *Centrophorus squamosus* and *Centroscymnus coelolepis* (Fossen et al., 2008), both listed on the OSPAR list of Threatened and/or Declining Species and Habitats (BDC/MASH 2007). Deep-water sharks are also common bycatch of deep-water longline fisheries conducted in the North MAR region of the Azores (Machete et al., 2011; Pham et al., 2014; Fauconnet et al., 2019). Given their life-history characteristics and in particular low productivity, all deep-water chondrichthyan species are highly vulnerable to fishing impacts, with limited ability to sustain high levels of fishing pressure and slow potential of recover from overfishing (Kyne & Simpfendorfer, 2007). Out of the 25 species of deep-water sharks occurring in the North MAR around the Azores, nearly half are listed under the IUCN Red List of Threatened Species, as Critically Endangered (n=1), Endangered (n=4), or Near Threatened (n=2), or as Data-Deficient (n=7), 2 are not even assessed (IUCN Europe 2018).

Some species of deep-sea chondrichthyans occurring in the MAR are very rare. An extreme example is the Azores dogfish (*Scymnodalatias garricki),* a species so rare that it is known only from two prototypes/ specimens caught in the Azores area in 1977 and 2001 at 300 m and 580 m depth respectively (Kukuev & Konovalenko, 1988; Kukuev, 2006). Another example is *Rajella pallida* (Pale ray), whose first record for the area between the Charlie-Gibbs Fracture Zone and the Azores (the wider MAR North of the Azores) was registered in 2004 (Orlov et al., 2006).

Cold-water coral species of Order Antipatharia (e.g. black corals *Leiopathes* spp., *Bathypathes* spp.), Scleractinia (e.g. reef building corals *Lophelia pertusa* and *Madrepora oculata*) and family Stylasteridae

(e.g. *Errina* spp., *Stylaster* spp.), are listed under Appendix II of the CITES convention. In addition, the communities formed by cold-water corals and sponges including deep-sea sponge aggregations, sea pen communities, coral reefs and coral gardens, as well as oceanic ridges with hydrothermal vents and seamounts that are listed on the OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR, 2009; 2010a,b,c,d).

Role of the North MAR in the Atlantic ecosystem function

The benthic ecosystems at the MAR perform several important ecosystem good and services. Hydrothermal vents are involved in the biogeochemical cycling and elemental transformation of carbon, sulfur, and nitrogen (Petersen et al., 2011; Lilley et al., 1995; Sievert & Vetrini, 2012) and contribute to the huge diversity of deep-sea organisms and habitats. They use chemical energy from hydrogen, methane, hydrogen sulfide, ammonium or iron to fix inorganic carbon and generate increased microbial and faunal biomass, making them unique ecosystems. By doing this, these ecosystems enhance trophic and structural complexity relative to the surrounding deep sea and provide the setting for complex trophic interactions (e.g., Colaço et al., 2007; Portail et al., 2018).

Cold-water coral reefs, gardens, sponge grounds and massif sponges also support and enhance highly diverse community, comprising faunal biomass that is orders of magnitude above that of the surrounding seafloor (Henry & Roberts, 2007; Roberts et al., 2008; Beazley et al., 2013). The three-dimensional structure created at the bottoms where they live, make then bioengineering species, providing habitat for several organisms. The composition of megafauna significantly differed between sponge grounds and non-sponge grounds and also between different sponge morphologies (Beazley et al., 2013).

The ability to construct calcium carbonate frameworks, makes deep-water coral reefs unique, and provides an important biogeochemical function in both the carbonate system (Doney et al., 2009) and in calcium balance (Moberg & Folke, 1999). Sponges, with their filter-feeding capacity are very important as carbon sinks, since they can filter more than 90% of bacteria and organic matter from seawater, having an impact not only on the benthic pelagic-coupling of carbon but also on the microbial loop itself (Yahel et al., 2007; Maldonado et al., 2012; Leys et al., 2018). Sponges also have a significant important impact on inorganic nutrients cycles, such as silicate, nitrate, nitrite, ammonium and phosphate (Maldonado et al., 2012). Both cold-water coral communities and sponge grounds are important for global biogeochemical cycles and the ocean's benthic pelagic coupling loop, being responsible for nearly 30% of the coupling between organic matter produced at the ocean surface and the seafloor (Cathalot et al., 2015). They represent hotspots of ecosystem functioning processing substantial amounts of Organic Matter (White et al., 2012; Cathalot et al., 2015) and release nutrients back into the surrounding water (Van Oevelen et al., 2009; Cathalot et al., 2015) that becomes available to associated fauna.

The structural framework of coral reefs and mounds formed over geological timescales represent carbon reservoirs, contributing to climate regulation. Carbonate accumulation rates by coral reefs is estimated in the order of 25-100 $g \cdot cm^2 \cdot kyr^{-1}$, which represents 4-11 times the accumulation rates at the seafloor (Lindberg & Mienert, 2005; Titschack et al., 2015). Octocorals, the main components of coral garden habitats, also have the ability to store carbonate in their skeletal elements contributing to the formation of carbonate sediments and limestone (Matsumoto et al., 2010), although their contribution to carbonate storage has not been yet quantified.

Corals and sponges also serve as important spawning, nursery, breeding and feeding areas for a multitude of fishes and invertebrates (Pham et al., 2015; Gomes-Pereira et al., 2017; Porteiro et al., 2013; Ashford et al., 2019). Deep-water sharks were found to lay eggs among cold-water corals (Henry et al., 2013). One-time haul of 34 specimens of frilled shark (*Chlamydoselachus anguineus*; 15 males and 19

females) from a seamount of the Mid-Atlantic Ridge was the first known case of mass capture of this rare and particularly vulnerable shark in waters of the Atlantic Ocean, suggesting the Mid-Atlantic Ridge could be a potential aggregation/mating site for this species (Kukuev & Pavlov, 2008). Two newly born individuals of *Rajella bigelowi* (Bigelow's ray) captured in the area between the Charlie-Gibbs Fracture Zone and the Azores (the wider MAR North of the Azores), also indicated that the Mid-Atlantic Ridge is part of their spawning ground (Orlov et al., 2006). The Mid Atlantic Ridge area was also identified as a spawning area for roundnose grenadier (*Coryphaenoides rupestris*; Danke et al., 1987).

The North MAR plays an important role in deep-sea populations' connectivity. It has been described both as an ecological barrier for megafaunal species (Gebruk et al., 2010; Alt et al., 2019) or a East-West Atlantic conduit for larval dispersal at fracture zones (German et al., 2011). However, the particular hydrographic conditions and high morphological relief of the MAR provides the necessary conditions for the recruitment and settlement of coral and sponge larvae with low dispersal potential and recruitment success (Hilário et al., 2015; Girard et al., 2016) and a potential connectivity corridor from South to North along the MAR. Furthermore, the North MAR may also become an important connectivity pathway even for the larvae of the reef-building coral *Lophelia pertusa* with high dispersal potential in a scenario of changes in climate. Connectivity modelling studies conducted within the framework of ATLAS suggest that the North MAR may be important connectivity pathway from the Azores to the North Atlantic for L. *pertusa* larvae under a scenario of reduced suitable habitat caused by projected changes in climate (Fox et al, unpublished data). These models also suggest that the dominant factors in future distribution and connectivity are likely to be the changes in local conditions, particularly temperature and ocean acidification. As such, shallower areas of the MAR may act as refugia for cold-water corals and other benthic calcifying species from ocean acidification as they lie in shallower waters with a higher aragonite saturation horizon, as suggested for seamount summits (Tittensor et al., 2010; Rowden et al., 2010).

H2020 ATLAS conservation planning approaches

The H2020 ATLAS project developed systematic conservation planning approaches based on objective and quantitative methodologies for allocating priority areas for biodiversity conservation. Spatial planning was implemented on a gridded region where each gridsquare represents a planning unit (PU) that can be either selected or excluded from the conservation solution, i.e. the set of planning units answering the conservation objective. Areas in the North Mid-Atlantic Ridge were frequently as priority areas for conservation on the habitats scenarios (Figure 9). In those planning scenarios combining the predicted distributions of VME indicator taxa (cold-water corals and sponge) together with the known distribution of VMEs and the geomorphological proxies for the occurrence of VMEs (e.g. seamounts, canyons), the solutions favored the continental slopes as well as the Mid-Atlantic Ridge (Figure 9).
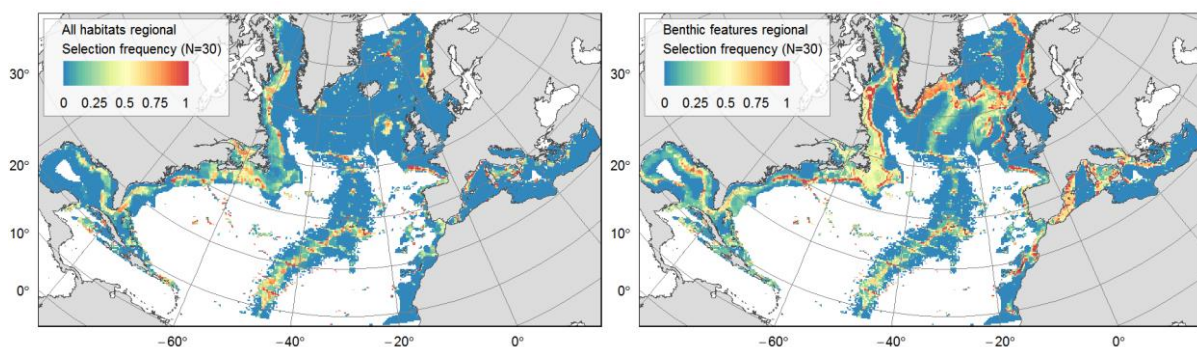

Figure 9. Selection frequency for the habitats scenarios (left) and for the benthic features scenario (right) (from the H2020 ATLAS deliverable D3.4).

Feature condition and future outlook of the proposed area

Human activities in the North MAR: Demersal fishing

In the inhabited areas of the North MAR (such as Iceland and the Azores) marine resource exploitation is undoubtedly a socio-economic sector of major importance (Carvalho et al 2011). In these areas, bottom fishing down to depths of ca. 600 m is an important fishing activity contributing significantly to the local livelihoods. However, the level of fishing activity in the North MAR, as measured by Watson & Tidd (2018) is relatively low when compared to the levels of fishing in the whole North Atlantic (Figure 10). Fishing intensity in this study was measured as the fishing catch rate, calculating the average over the period 2010-2015 of annual tonnage per square km of bottom contact gears.

It is well established that deep-sea trawling has dramatic impacts on deep-sea benthic communities, with damages analogous to forest clear cutting (Watling and Norse, 1998). Other techniques such as longlines have been suggested to be less harmful to the environment (Chuenpagdee et al., 2003). The North MAR is no exception. A recent report (Pham et al., 2014) conducted in the North MAR around the Azores showed that handline fishing for bottom species had no impact on benthic organisms. On the other hand, a typical longline set in the Azores had an expected bycatch of 1.23 sessile organisms or 0.96 cold-water corals (0.48kg ±0.16) much smaller than the expected bycatch of a bottom trawler operating in the Flemish Cap towing over the same area (37-59 kg; Murillo et al., 2011). Primary bycatch was composed of more than 79 different taxa belonging to 4 different phyla (Cnidaria, Bryozoa, Foraminifera and Porifera). Cold-Water-Corals represented 74% of the bycatch, whilst sponges represented 19%. Bycatch was found to be higher between 200 and 450 m depth and on seamounts when compared to island shelves. Analysis of video footage suggested that additional impacts were found in the sea bed with some cold water corals being seriously impacted by bottom longlines. A typical longline set in the North MAR around the Azores has an expected in situ impact of 9.6-14.5 CWC, but these numbers still need further validation. Longline have a selective impact on mostly 3-dimensional and branched colonies (Sampaio et al., 2012) which may alter benthic community structure. Even though the impact of bottom longlining may be significantly lower than that of other fishing gears such as bottom trawl, it still affects some of the oldest continuously living organisms on the North MAR such *Leiopathes* sp.
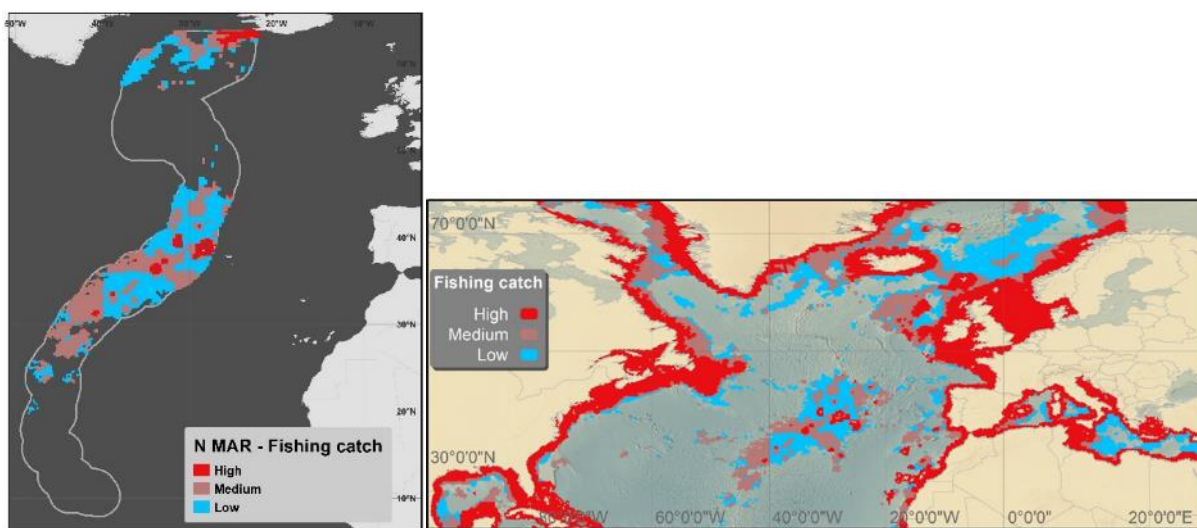

Figure 10. Map of bottom contact fishing catch based on data from Watson & Tidd (2018).

Human activities in the North MAR: Deep-sea mining

The recognition that the deep sea could provide a valuable source of metals has become increasingly widespread in recent years. Large sources of copper, zinc, silver and gold ores have been identified in Seafloor Massive Sulphide (SMS) deposits at deep-sea hydrothermal vents in many areas around the world (Hannington et al., 2011; Van Dover, 2011). In the North MAR south of the Azores major SMS deposits have been identified (Cherkashov et al., 2010) and the International Seabed Authority (ISA) has approved three exploration contracts to Poland, Russia and France (Figure 11). In the Azores waters, including the extended continental shelf, Nautilus Minerals expressed the interest for exploration licenses for massive sulfide deposits. North of the Azores, hydrothermal sulfide deposits are also known to occur on the Portuguese claimed extended continental shelf (Moytirra) and on the ridge north of Iceland (Hannington et al., 2011; Wheeler et al., 2013).

To date, no commercial deep-sea mining has occurred anywhere in the North MAR but the activity is likely to happen in the future and is anticipated to cause significant impacts on the marine environment and other human activities (Van Dover, 2011; Boschen et al., 2013; Wedding et al., 2015). The scale and nature of these impacts remains uncertain but will involve extensive physical destruction of the seabed, alteration in hydrothermal circulation at the active vent sites and production of considerable potentially toxic sediment plumes over both short and prolonged durations, depending on the size and duration of discharge, oceanographic conditions and dilution factors on different environments (Boschen et al., 2013). Predicted direct impacts on deep-sea ecosystems include the potential reduction in biodiversity, species abundance and ecosystem services, due either to loss of habitat or smothering of benthic communities by sediments in the close vicinity of the mining operations (Gwyther, 2008, Boschen et al., 2013; Van Dover et al., 2017). The organisms that are expected to be most affected by smothering are the benthic sessile fauna (such as CWC and sponges) and the infauna, with reduced mobility that limits their escape capabilities (Hughes et al., 2015;). Secondary effects include potential uptake of bioavailable trace metals released by sediment particles into tissues of marine organisms resulting in organisms' death and/or bio-accumulation of these metals through the food web (Brewer et al., 2007; 2012; Koski, 2012), and potential human health risks from fish and shellfish consumption (Reichelt-Brushett 2012).
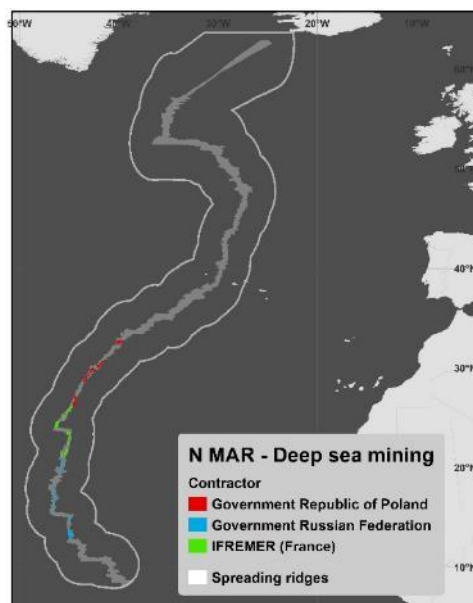

Figure 11. Deep-sea mining exploration licenses on the North Mid-Atlantic Ridge.

Climate change

Recent projections of deep water mass properties suggested that portions of the seafloor will experience significant changes (Gehlen et al., 2014; Sweetman et al., 2017). These forecasted changes may severely affect productivity, biodiversity, and distribution of deep-sea fauna, especially Vulnerable Marine Ecosystems (VMEs) indicator species compromising key ecosystem services (Levin & Le Bris, 2015). In the North MAR the bottom seawater properties were forecasted to change by 2100 with a decrease in seawater temperature in most of the area, a loss of dissolved oxygen up to 3.7%, a 40-55% decrease in the flux of particulate organic matter to the seafloor, a decrease in pH greater than 0.3 units in most area, and a decreases in the saturation horizon for calcite and aragonite (Figure 12).
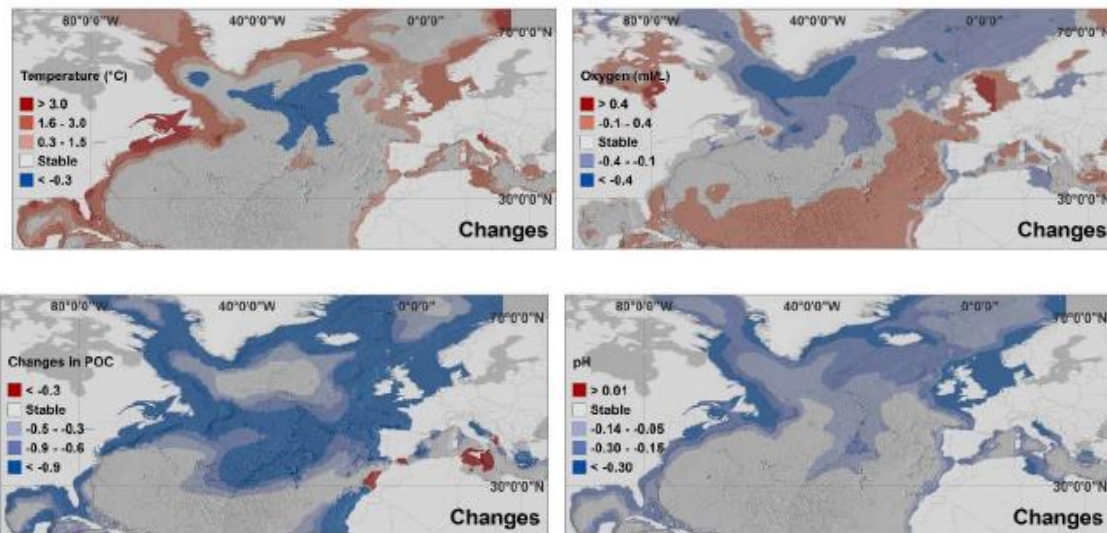

Figure 12. Changes in environmental predictors between present and future conditions in the North Atlantic Ocean.
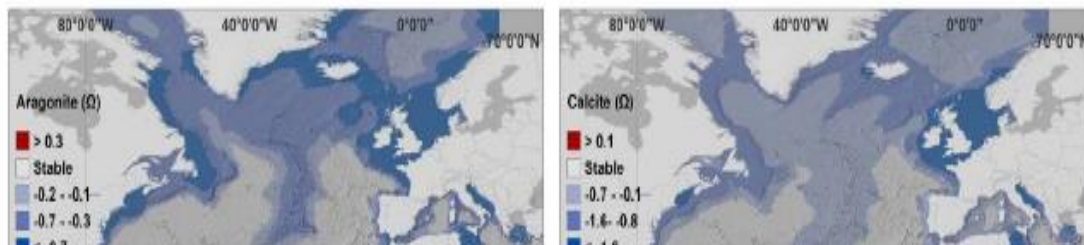

Figure 12 (cont.). Changes in environmental predictors between present and future conditions in the North Atlantic Ocean.

These forecasted changes in the water mass properties of the deep North MAR were forecasted by the H2020 ATLAS project to produce a significant impact in the suitable habitat for many VME indicator taxa (Figure 13). The ATLAS results showed a marked decrease of 30% to 100% in suitable habitat for cold-water corals and a marked shift in the suitable habitat of deep-sea fishes from 2.0° to 9.9° towards higher latitudes. The projections forecasted the largest reductions in suitable habitat for the scleractinian coral *Lophelia pertusa* and the octocoral *Paragorgia arborea*, with declines of at least 79% and 99%, respectively. ATLAS predicted an expansion of suitable habitat by 2100 for the fishes *Helicolenus dactylopterus* and *Sebastes mentella* by about 20 to 30%, mostly through northern latitudinal range expansion. In the North MAR a significant loss of suitable habitat was forecasted for most species, mostly around the Reykjanes Ridge and the Azores region. The modelling results forecasted limited

climate refugia locations in the North Atlantic by 2100 with the North MAR containing important refugia areas for two scleractinian corals (*Madrepora oculata* and *Desmophyllum dianthus*).
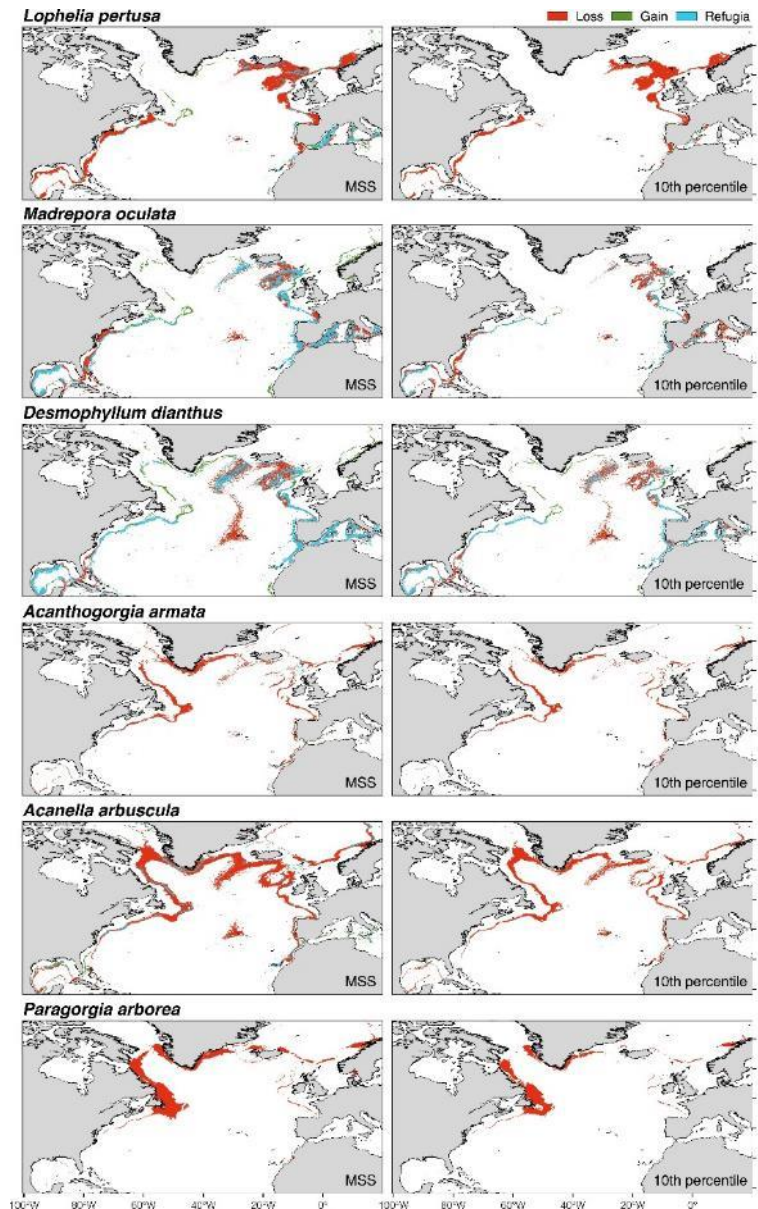

Figure 13. Forecasted present-day suitable habitat loss, gain, and acting as climate refugia areas (sensu Keppel & Wardell, 2012) under future (2081-2100; RCP8.5 scenario) environmental conditions for cold-water corals fish in the North Atlantic Ocean. Areas were identified from binary maps built with an ensemble modelling approach and two thresholds: 10-percentile training presence logistic threshold (10th) and maximum sensitivity and specificity (MSS).

Feature condition and future outlook

Several areas along the Mid-Atlantic Ridge have been protected with either bottom fishing closures and/or have been designated as OSPAR High Seas Marine Protected Areas. As an example, a larger area of the North MAR north of the Azores was declared as a NEAFC fisheries closures and after declared as OSPAR MPAs; the Mid Atlantic Ridge North of Azores (MARNA). The hydrothermal fields located in the North MAR (Lucky Strike, Menez Gwen and Rainbow) were classified as Sites of Community Importance under the Natura 2000 habitat directive and also declared as OSPAR MPAs. The Charles Gibbs Fracture Zone is another examples of an area in the North MAR listed as OSPAR MPA.

The actual condition of the benthic communities of the North MAR is unknown due to the lack of baseline data for the region. However, it is well accepted that bottom fishing (both bottom trawling and longlining) have produced significant impacts in the North MAR benthic ecosystems by removing habitat forming, slow-growing and long-lived cold-water corals (Sampaio et al., 2012; Pham et al., 2014). However, great concerns on the status of the benthic communities of the North MAR have arisen from the potential future developments of deep-sea mining for massive seafloor sulphides on hydrothermal vents. In fact, the approved three exploration contracts to Poland, Russia and France may, in the future, significantly impact both the biological communities living on hydrothermal vents but also the background fauna composed of cold-water coral gardens and sponge aggregations. The true scale of impacts of this activity is still unknown but if biological connectivity of vent fauna and col-water corals is disrupted, the impacts may well expand southern to the whole Mid-Atlantic Ridge.

Currently the EU H2020 ATLAS and SPONGES projects are producing important information regarding the benthic communities inhabiting different habitats of the northern part of the MAR. This project will finish in 2020, but luckily another H2020 project called iAtlantic has recently started. iAtlantic will provide new knowledge of deep ocean benthic ecosystems in the North and South Atlantic. This ambitious project will explore the world of deep-sea habitats (200-2000 m) where the greatest gaps in our understanding lie and certain populations and ecosystems are under pressure. iAtlantic targets 12 large marine regions including the subpolar Mid-Atlantic Ridge open-ocean ecosystem off Iceland, and deep-sea coral and hydrothermal vent ecosystems of the central Mid-Atlantic Ridge.

Assessment of the area against CBD EBSA Criteria

CBD EBSA Criteria (Annex I to decision IX/20)	Description (Annex I to decision IX/20)	Ranking of criterion relevance (please mark one column with an X)			
		No information	Low	Medium	High
1- Uniqueness or rarity	Area contains either (i) unique ("the only one of its kind"), rare (occurs only in few locations) or endemic species, populations or communities, and/or (ii) unique, rare or distinct, habitats or ecosystems; and/or (iii) unique or unusual geomorphological or oceanographic features.				X

Mid-ocean ridges are by definition unique, rare, and distinct habitats supporting some unique, rare, and distinct ecosystems. The North MAR presents several of these unique geological habitats such as underwater ridges and ridge valleys. These areas contain 90% of the known and predicted hydrothermal vents which are the most unique and rare ecosystems on the world's oceans (Harris et al., 2014). The North MAR is a hotspot of hydrothermal vents, with 64 known and inferred hydrothermal vent fields; with 22 being confirmed as active vents, 28 being inferred active vents, and 14 being inactive sites (InterRidge Vents Database v3.4). Some of the most well-known vents in this region are the Broken Spur, Logatchev, Lost City, Lucky Strike, Menez Gwen, Moytirra, Rainbow, Saldanha, Snake Pit, Steinahóll, and TAG. The hydrothermal vents of the North MAR may represent a unique biogeographic region of invertebrate species (Van Dover, 2010). They host endemic species that cannot live anywhere else, dominated by the blind shrimp *Rimicaris exoculata*, the mussel *Bathymodiolus azoricus* (Desbruyères et al., 2001). The uniqueness of each vent, due to the diversity

of hydrothermal settings, the depth range and water mass distribution over oceanic ridge crests, volcanic arcs and back-arc systems significantly influence biomass production rates in the vicinity of these areas (LeBris et al., 2019).

In addition to the endemic vent fauna, there are also several reported endemic cold-water corals in North MAR region of the Azores (Braga-Henriques et al., 2013; de Matos et al 2014; Moldstova et al., 2016; Sampaio et al., 2019). An recent example is the new species of black coral *Heteropathes opreski*, which is known exclusively from the North MAR at depths 1,955–2,738 m (Moloddtsova, 2016). The MAR is also home to species, or species associations that are not present elsewhere. This is the case of the occurrence of a unique 'living-fossil community' formed by a long-lived deep-sea oyster and a cyrtocrinid (Wisshak et al., 2009) and coral reefs formed by the azooxanthellate scleractinian *Eguchipsammia* c.f. *cornucopia* Cairns, 1994 (Dendrophylliidae) (Tempera et al., 2015).

Moreover, the waters around the North MAR and in particular the Azores also host a number of rare deep-water shark species. An extreme example is the Azores dogfish (*Scymnodalatias garricki),* a species so rare that it is known only from two specimens caught in the Azores area in 1977 and 2001 at 300 m and 580 m depth respectively (Kukuev & Konovalenko, 1988; Kukuev, 2006). The North MAR is also a preferred habitat for the sailfin roughshark *Oxynotus paradoxus*, a very rare species of deep-water sharks, endemic to Eastern Atlantic (Ebert & Stehmann, 2013) and the frilled shark *Chlamydoselachus anguineus* that could use the MAR as aggregation or mating area (Kukuev & Pavlov, 2008).

2-Special importance for life-history stages of species	Areas that are required for a population to survive and thrive.				X

Endemic chemosynthetic fauna associated with the hydrothermal vents in the North MAR have metabolic adaptations that depend on the particular physical-chemical conditions of such vents and therefore cannot survive elsewhere (Van Dover, 2000). In the North MAR, *Bathymodiolus azoricus* are foundation species forming dense mussel beds that serve as habitats and settlement substrates for other vent-associated organisms (Govenar, 2010). In addition, most vent species have leucitotrophic larvae with poor dispersion capabilities that can only survive if they settle close to the active field (Mullineaux et al., 2018). Recent studies (not in the North MAR) demonstrated the importance of hydrothermal vents for deep-water skates which seems to actively use the high temperature of a hydrothermal vent to naturally incubate egg cases (Salinas de León et al., 2018).

The diverse benthic communities at North MAR, comprising of cold-water coral reefs, gardens, sponge grounds and massif sponges, provide complex three-dimensional structural habitat that provide refuge, feeding opportunities, and spawning and nursery areas for a wide range of associated sessile and vagile species, including commercially important fish and crustacean species (Buhl-Mortensen et al., 2010; Beazley et al., 2013; Pham et al., 2015; Gomes-Pereira et al., 2017). For example, deep-water sharks were found to lay eggs among cold-water corals (Henry et al., 2013).

There is also evidence that the North MAR may be a potential aggregation/mating site for the rare and vulnerable shark *Chlamydoselachus anguineus* (Kukuev & Pavlov, 2008) and a spawning area for roundnose grenadier (*Coryphaenoides rupestris*; Danke et al., 1987) and the Bigelow's ray *Rajella bigelowi* (Orlov et al., 2006). There is also evidence from the recent H2020 ATLAS expeditions that

the Gigante Complex Area (GCA) in the MAR may be nursing area for the shark *Dalatias licha*.

The particular hydrographic conditions and high morphological relief of the MAR also provides the necessary conditions for the recruitment and settlement of coral and sponge larvae with low dispersal potential and recruitment success (Hilário et al., 2015; Girard et al., 2016). Furthermore, the North MAR may also become an important connectivity pathway even for the larvae of the reef-building coral *Lophelia pertusa* with high dispersal potential in a scenario of changes in climate. Connectivity modelling studies conducted within the framework of ATLAS suggest that the North MAR may be important connectivity pathway from the Azores to the North Atlantic for *L. pertusa* larvae under a scenario of reduced suitable habitat caused by projected changes in climate (Fox et al., H2020 ATLAS project unpublished data). These models also suggest that the dominant factors in future distribution and connectivity are likely to be the changes in local conditions, particularly temperature and ocean acidification. As such, shallower areas of the MAR may act as refugia for cold-water corals and other benthic calcifying species from ocean acidification as they lie in shallower waters with a higher aragonite saturation horizon, as suggested for seamount summits (Tittensor et al., 2010; Rowden et al., 2010).

Habitat suitability models developed within ATLAS show the contraction on the area of suitable habitat for cold-water corals, particularly for octocorals, in the North Atlantic, both in geographic range and depth under future projected climate conditions, further demonstrating the importance of the North MAR to the life histories of cold-waters.

3-Importance for threatened, endangered or declining species and/or habitats	Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species.				X

A large proportion of the species and habitats identified in the North MAR are under some type of legal protection or threatened status from different sources, including a large diversity of cold-water corals and deep-sea fishes. Cold-water coral species of the Order Antipatharia (e.g. black corals *Leiopathes* sp, *Bathypathes* sp), Scleractinia (e.g. reef building corals *Lophelia pertusa, Madrepora oculata*) and family Stylasteridae (e.g. *Errina* spp, *Stylaster* spp), are listed under Appendix II of the CITES convention (https://www.cites.org/eng/app/appendices.php). Many of these habitats, including the cold-water corals gardens and sponges aggregations, sea-pen and burrowing megafauna communities, as well as oceanic ridges with hydrothermal vents and seamounts are all listed on the OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR 2009; 2010a.,b,c,d).

Deep-water sharks have limited productivity and limited ability to sustain high levels of fishing pressure, and will unlikely recover from serious overfishing (Kyne & Simpfendorfer, 2007). Out of the 25 species of deep-water sharks occurring in the North MAR around the Azores, nearly half are listed under the IUCN Red List of Threatened Species, as Critically Endangered (n=1), Endangered (n=4), or Near Threatened (n=2), or as Data-Deficient (n=7), 2 are not even assessed (IUCN Europe 2018). Additionally, *Centrophorus squamosus* and *Centroscymnus coelolepis* (Fossen *et al*. 2008), along with *Centrophorus granulosus* are occasionally caught as bycatch of the longline fisheries in the North MAR off the Azores (Fauconnet et al., 2019). These three shark species are included in the

OSPAR list of Threatened and/or Declining Species and Habitats (BDC/MASH, 2007), along with *Dipturus batis*, *Raja clavata* and *Hoplostethus atlanticus*. The North MAR is also home to the charismatic and endangered Greenland shark (*Somniosus microcephalus*).

4- Vulnerability, fragility, sensitivity, or slow recovery	Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.				X

Hydrothermal vent fields are known as ephemeral or transient habitats because of the close relationship of hydrothermal vent activity with spreading centres. Hence, only partial knowledge of the natural succession patterns occurring at these vents is available, and no knowledge is available on nascent hydrothermal vent sites in the North MAR. The particular nature of every hydrothermal vent field and stochastic ecological succession of vent communities means that if destroyed by the emergent threat of deep-sea mining, there is very little potential for recovery. Active hydrothermal vent ecosystems are vulnerable and at risk of serious harm (Van Dover et al., 2018).

Most benthic communities occurring in the MAR, such as hydrothermal vent fields, cold-water reefs and gardens and sponge aggregations are considered as vulnerable marine ecosystems (VMEs), a term coined by Food and Agriculture Organization of the United Nations (FAO) which identifies species, communities, or habitats vulnerable to fishing activity (FAO, 2009). This is because these organisms have life history traits such as slow growth, high longevity, low reproductive potential that makes their recovery from human impacts very slow (Clark et al 2016; 2019). Cold-water corals form reefs that can reach 8 000 years, with *L. pertusa* colonies growing linearly at 6–35mm year-1 (Roberts et al., 2009). Octocorals and black corals, which dominate benthic assemblages in the North MAR region, have growth rates of less than 1 cm a year and age spans of hundreds (e.g. bamboo coral *Keratoisis* sp.: Watling et al., 2011) to thousands of years (black coral *Leiopathes* sp. Roark et al., 2009; Carreiro-Silva et al., 2013). This means that if removed from the seabed, these species and the communities they form can take centuries to millennia to recover from human impacts. Although age estimates for sponge species are scarce, studies suggest multi-centennial age spans, e.g. 220 and 440 years (Leys & Lauzon, 1998; Fallon et al., 2010), whereas some sponge reefs are estimated to be up to 9,000 years old (e.g. Krautter et al., 2001).

Because of the inherent difficulties in surveying large areas of the deep-sea, the ATLAS project used a multi-criterion assessment (MCA) to evaluate how likely an area represents a VME. Outputs of this exercise identified the Reykjanes Ridge and southern Iceland, and the Azores as areas with high values of VME index. Unfortunately, most of the North MAR south of the Azores have been scientific sampled mostly in hydrothermal vent fields; which are defined as bona fide VME habitats. Nevertheless, it is clear that when studied and sampled every region of the North MAR reveals important habitats, namely cold-water coral gardens and sponges' aggregations. Further, studies by Clark & Tittensor (2010), which created an index to assess the risk to stony corals by fisheries, considered the North MAR one of the most relevant areas of the all oceans in terms of stony corals.

The North MAR may also become an important refugia area for many benthic species and fish in the near future. Predicted changes in the suitable habitat under future climate conditions within the ATLAS project indicate a marked decrease in in the suitable habitat scleractinian corals and gorgonians towards the 2100. As such, the North MAR may act as a refugia from habitat loss in other regions of the Atlantic.

As described above, the North MAR is also home to the Greenland shark, which has an estimated growth of only about 1 centimetre a year and may live more than 400 years; making it the longest lived vertebrate (Nielsen et al., 2016). Its maturity would only be reached by around 150 years (Nielsen et al., 2016), making it particularly vulnerable to fishing.

5-Biological productivity	Area containing species, populations or communities with comparatively higher natural biological productivity.				X

The complex hydrographic setting around the North MAR and the presence of the ridge itself leads to enhanced vertical mixing and turbulence that results in areas of increased productivity (Falkowski et al., 1998; Heger et al., 2008). The productivity over mid-ocean ridges has been described as a major factor influencing patterns of fauna abundance and distribution (King et al., 2006; Bergstad et al., 2008). The high geomorphological relief also promotes strong near-bed currents and enhanced food supply, providing ideal conditions for the colonization of deep-sea suspension-feeding fauna such as cold-water corals and sponges (Mortensen et al 2008; Moldstova et al 2013; Lopes & Tabachnik 2013; Tabachnik & Menshenina 2013). As such, many areas of the North MAR support extremely rich communities of cold-water corals reefs and gardens, sponge aggregations, and demersal fish communities. As described above, cold-water coral reefs and gardens and sponge aggregations provide structural habitat having a positive effect on benthic megafauna and fish abundance (Mortensen et al., 2008; Linley et al., 2017). Both cold-water coral communities and sponge grounds are important for global biogeochemical cycles and the ocean's benthic pelagic coupling loop, being responsible for nearly 30% of the coupling between organic matter (OM) produced at the ocean surface and the seafloor (Cathalot et al., 2015). They represent hotspots of ecosystem functioning processing substantial amounts of OM (White et al., 2012; Cathalot et al., 2015) and release nutrients back into the surrounding water (Van Oevelen et al., 2009; Cathalot et al., 2015) that becomes available to associated fauna potential increasing overall biodiversity and biological productivity of these habitats.

At hydrothermal vents, micoorganisms play the role of primary producers, fuelling faunal communities that are believed to be amongst the most productive on Earth (Van Dover, 2000; Cavanaugh et al., 2006). Deep-sea hydrothermal fields are biological oasis compared to the surrounding abyssal environments. Chemosynthetic microorganisms serve as food for mussels, shrimps and other species that are densely aggregated around hydrothermal vents, with biomass at deep-sea hydrothermal fields that can reach value of 20 kg·m^{-2}. The organic matter produced at vents is also spread with the buoyant plume, contributing to the global ocean micronutrient budgets (Tagliabue et al., 2010; Resing et al., 2015). The chemosynthetic productivity from vents is therefore exchanged with the nearby deep-sea environments, providing labile organic resources to benthic and pelagic ecosystems that rare otherwise food limited (Levin et al., 2016). Vent-derived organic carbon flux supplements the metazoan food web beyond the areas where hydrothermal venting occurs (Bell et al., 2017).

6-Biological diversity	Area contains comparatively higher diversity of ecosystems, habitats, communities, or species, or has higher genetic diversity.				X

The North MAR region is considered a cold-water coral hotspot, with about 200 species (Braga-Henriques et al., 2013; Sampaio et al., 2019) and more than twenty different types of coral gardens (Tempera et al., 2013) identified to date. A large proportion of CWCs belongs to the subclass

Octocorallia with 98 species identified (Sampaio et al., 2019), representing the highest octocoral diversity given for European waters (75% of Octocorallia recorded in European Register of Marine Species (Costello et al., 2001). Among these there are several examples of endemic fauna to the North MAR with the occurrence of species association and habitats that do not exist elsewhere in the Atlantic. During ROV dives in the North MAR, Mortensen et al. (2008) observed 28 different coral taxa (including *Lophelia pertusa*). Of those, seven were unique to the area (*Madrepora oculata*, *Solenosmilia variabilis*, *Stephanocyathus moseleyanus*, *Scleroptilum grandiflorum, and three Radicipes* species), as compared to sample sites around and north of the Charlie-Gibbs Fracture Zone. The recent H2020 ATLAS scientific surveys on the ridges and seamounts of the North MAR revealed many more types of undescribed habitats and species that may be new to science. Examples of such habitats recently discovered include one new unusual chemosynthetic hydrothermal vents, still of unknown biogeographic placement, several new types of coral gardens dominated by large long-lived coral species such as *Paragorgia johnsoni*, *Pleurocorallium johnsoni* and *Callogorgia verticillata*. Extensive sponge aggregations dominated by *Pheronema carpentieri* and *Poecillastra compressa* were also identified during these surveys. The high number of morphospecies (200 morphospecies of Cnidaria, Porifera and Actinopterygii) found in Gigante Complex Area demonstrates the high biological diversity associated with the North MAR.

The number of associated species to cold-water corals is also large with the high potential for the discovery of new species to Science (e.g. Carreiro-Silva et al., 2011; 2017; Linley et al., 2017). Almost the least recognized, are the high diversity microorganisms associated to cold-water corals and sponges (Naim et al., 2014; Goldsmith et al., 2018) which largely increases the pool of genetic diversity of the MAR and may offer Blue Growth applications not yet recognized.

Naturalness	Area with a comparatively higher degree of naturalness as a result of the lack of or low level of human-induced disturbance or degradation.			X	

It is well known that deep-sea trawling has dramatic impact on deep-sea benthic communities, while bottom longlines have a much smaller impact but still affect some of the oldest continuously living organisms on the North MAR (Pham et al., 2014). However, the level of fishing activity in the North MAR, as measured by Watson & Tidd (2018), is relatively low when compared to the levels of fishing in the whole North Atlantic. The large specimens of the gorgonian coral *Paragorgia johnsoni*, found in the Gigante Complex Seamount with colonies reaching heights of over 1.5 m, are one of the best-preserved aggregations of this species identified in the North MAR. Although some colonies on the summit showed signs of fishing impact, a large number of colonies on the flanks remain in a very good conservation status, with all their branches still intact. The presence of large black coral colonies with high longevity (several millennia) in the MAR is also indicative of well-preserved environments.

It should be noticed that several areas along the North MAR have been protected with either bottom fishing closures and/or have been designated as OSPAR High Seas Marine Protected Areas.

Currently, there has been a rising interest in exploration of minerals of high value in various areas of the North MAR, especially associated with deep-sea hydrothermal fields. In the North MAR south of the Azores major SMS deposits have been identified (Cherkashov et al., 2010) and the International Seabed Authority (ISA) has approved three exploration contracts to Poland, Russia and France. Those mining activities could have strong impacts on the ecosystems associated with the MAR, so it is important to ensure that these future activities are developed in a sustainable manner, safeguarding the unique natural values.

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Maps and Figures

A shapefile of the area was provided as supplementary information