Chapter 17
An Overview on Biodiversity and Ecosystems Off Mauritanian Deep-Waters

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Abstract Human activities in continental margins have progressively increased during the last decades, threatening vulnerable marine ecosystems in many continental slopes, such as cold-water coral reefs, seamounts and canyons. In order to protect these ecosystems and ensure the sustainable management of resources, countries and organizations should endorse effective policy actions. However, nowadays about only 0.8% of the oceans and 6% of the territorial seas belong to conservation area systems, a lack of protection that is particularly acute in deep-sea waters. The Mauritanian continental margin is the outcome of exceptional marine features, with abrupt canyon systems, sediment slides and a giant carbonate-

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mounds barrier occurring together. Mauritanian waters have both tropical and subtropical origins, being affected by coastal and offshore upwelling that leads to elevated productivity and abundant fishery resources. Soft-bottom habitats hold high diversity of species, and hard-bottoms sustain assemblages of suspension-feeders and vulnerable species. Nevertheless, despite the recent increase of extractive activities, the location and characterization of those Mauritanian deep-water areas of biological or ecological interest that require protection remain poorly known. The *Maurit* surveys have offered the opportunity to perform a first approach to the biodiversity and ecosystems in soft and hard bottoms of the Mauritanian outer shelf and slope. This last chapter provides an integrated overview of the demersal and benthic communities inhabiting Mauritanian deep waters and describes areas of particular ecological and/or biological interest that are vulnerable habitats and should be preserved according to international conventions.

Keywords Geomorphology · Water masses · Biodiversity · Ecosystems · Megabenthos · Demersal fauna · Soft-bottom habitats · VMEs · EBSAs · Coral carbonate mounds · Canyons · Seamount · Deep sea · Mauritania · Northwest Africa

Introduction

The Mauritanian continental margin, because of its singular geomorphological, hydrological and biological features, is one of the most interesting areas of the world's oceans. The seabed is characterized by the dominance of soft sediments, including one of the largest sediment slides in the world, and abrupt submarine canyons system, some of which extend as far as the Mid Atlantic Ridge (Jacobi and Hayes 1982, 1992; Krastel et al. 2004, 2006). Mauritanian waters formally belong to the North Atlantic tropical gyre but are influenced by waters of subtropical origin both over the shelf and at water depths between 300 and 600 m (Peña-Izquierdo et al. 2015; Pelegrí and Peña-Izquierdo 2015). Further, the continental shelf is largely influenced by coastal upwelling, all year long to the north and during winter and spring to the south. The combination of wind-induced coastal and offshore upwelling of nutrient-rich tropical waters drives high primary production in the entire coastal and offshore ocean, becoming one of the four worldwide major eastern boundaryupwelling systems (Demarcq and Soumou 2015).

As a consequence of the high productivity of the Mauritanian shelf and slope, its economic exclusive zone (EEZ) is characterized by the richness and abundance of marine resources (Domain 1980; Le Loeuff and von Cosel 1998) that have attracted foreign fishing fleets to operate in the region for over 50 years (Sobrino and García 1992). This has been followed by the development of local artisanal and industrial fleets in more recent years (FAO 2006). Although this strong fishing activity has historically been carried out over the continental shelf, during the last years some trawling fleets have extended their fishing grounds down to 1000 m depth (FAO 2006, 2012; Fernández-Peralta et al. 2011). In addition, oil and gas exploitations have recently started in several slope areas (Kloff and van Spanje 2004; Colman et al. 2005). These activities could seriously threat the yet rather unknown deep-water ecosystems of the Mauritanian slope.

As it happens in other African countries, marine research in Mauritania has traditionally been focused on biological studies and the assessment of exploited fish, shrimp and cephalopodstocks (FAO 2012). Ecological studies are limited to coastal ecosystems of the Banc d'Arguin and the Baie de l'Etoile (Wolff et al. 1993; Ould Baba 2010). Despite the large number of expeditions carried out off Northwest Africa since the nineteenth century, which resulted in the collection of an important number of fishes and invertebrates, this region is still one of the most unknown of the world oceans, especially for waters deeper than 30 m (Decker et al. 2004). This is confirmed by recent findings for habitats in the Mauritanian slope: the giant structure of cold-water coral reefs discovered last decade during the multibeam prospection by oil companies (Colman et al. 2005) and the rich benthic suspension-feeder communities photographed in the northern canyons during the 2010 German geophysical survey (Westphal et al. 2012; Freiwald, Senckenberg Institute, unpublished data, 2015).

Nowadays, the adverse impact that bottom fishing and other human activities may have over the deep-sea ecosystems is a matter of concern for the scientific community, the industry and the national and international organizations (Ramírez-Llodra et al. 2011). Under the legal framework of the United Nations (UN) Convention of the Law of the Sea (UNCLOS 1982), the UN General Assembly, the Food and Agriculture Organization (FAO) and the Convention on Biological Diversity (CBD) have issued directives and guidelines to preserve biodiversity and ecosystems, to ensure sustainability of fish stocks and to improve fisheries management (UNGA 2007; FAO 2008, 2009; CBD 2009a, b, 2011). In particular, the coastalstates and Regional Fisheries Management Organizations (RFMOs) have been required to make biodiversity inventories by year 2020, in order to identify the potential presence of vulnerable and significant habitats, and to establish a representative network of Marine Protected Areas forbidden for bottomtrawling fisheries.

The main original objective of the *Maurit* surveys was the prospection of new deep-water resources and the direct assessment of exploited demersal stocks. However, the important findings during the first cruise led to extend these objectives during the following three surveys. Thus, the four cruises enabled a first study of vulnerableslope ecosystems such as the cold-water corals reef, the Arguin and Timiris canyon systems and the small Wolof's Seamount (Ramos et al. 2010).

The purpose of this chapter is to offer a synthetic overview of the main faunistic and environmental features occurring in the Mauritanian continental slope. Our aims are to set a baseline for an ecosystem approach towards the sustainable management of fisheries resources and to provide the required tools for implementing conservation measures and guidelines (Bianchi 2008; UNGA 2007, 2009).

First, we highlight the general characteristics related to biodiversity, distribution patterns and assemblages of demersal fishes and megabenthos occurring in Mauritanian soft-bottoms. Then, we identify the main ecologically and biologically interesting areas, including the zone of minimum oxygen values, and discuss the environmental conditions that are responsible for their location. The hard-bottoms habitats—coral carbonate mounds reef, northern canyons and seamount—are subsequently characterized and the specific ecological reasons for their protection are identified.

Slope Soft-Bottoms

The Mauritanian slope is part of the Northwest Africa continental margin, characterized by a high rate of sedimentation from marine, fluvial and eolian sources. These sediments are later remobilized down-slope by landslides and turbidity currents that use the canyons as cross-margin preferential pathways.

Although the Mauritanian margin holds extensive hard structures, such as cold-water corals reef, the 99% of the slope seabed between 100 and 2000 m is covered by soft sediments composed of different proportions of sand and mud (see Chap. 2). Despite its apparent uniformity, many physical factors—depth, slope gradient, sediment nature, instability, slides—act at different spatial scales generating both high heterogeneity within soft-bottoms and important differences in the diversity and structure of deep-sea communities. In general, sedimentary habitats of the upper slope are considered as the most affected by the human activity, as a consequence of the important fishing effort developed down to 1000 m depth, and by changes in nutrient input, ocean acidification and spreading of hypoxia (Ramírez-Llodra et al. 2011).

These soft bottoms were intensively sampled between 2007 and 2010, during the four *Maurit* surveys, with a commercial otter trawl in 291 trawling stations (281 of them valid) and a beam trawl in 25 stations (Ramos et al. 2010) (Fig. 17.1).

Biodiversity Overview

More than three millions of specimens and 213 tons of biomass, belonging to 40 high-range taxa (phylum, class, order) of fishes and megabenthicinvertebrates, were collected in the 316 trawl stations carried out on the Mauritanian shelf and slope, from 79 m to 1867 m depth. Demersal fishes and decapods were collected in all stations and with the two trawling gears, despite their different efficiency. Fishes were the dominant taxa in the catches from the commercial otter trawls (83 and 90% of the total in abundance and biomass, respectively) but not in those from the beam trawl, because this is a specific highly-effective gear for sampling crabs (Fig. 17.2), flat fishes and small-sized invertebrates (Sánchez et al. 2008).

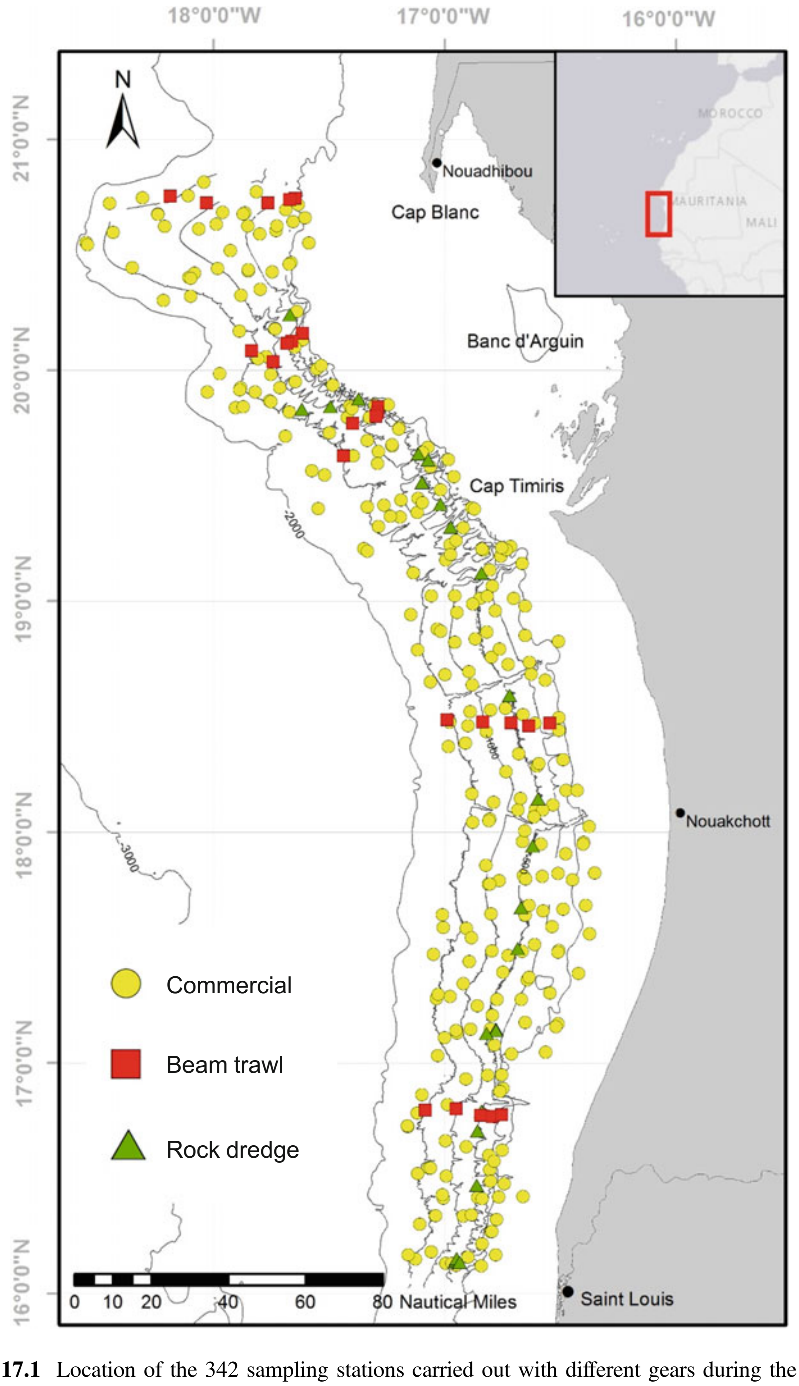

Fig. 17.1 Location of the 342 sampling stations carried out with different gears during the four *Maurit* surveys (commercial trawl: *yellow*; beam trawl: *red*; rock dredge: *green*) (in Ramos et al., Chap. 1)

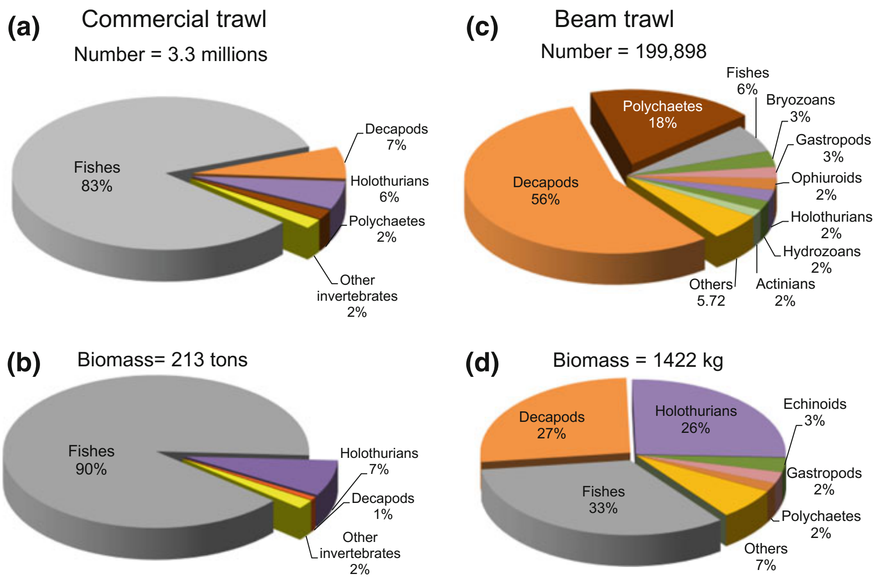

Fig. 17.2 Globalcomposition, in numerical abundances and biomass (in %) of the demersal fishes and megabenthic invertebrates from commercial (**a**–**b**) and beam trawl catches (**c**–**d**) in Mauritanian slope soft-bottoms (data standardized to a swept area of 0.1 km^2 and ha, respectively, for the two gears)

Holothurians, decapods and, to a lesser extent, polychaetes were the macrobenthic invertebrates best represented in the Mauritanian slope (Fig. 17.2).

A preliminary estimation of globalbiodiversity in the Mauritanian deep-shelf and slope accounts for around 1100 species. This number is based on the taxonomic work carried out so far, that has allowed the identification of 720 species of Actynopterigii, Chondrichthyes, Decapoda, Cephalopoda, Echinodermata and Cnidaria (Hydrozoa and Pennatulacea), and considering that approximately 400 species belonging to other invertebrate benthic taxa are currently under study. In spite of the high number of stations and the wide sampling coverage, in the case of the total megabenthos, it was not possible to predict the theoretical diversity; the cumulative species curve does not reach the asymptotic value because 40% of the species were collected at only one station and 56% at two localities (see Chap. 7). This is a phenomenon usually reported for the deep-sea macrobenthos (Grassle and Maciolek 1992), supporting the idea that the γ-diversity of the Mauritanian slope is higher than our estimates.

With 403 species, fishes were the most diverse group in the otter trawl catches. Among the invertebrates, Decapoda showed the highest diversity (118 species), followed by Echinodermata (82 species), Hydrozoa (63 species), Cephalopoda (48 species), Prosobranchia (39 species) and Pennatulacea (10 species) (Fig. 17.3). Preliminary numbers for those taxa that are still under study are: Polychaeta, Porifera and other Mollusca (around 70 species each), Anthozoa (50 species), other Crustacea

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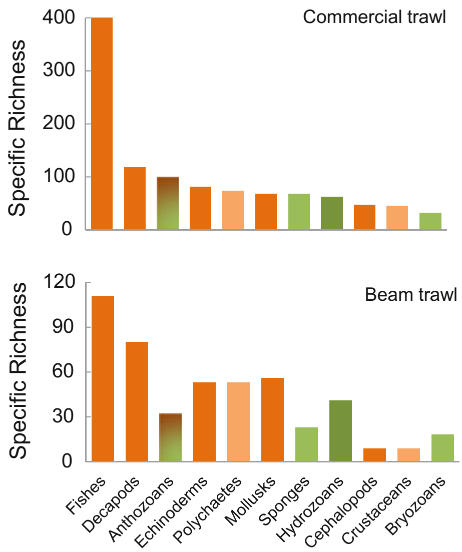


Fig. 17.3 Specific richness for the demersal fishes and main epibenthic invertebrate groups from commercial and beam trawl samples in Mauritanian slope soft-bottoms (*green*: exclusively suspension-feeders taxa; *orange*: others; *darker*: currently identified taxa)

not Decapoda (46 species) and Bryozoa (32 species). Fishes and decapods also showed high diversity in beam trawl samples (111 and 80 species), followed by molluscs, echinoderms and polychaetes (Fig. 17.3) (see Chaps. 7 and 8).

A new genus and four new species of decapods from Mauritanian slope have been described (Matos-Pita and Ramil 2014, 2015a, b, 2016). Several new species of other invertebrate groups have also been identified and are still in the process of taxonomic description.

The Mauritanian benthic fauna, considered as a whole, exhibits higher diversity than in other Atlantic areas. This seems to be a consequence of the transitional character of the Mauritanian shelf and slope, with a succession of water layers of northern and southern influence: the surface and upper-central layers (down to 300 m) are dominated by tropical waters, the lower-central layers (300–600 m) have a substantial influence of subtropical waters, the intermediate layers (600–1000 m) are of subantarctic origin, and the deep stratum is of North Atlantic origin (see Chap. 3). As a consequence, species with different biogeographical affinities are found mixed (Maurin 1968; Domain 1980; Duineveld et al. 1993): tropical species, which reach their northern distribution boundary in Cape Blanc, cohabit with Atlantic-Mediterranean species coming from northern latitudes. This is most evident at depths down to 1000 m, in the case of the mobile demersal and benthopelagic fauna, as fishes, decapods and cephalopods, present diversity values higher than at northern latitudes in the North Atlantic and Mediterranean (Nesis 2003; Company et al. 2004; Arkhipkin and Laptikhovsky 2006; Priede et al. 2010; Serrano et al. 2011; Cartes et al. 2014; Fernández-Peralta and Sidibe 2015). Nevertheless, the sessile and semi-sessile epibenthos presents high affinity with the Atlantic-Mediterranean fauna, with the tropical components being virtually absent. For example, only one of the 63 species of hydrozoans recorded in Mauritanian waters has West African distribution (see Chap. 11). Beyond 1000 m depth, the fauna was mainly composed by species widely distributed in the Atlantic or even cosmopolitan.

The Cape Verde Front, a hydrological zone that separates tropical and subtropical regions, is located in the northern part of the Mauritanian margin (see Chap. 3). As it extends from Cape Blanc to the Cape Verde Islands, it would appear as if all Mauritanian waters had to be part of the southern tropical domain, but this is not always the case. The frontal region itself is the site of along-slope flow convergence between the Canary Upwelling Current (Pelegrí et al. 2005, 2006) and the Mauritania Current and Poleward Undercurrent (Peña-Izquierdo et al. 2012, 2015). This results in major offshore water export, clearly visible in satellite images as the Cape Blanc giant filament (Gabric et al. 1993; Sangrá 2015), and substantial mesoscale mixing and cross-frontal flows on the continental shelf (Pastor et al. 2008; Peña-Izquierdo et al. 2012). The top 300 m of the water column are indeed dominated by the southern waters but the layers between 300 and 600 m, coinciding with those layers of minimum oxygen concentrations, are substantially influenced by subtropical waters. The presence of these different waters masses, with distinct physico-chemical characteristics, is a major factor affecting the faunal composition (transitional or not) of the different water strata. The resulting distribution is also linked to the dispersal capability of the individuals during their adult phase. Motile groups have possibilities to migrate latitudinally, probably coupled with the seasonal displacement of the Cape Verde Front. The dispersion capacity of sessile and semi-sessile benthic taxa, on the other hand, is limited to larval transport.

The Mauritanian waters are also largely influenced by coastal and offshore upwelling (see Chap. 3). Coastal upwelling is permanent all year long north of Cape Timiris and, during winter and spring, reaches the southern Mauritanian areas. Upwelling affects only the shelf and upper slope waters, leading to very high levels of primary productivity, and contributes to the penetration of subtropical waters over the northern shelf. Coastal upwelling, hence, would also contribute to enhancing the existence of different geographical and vertical patterns in the distribution of Mauritanian marine fauna.

In relation to trophic strategies, the slope soft-bottom communities are basically composed by non-suspension-feeder groups. Despite suspension-feeders (sponges, cnidarians, bryozoans, ascidians) were represented by around 280 species—38% of the benthicinvertebrates and 25% of the total fauna (Fig. 17.4a)—these groups only contributed to 9% of the abundance and 1% of the biomass of the total megabenthos (Fig. 17.4b, c). These results do not depend on the sampling gear used—commercial or beam trawl—which would indicate that the megabenthos of soft-bottoms maintains a consistent structural pattern along the Mauritanian slope. It is also worth noting that, despite the high productivity of Mauritanian waters, suspension-feeders are small sized. That agrees with observations of Van Soest (1993) for sponges of the Banc d’Arguin area, who pointed out that only small and *mobile* species were abundant.

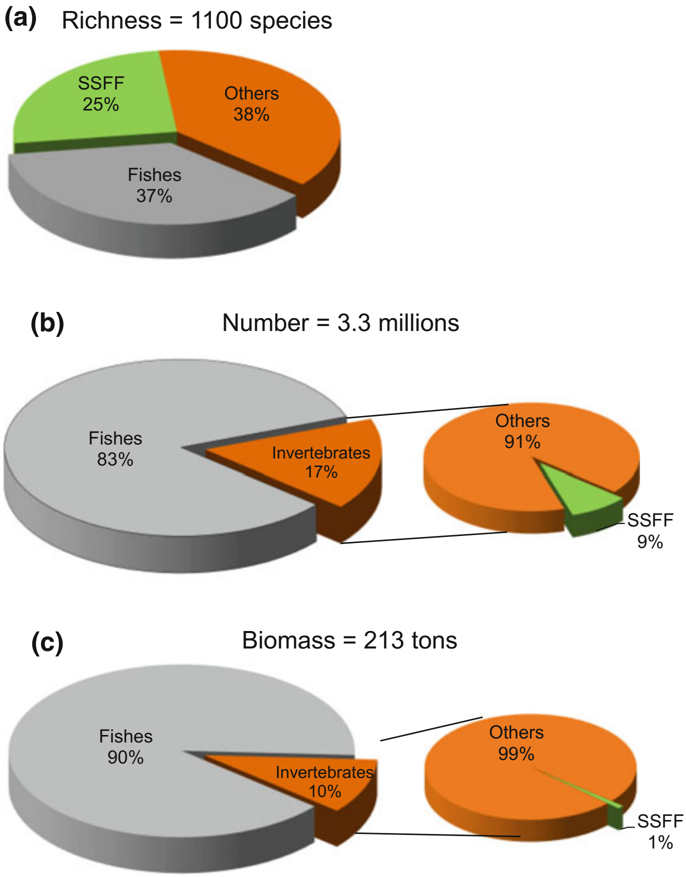


Fig. 17.4 Specific richness (**a**), numerical abundance (**b**) and biomass (**c**) (in %) for exclusively suspension-feeders taxa as part of the global megabenthos in Mauritanian slope soft-bottoms

Although Thiel (1982) reported important suspension-feeding communities between 50 and 350 m depth around Cape Blanc, it seems that these are currently absent.

Biodiversity Distribution Patterns

During the *Maurit* cruises, the species richness showed a common pattern for fish (including elasmobranches) and the entire megabenthos, with maximum values along the deep slope (Fig. 17.5 left, centre) (see Chaps. 4 and 7). The richness of demersal fishes and megabenthos together, obtained after applying kriging techniques, confirms the high diversity in deep-slope waters, especially below 1000 m depth (Fig. 17.5 right). Although maximum local values—up to 96 species by station—

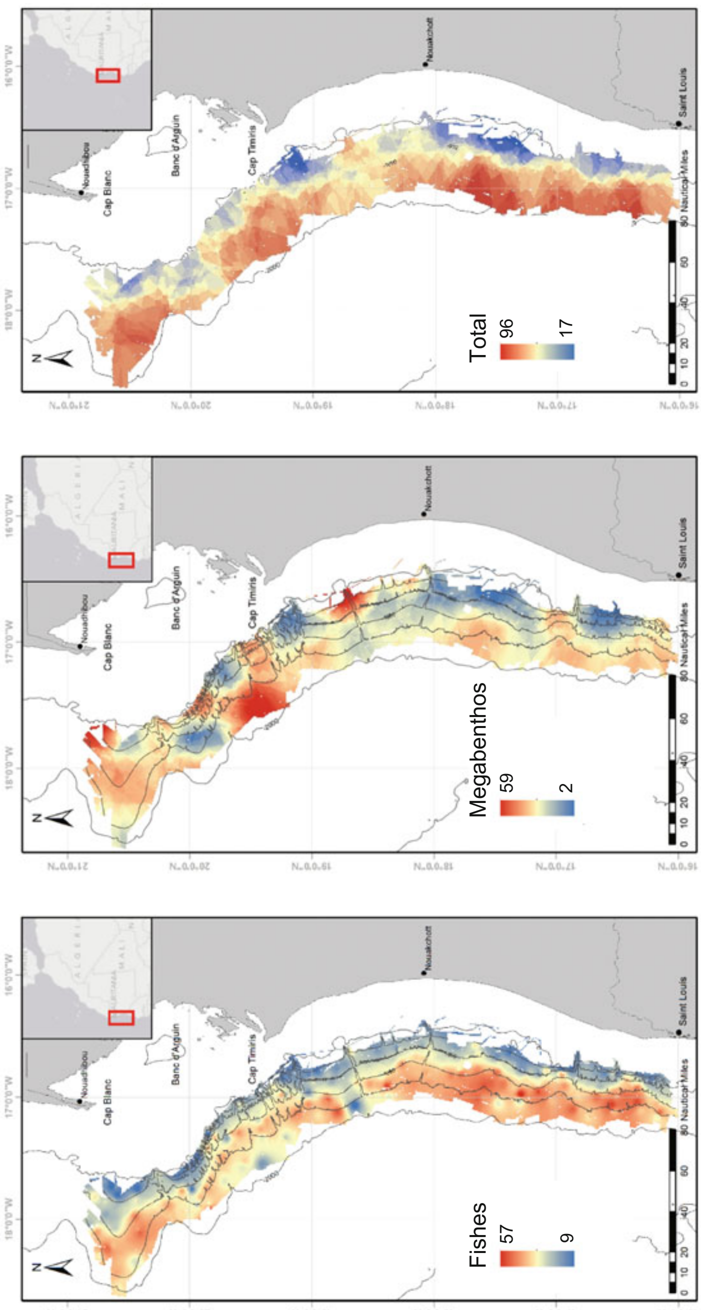


Fig. 17.5 Geographical distribution of specific richness of demersal fishes *(left)*, global megabenthos *(centre)* and total *(right)* in Mauritanian slope soft-bottoms (after kriging the original specific richness per station) (in Chaps. 4 and 7)

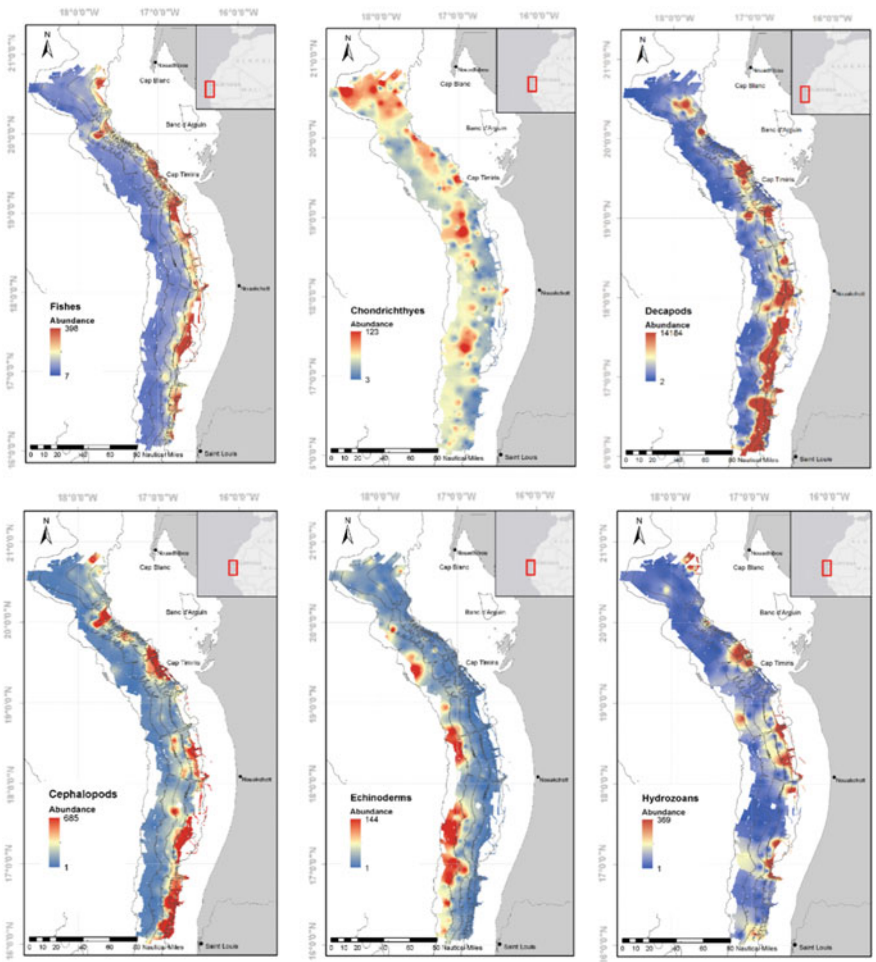


Fig. 17.6 Geographical distribution of densities of main demersal and megabenthic taxa (teleost fishes and chondrichthyes, decapods, cephalopods, echinoderms and hydrozoans) in Mauritanian slope soft-bottoms (after kriging the original densities per station) (in Chaps. 4, 5, 9–12)

were registered off Cape Blanc and Cape Timiris, diversity increases in the southern area, where high values occur along the entire lower slope between 18°30′N and the Senegalese border (Fig. 17.5 right). This trend is mainly due to the high fish diversity as megafaunarichness showed their lower values to the south (Fig. 17.5 left, centre).

The densities and biomass of the main taxa presented a clear depth zonation pattern along the deep shelf and continental slope. Thus, maximal values of teleosts were mainly found in the upper slope, down to 450–500 m depth and the highest densities and biomass of decapods were located at 400–550 m (Figs. 17.6 and 17.7). The chondrichthyes were especially abundant from 1000 to 1300 m (Fig. 17.6),

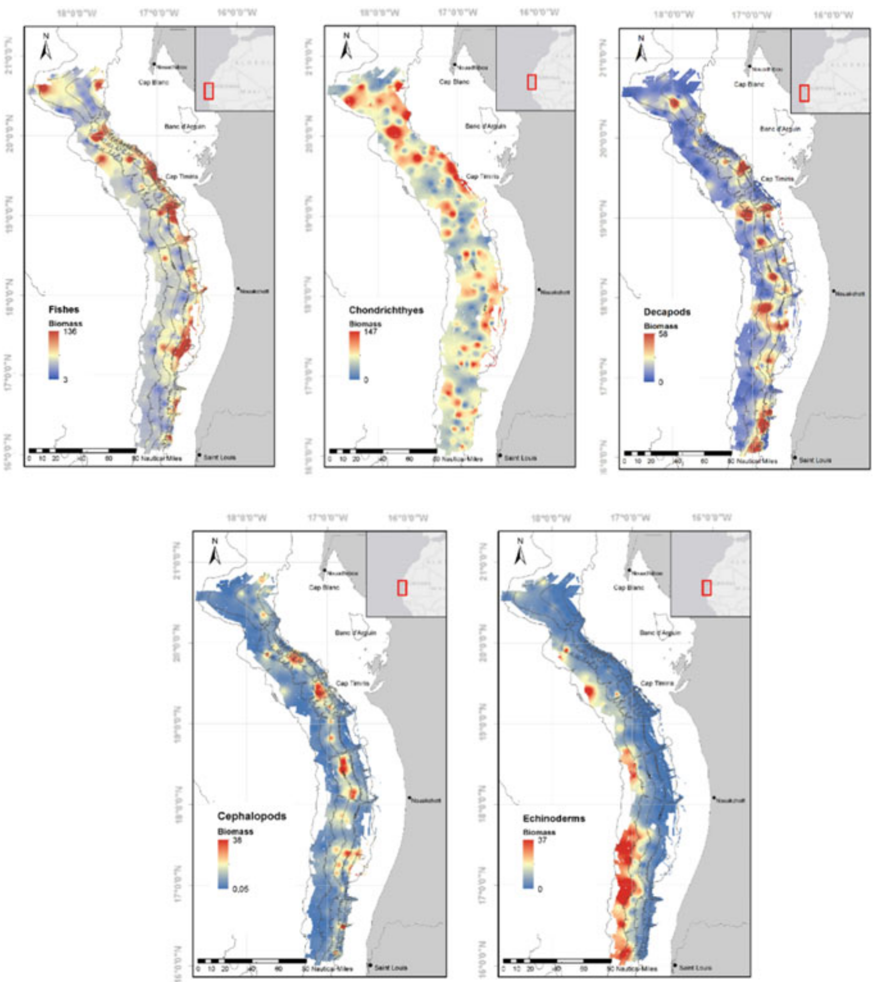


Fig. 17.7 Geographical distribution of biomass (in kg) of main demersal and megabenthic taxa (teleost fishes and chondrichthyes, decapods, cephalopods and echinoderms) in Mauritanian slope soft-bottoms (after kriging the original biomass per station) (in Chaps. 4, 5, 9, 10 and 12)

while high values for cephalopods were found down to 1000 m and even 1500 m in certain areas (Figs. 17.6 and 17.7). Finally, megabenthos—particularly echinoderms—were more abundant in bottoms deeper than 1500 m (Fig. 17.6). At latitudinal level, only the elasmobranches and the megabenthos, that follow the echinoderms trend, showed clear and opposed patterns, being the former more abundant in the northern area and the latter in the southern area (Chaps. 5, 10 and 12).

Certain concentration areas with high biomass values for benthic and demersal fauna could be identified (Fig. 17.8): (i) the greatest concentration area was located in front of the Banc d'Arguin at the entire prospected bathymetric range, from the

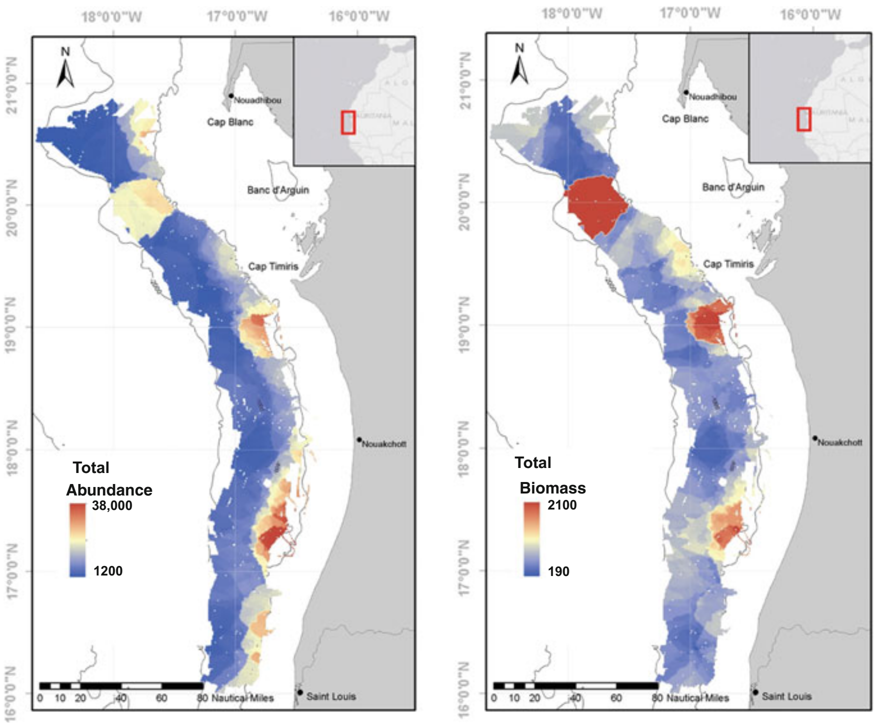


Fig. 17.8 Geographical distribution of total densities and biomass (in kg) (demersal fishes and megabenthos) in Mauritanian slope soft-bottoms (after kriging the original densities per station)

deep-shelf to 2000 m; (ii) the second most important concentration zone occurred in the system of canyons south of Cape Timiris, reaching down to 1300 m; (iii) a third area with high biomass was located around 17°30′N, down to 1000 m; (iv) a fourth area, with values lower than the previous ones, was identified north of Cape Timiris and down to 500 m. Densities followed a similar distribution pattern, but with the maximum values not exactly occurring in the same places as the biomass maxima. In addition, areas with intermediate densities were identified to the north, in front of Cape Blanc, and to the south, close to the Senegalese border (Fig. 17.8).

The suspension-feeder groups were mainly distributed in shallower waters (100–200 m) and concentrated in some particular zones (Fig. 17.9); these groups were characterized by small size and low density and biomass (9 and 1% of the total megabenthos, respectively) (Fig. 17.4). The highest density and richness of hydrozoans were recorded on the shelf break and upper slope, mainly around canyons (Fig. 17.6) (see Chap. 11). Curiously, despite its minor representation in megabenthic communities, the α-diversity of suspension-feeders (37 species per station in several particular areas) was only slightly less than for groups with other trophic strategies (non suspension-feeders) (42 species per station) (Fig. 17.10). The zones of main diversity and/or density/biomass concentrations of suspension feeders (including

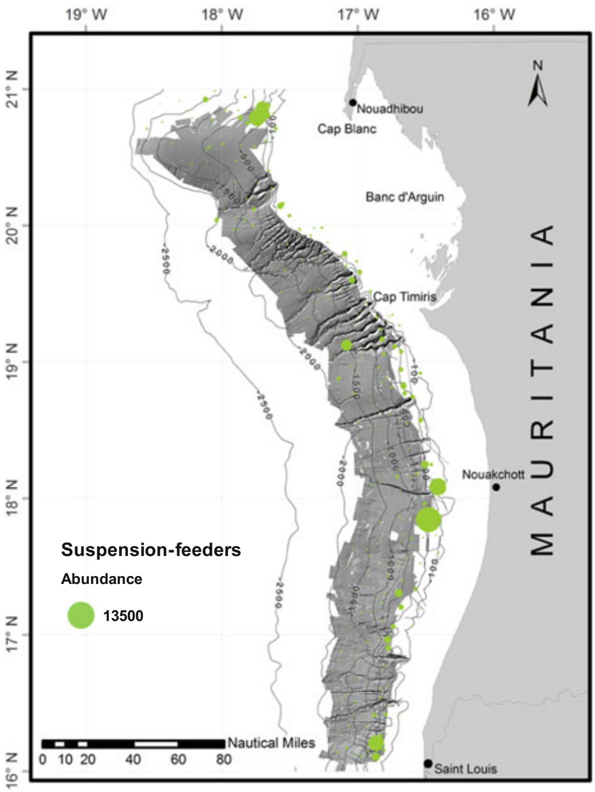


Fig. 17.9 Geographical distribution of numerical abundances per station of exclusively suspension-feeders groups in Mauritanian slope soft-bottoms (data standardized to a 0.1 km^2 swept area) (in Ramil and Ramos, Chap. 7)

sponges, cnidarians, ascidians and bryozoans) were located in front of Nouakchott (18°N), in the region off Cape Blanc and near the southern border of Mauritania (Figs. 17.9 and 17.10), coinciding with those areas where the highest densities of filter-feeder tubeworm polychaetes were found.

These concentration and high diversity zones of suspension-feeders were located in the deep-shelf and the upper-slope, being largely influenced by the high primary production linked to the upwelling system. However, the small size of the species and the absence of long-lived suspension-feeder communities, like those found in the Moroccan and Saharan slopes (Ramos et al. 2015), indicates that some factors other than productivity may drive the development of the sessile epibenthos. The dominance of muddy bottoms and the occurrence of large sediments slides, common features in the Mauritanian slope, hamper the stability of environmental conditions, which is essential for the development and growth of such communities. Nevertheless, the presence of highly diverseassemblages of small suspension-feeders on tubes of chaetopterid polychaetes suggest the existence of source

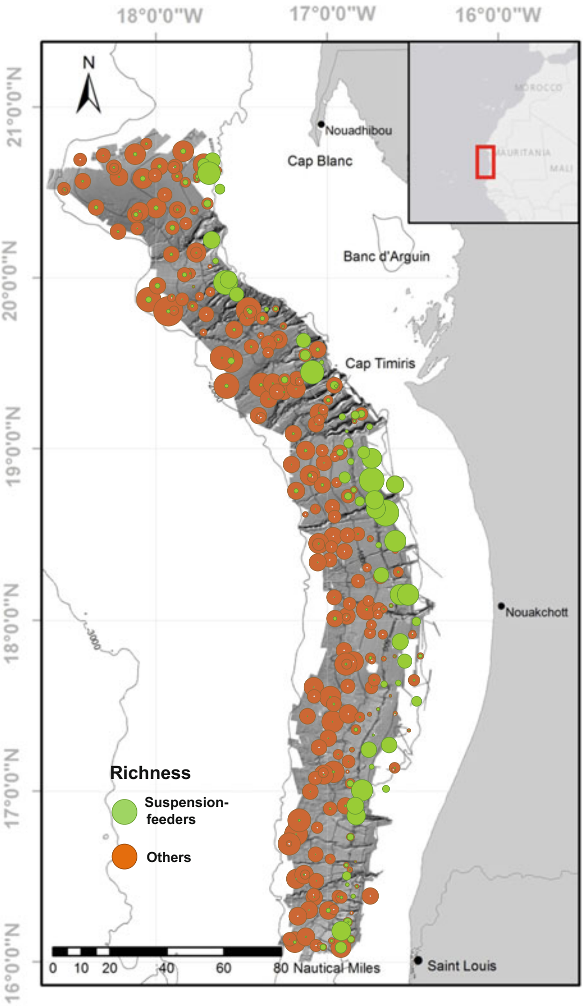


Fig. 17.10 Geographical distribution of specific richness per station of exclusively suspension-feeders groups and benthic invertebrates with other trophic strategies in Mauritanian slope soft-bottoms (*green*: suspension-feeders; *brown*: others)

populations, probably linked to the submarine canyons, that provide larvae to maintain these communities.

Besides the low diversity of the entire megabenthos in the deep-shelf and upper slope, it is worth noting its general scarcity, mainly in terms of the biomass, registered down to 700–900 m depth. The peak of abundance found in shallower bathymetric ranges was mainly due to the presence of decapods and, in some particular areas, of communities of small and short-living suspension-feeders. The low diversity and absence of epibenthos down to almost 1000 m could be attributed to the intensive trawl fishing activity developed for over 50 years, progressively reaching deeper and deeper waters. Shrimp trawlers operate at depths down to 750 m (Sobrino and García 1992; García-Isarch, Spanish Institute of Oceanography, unpublished data, 2015), but hake trawlers have increased their fishing depths during the last 15 years, reaching down to 1000 m (FAO 2006; Fernández-Peralta et al. 2011). The increased and continued trawling activity may have impacted the benthic communities by removing both target and non-target benthic species, the latter caught as bycatch (Kaiser et al. 2006) (see Chap. 9). Some authors emphasise that bottom fishing activity removes large bodied and colonial epifaunal species, thereby reducing the complexity and diversity of the benthic community and favoring scavenging species (Collie et al. 2000). In addition, the intensive bottom trawling would originate an enormous plume of resuspended sediments (Martin et al. 2014) that could hinder the settlement and/or survivor capacity of particular benthic taxa.

Soft-Bottom Assemblages

Independently of the number of assemblages per taxa identified through multivariate analysis, from two for cephalopods to six for bony fishes, a clear separation was observed between the communities in the outer shelf and upper slope with those on the middle and lower slope off Mauritania (Fig. 17.11). This separation occurs at around 400–550 m for all groups, with the exception of decapods, which conform a specific community occupying this bathymetric range and linked to the deep-water corals reef and oxygen minimum values (see Chap. 9).

In general, the dissimilarity among the shallowest and the deepest assemblages is very high, almost reaching 100%. This means that the fauna inhabiting the two zones is completely different, with few common species. However, while there is a strong dominance of certain species in the shallower assemblages, with few species contributing to the intra-group similarity, the deeper assemblages are characterized by low dominances, with many species accounting for similarity.

Bottom temperature and depth were identified as the main factors structuring the assemblages, at least for fishes, decapods, echinoderms, macro- and megabenthos. Besides, other environmental features, such as the presence of the coral carbonate mounds barrier and the existence of an oxygen depleted layer (with minimum values of 1.0–1.3 mL L^{-1}) may play a significant role in the assemblage's structure. Both features occur between 400 and 550 m depth (Fig. 17.12), acting as a barrier between assemblages and creating the main faunal discontinuity in the Mauritanian slope. This faunistic*jump* is particularly noticeable in echinoderms, which are virtually absent from 500 to 800 m depth (Fig. 17.13). On the contrary, certain decapods species seem to be adapted to these special environmental conditions, constituting a specific assemblage located on the reef-oxygen minimum area, characterized by low diversity but extremely high biomass, the maximum registered among all the decapod assemblages (Fig. 17.11) (see Chap. 9).

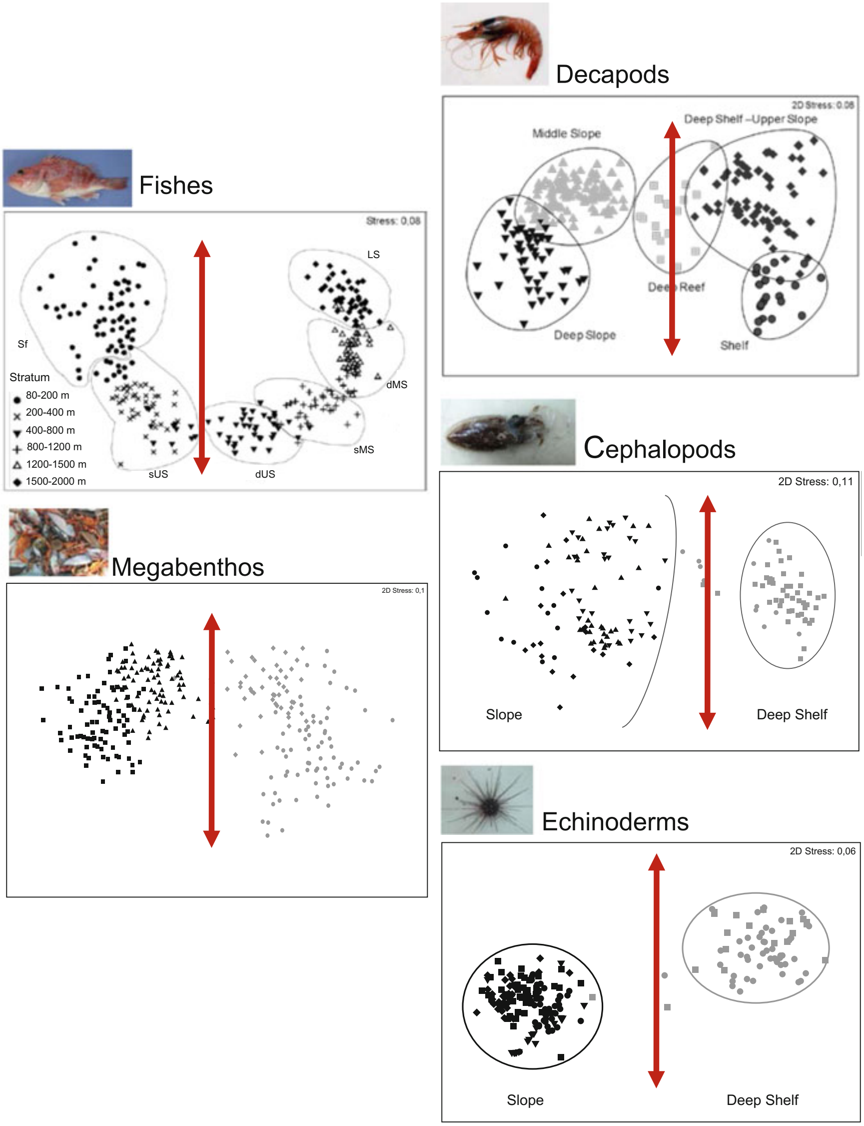


Fig. 17.11 Multidimensional scaling (MDS) plots for the main demersal and megabenthic taxa (teleost fishes and chondrichthyes, decapods, cephalopods and echinoderms) after the multivariate analysis of biomass data from 281 trawl stations in Mauritanian slope soft-bottoms during *Maurit* surveys (in Chaps. 4, 7, 9, 10 and 12)

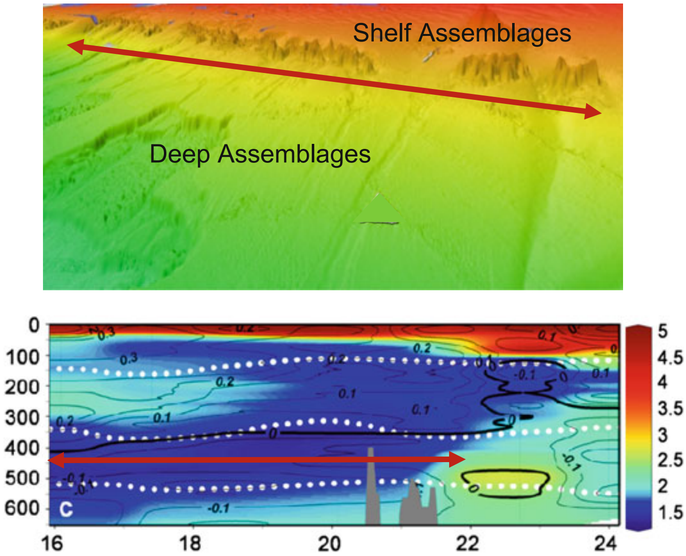
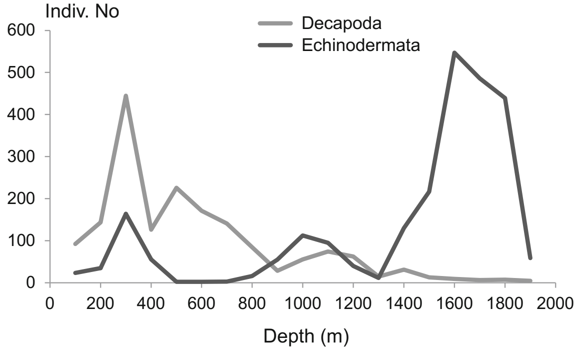


Fig. 17.12 The coral carbonate mounds barrier and the oxygen minimum layer, occurring in the Mauritanian slope at depths between 400 and 550 m depth, are responsible for the main faunistic discontinuity observed for different demersal and benthic taxa. (*Top panel*) Three-dimensional overview of the carbonate mounds barrier as obtained by multibeam echosounder during the *Maurit* surveys; (*bottom panel*) distribution of oxygen content in a 1000-m isobath section along the Mauritanian slope (from Pelegrí et al. this book)

Fig. 17.13 Bathymetric distribution of average abundances (per 100 m depth interval) of decapods and echinoderms in the Mauritanian deep-shelf and continental slope



Ecologically and Biologically Interesting Areas in Slope Soft-Bottoms

Some areas, characterized by high values of diversity, abundance and/or biomass, were linked to special geomorphological and oceanographic features on the soft-bottoms of the Mauritanian slope (Fig. 17.14).

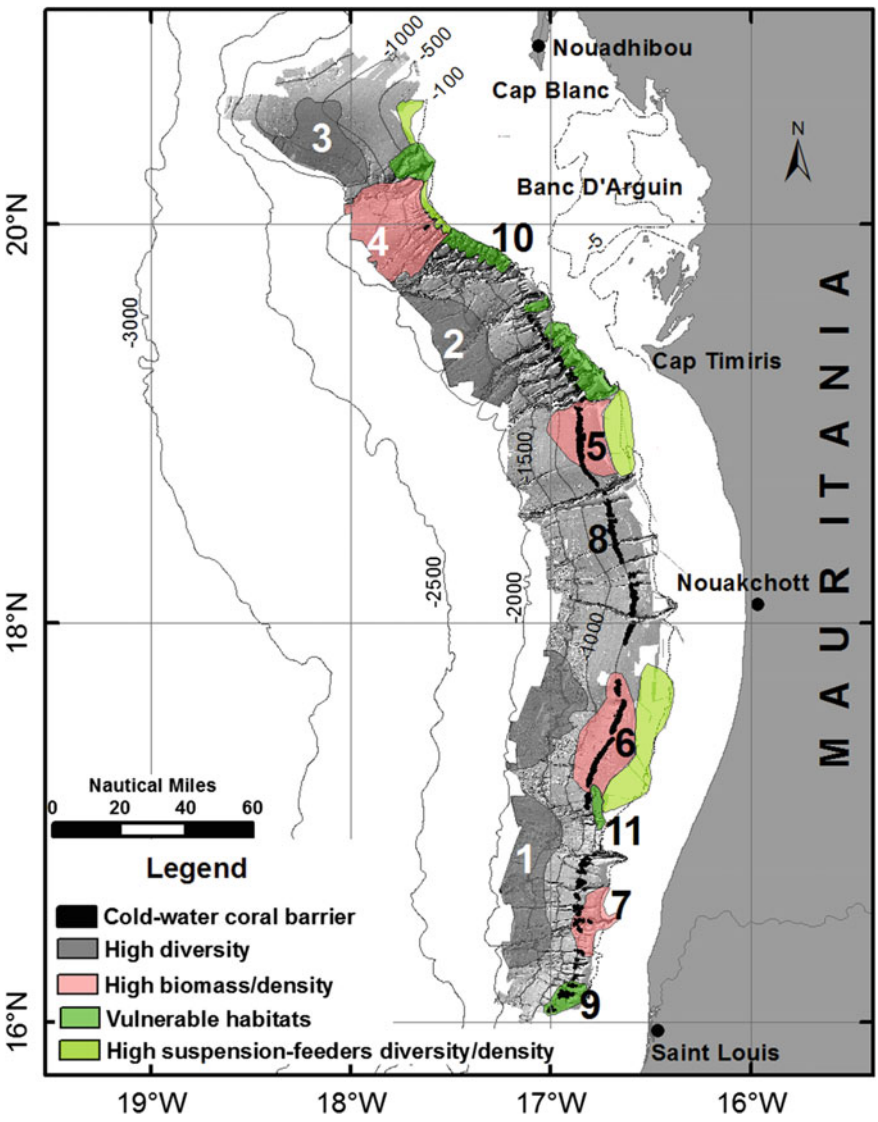


Fig. 17.14 Schematic representation of the main ecologically and biologically interesting and vulnerable areas in the Mauritanian slope: (*1–3 grey*) high diversity, (*4–7 pink*) high biomass/density, (*5–6 light green*) high suspension-feeders diversity and density, (*8 black line*) coral carbonate mounds barrier, (*9–11 dark green*) main vulnerable zones

Highly-Diverse Soft Slope Areas (Areas 1, 2 and 3) (Annexe 17.1)

A large zone with especially high biological diversity was identified in an area extending on a virtually continuous band from south of Nouakchott (18ºN) to the Senegalese border (16ºN), beyond depths of 1000 m (Area 1 in Fig. 17.14). Local

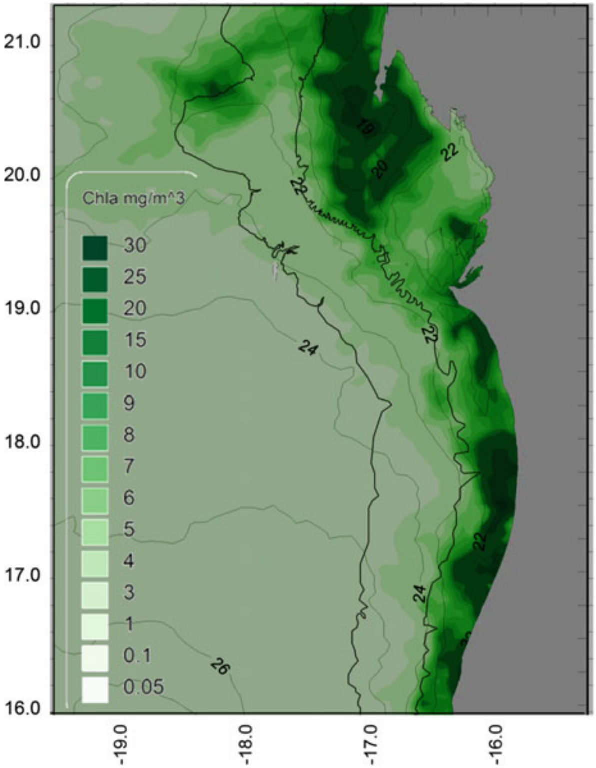


Fig. 17.15 Distribution of chlorophyll values (mg m^{-3}) as a function of SST in November–December 2009 (from Pelegrí et al., Chap. 3)

richness reaches almost 100 species, especially due to the high number of fishes (both, teleosts and chondrichthyans), cephalopods and actinians. Holothurians and echinoids were the most diverse groups among the echinoderms in this zone.

The geomorphology of the area is characterized by the Mauritania Slide Complex (MSC) and the canyons systems off the Senegal River area, where highly unstable slope soft-bottoms favor rapid downhill flow of water and sediments (turbiditic currents). Despite being apparently unfavourable factors for the life of benthic and demersal organisms, especially for non-motile invertebrates (Gage and Tyler 1991), these physical disturbances could favor the re-suspension of sediments and the availability of organic matter to fauna. These conditions would provide a richer environment that could maintain high diversity among all food-web levels. Moreover, the productivity of this zone may be enhanced by inputs of organic matter from the Senegal River through the southern canyons of Trarza, Senegal and Saint Louis. The deep-slope Poleward Undercurrent (Peña-Izquierdo et al. 2012; Pelegrí and Peña-Izquierdo 2015) could also contribute to the northward transport of sediments.

Two other highly-diverse areas are located in deep waters south and north of the Banc d’Arguin (North Mauritania), more specifically off Cape Timiris and Cape

Blanc (Areas 2 and 3 in Fig. 17.14). Teleosts, cephalopods and echinoids are the main contributors to the high diversity observed in Area 2, located between the Arguin and Timiris canyon systems. The high species richness in Area 3, in the northern part of Tanoûdêrt canyon, is largely associated to deep fishes (teleosts and elasmobranches) and certain megabenthos groups, mainly to echinoderms (sea-stars, echinoids, holothurians and brittle-stars). As for Area 1, these two zones are characterized by fairly regular muddy bottoms, affected by landslides. Deep-sea fauna probably takes advantage of the resuspended organic matter and phytodetritus input coming from the Banc d'Arguin and arriving through the canyons.

Highly-Productive Slope Areas (Areas 4–7) (Annexe 17.2)

– ***Tongue off the Banc d'Arguin*** (Area 4)

The area is located between the Tanoûdêrt canyon to the north and the Arguin canyons system to the south. It is the only zone of the study area where sands stretch from the shelf to the lower slope (2000 m), possibly indicating the existence of bottom currents that inhibit the deposition of fine sediments. Along the southern part of this offshore tongue, the carbonate (50–75%) and organic matter (15–20%) contents reach maxima for the entire Mauritanian seabed, particularly in the bathymetric band between 1500 and 2000 m (see Chap. 2).

The Banc d'Arguin belongs to the along-slope upwelling region, being adjacent to the giant filament of Cape Blanc, which is considered as an exceptionally productive area (Hernández-León et al. 2007; Peña-Izquierdo et al. 2012). This high productivity is reflected by the high chlorophyll values showed in Fig. 17.15 (see Chap. 3). This causes the area to be characterized by very high values of density and biomass, in a continuous band that extends crossing the isobaths, from the shelf to the deep slope. Biomass can locally reach up to 2000 kg per 0.1 km^2 (Fig. 17.8). Teleosts and cephalopods are most abundant in the 1200–1500 m depth range, while elasmobranches exhibit higher values at waters deeper than 1500 m. In this area the megabenthos reaches moderate values, but only within deep-waters. The latitudinal range with both biomass and density coincides with a disruption area of the oxygen minimum zone (OMZ), which extends between 400 and 550 m along the entire slope; peak values take place at latitudes around 19°30′N and 20°30′N, where the minimum oxygen concentrations do not fall below 1.75 mL L^{-1}.

Very high concentrations of small individuals of *Hoplostethus mediterraneus* and *Helicolenus dactylopterus* (among teleosts), and medium size individuals of *Deania calcea, Centroscymnus coelolepis* and *Centroscymnus crepidater* (among elasmobranches), characterize this area. The cephalopods *Sepia elegans*, *Opisthoteuthis agassizii* and *Bathypolypus* sp, the big holothurid *Paelopatides grisea*, the sea-stars *Psilaster cassiope* and *Pseudarchaster gracilis*, and actiniarians are the most remarkable megabenthic species, the latter ones reaching their highest density in this zone (see Annexe 17.2).

The exceptional productivity of the area also enhances the concentration of seabirds and cetaceans that find an excellent feeding habitat in these waters (Wynn and Knefelkamp 2004; Camphuysen and van der Meer 2005; Camphuysen et al. 2012; Wynn and Krastel 2012; Baines et al. 2014). This high productivity is responsible for the intense fishing activity traditionally developed in the Banc d'Arguin (Mahfoud et al. 2013; Guénette et al. 2014; IMROP 2014; Rocha and Cheikh 2015). The abundance of demersal elasmobranches in the northern area may actually be an indirect effect of upwelling on the deep-sea communities off Cape Blanc (see Chap. 5 for discussion), as upwelling enhances the diversity in the trophic chain that increases the concentrations of natural preys. Besides, the discards from the fishing activity would constitute a food supply for elasmobranches and other species (Balguerías et al. 2004). In fact, the most frequented fishing grounds in Mauritanian waters are located in the northern area, where large pelagic trawlers and artisanal and coastal fleets operate (Mahfoud et al. 2013).

– ***South of Cape Timiris*** (Area 5)

Area 5 is located between Inchiri and Tioulit canyons, being characterized by a narrow shelf, a steep slope and sandy bottoms. It is crossed by the cold-water coralsstructure at depths around 400–550 m. In this zone it was located a semi-permanent filament that transports the highly productive waters offshore, enhancing the food input to the deep-shelf and slope.

This is a zone with high densities and biomass of decapods and teleosts, the latter as a result of high concentrations of *Helicolenus dactylopterus*and *Chlorophthalmus agassizi*. High concentrations of decapods, particularly of deep-water rose shrimp *Parapenaeus longirostris*, were found near 19ºN at depths between 200 and 300 m (see Annexe 17.2). At this latitudinal rang, the king crab*Neolithodes asperrimus* was the main biomass contributor to other decapods major area identified at deeper waters (around 1500 m). The most diverse community of suspension-feeders was found in shallow waters (less than 200 m depth), reaching nearly 40 species per station and with hydrozoans and small gorgonians as the richest groups.

– ***North of 17°N*** (Area 6)

A very peculiar geomorphological area is located between 17°43′N and 17°12′N. It stretches on both sides of the carbonate mounds barrier—here running along the slope almost continuously—and southwards to the Wolof's Seamount. Its offshore limit is constituted by the uppermost head-scares of the Mauritanian Slide Complex, which are found west of the coral mound. Between 200 and 450 m, the sea-bottom is sandy and characterized by an undulating surface with sand waves that reach up to 5 m height (see Chap. 3).

This area is characterized by seasonal wind-induced upwelling, forced by the winter Harmattan, causing the nutrient- and oxygen-rich (about 5 mL L^{-1}) waters to emerge and enrich the continental shelf (Fig. 17.15). The presence of ripples, parallel to the barrier, suggests the existence of bottom currents perpendicular to the coastline that may induce the resuspension of sediments, hence favouring the suspension-feeder communities.

This area presents the highest densities but, contrary to what happens in areas 4 and 5, they do not coincide with the highest biomasses. Teleosts, decapods and cephalopods are the main representative groups. Among the fishes, the most abundant species were the small Acropomatidae*Synagrops microlepis*, caught abundantly at depths between 100 and 200 m, and the black hake*Merluccius polli*, between 130 and 440 m. The deep water rose shrimp *Parapenaeus longirostris*, located at depths between 180 and 430 m, and the African spider shrimp *Nematocarcinus africanus*, found near 400–700 m, were the most abundant decapods (both in terms of biomass and density). In fact, *N. africanus* was the most abundant species in the decapod community of the deep-water coral reef. The cephalopod*Loligo vulgaris* and the coastal holothurid *Parastichopus regalis* were also representative among the invertebrates (see Annexe 17.2). Suspension-feeders, particularly the hydrozoans, showed their highest richness and density between 100 and 200 m.

Slope Hard-Bottoms

Hard-bottoms are represented in the Mauritanian slope by three important structures that constitute the main habitats described in the continental margins worldwide (Menot et al. 2010; Ramírez-Llodra et al. 2010; Levin and Sibuet 2012): the giant barrier of cold-water coral mounds, the Arguin and Timiris canyon systems and other isolated canyons, and the small Wolof's Seamount.

Most hard bottoms along the carbonate mounds barrier and canyons area have a framework of dead cold-water corals, mainly *Lophelia pertusa*, and coral rubbles of different sizes, from small fragments (2–4 cm) to large pieces (40–50 cm). The dead coral framework is virtually everywhere at depths from 400 to 550 m, being *Lophelia pertusa* undoubtedly the most characteristic component off Mauritanian hard-bottoms. Nevertheless, corals were not found over the seamount. Rocks only occurred at the head of several northern canyons—especially sandstones—and over the seamount, where we collected some carbonated chimneys debris (Chaps. 13, 14 and 15). These hard bottoms play a fundamental role structuring and giving physical support to small sessile fauna (in some areas of the coral mounds reef) or to rich suspension-feeders communities (in some canyons edges and the seamount).

Twenty six stations were sampled with a specialized hard-bottom dredge during the *Maurit-0911* and *Maurit-1011* surveys along the coral mounds reef (13 stations), northern canyons (11 stations) and Wolof's Seamount (two stations) (Fig. 17.1) (Ramos et al. 2010).

Although big-size suspension-feeders, as sponges, gorgonians or antipatharians —similar to those recorded in the Morocco and Western Sahara slopes

(Ramos et al. 2015)—were absent on the Mauritanian soft bottoms, we found some hard substrata hosting important three-dimensional communities constituted by vulnerable and threatened species (IUCN 2016). Some of these species were exclusively collected on hard-bottom habitats (Annexe 17.3). This is the case of colonial cold-water corals (*Lophelia pertusa*, *Madrepora oculata* and *Dendrophyllia cornigera*), Geodidaesponges, Dendrochirota holothurids and some brittle-stars belonging to the Ophiothrichidae family. In addition to these suspension-feeders, some motile invertebrates seem to live associated to canyons and/or coral mounds habitats, being absent in slope soft-bottoms. These included two species of decapods: *Ezaxius ferachevali* and *Munida intermedia*, which were exclusively collected over the canyons. *Ezaxius ferachevali* is a new genus and new species described after material collected during the *Maurit* surveys (Matos-Pita and Ramil 2015b). Three other decapod species (*Alpheus macrocheles*, *Calocaris macandreae* and *Munidopsis vaillantii*) were found in the canyons and in the coral mounds. Nevertheless, despite their suspensivorous strategy and their preference to hard substrata, none of the 63 benthic hydrozoan species recorded on the Mauritanian slope were exclusive of hard bottom habitats. Apparently, these species develop particular adaptations for living in sedimentary bottoms, exhibiting a noticeable euribathic distribution (see Chap. 11).

Coral Carbonate Mounds Barrier (Areas 8 and 9)

Cold-water coral reefs are considered the richest and most complex three-dimensional ecosystems in the continental margins of the world oceans that can give rise to giant carbonate mound structures, built up over several million years (Rogers 1999; Freiwald et al. 2004; Foubert and Henriet 2009; Roberts et al. 2006, 2009). Cold-water corals are especially vulnerable to fishing activities, because trawling gears physically destroy the entire long-lived three-dimensional structures and their rich associated fauna (Ramírez-Llodra et al. 2011).

The coral carbonate mounds reef off Mauritania was discovered during the hydrocarbon offshore exploration (Colman et al. 2005) and afterwards investigated during German cruises (Westphal et al. 2007, 2012) and the *Maurit* surveys (Ramos et al. 2010). The along-slope cold-water corals reef, running from southern Cape Timiris to the Senegalese border, is the largest known one in the world (Hovland 2008). The reef runs at a depth of about 500, have about 1700 m wide and elevating some 100 m above the sea floor. Although the structure seems to disappear further north of Cape Timiris, it can still be weakly traced across the canyons in the multibeam records. Further, pieces of the coral framework were collected in rock-dredge samples from the northern canyons. This means that the entire reef structure may stretch almost 580 km (see Chaps. 2 and 13).

Lophelia pertusa is clearly the main component of the Mauritanian giant carbonate mounds. However, the reef is currently very impoverished, being basically composed of death coral framework scarcely colonized by living sessile epifauna.

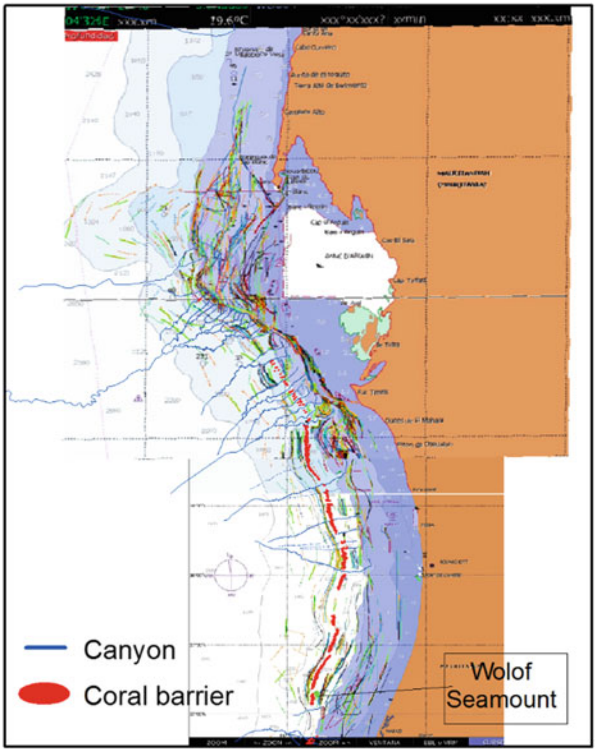


Fig. 17.16 Schematic representation of the main hard-bottoms features in the Mauritanian slope with superimposed tracks of commercial bottom trawlers (from low-quality original fishing information used by the R/V *Vizconde de Eza* during the *Maurit* surveys)

Some authors suggested that trawling activity could hinder the long-term coral growth (Colman et al. 2005). Nevertheless, it is known that fishermen do not trawl on this structure—which they call *cathedrals*—to avoid gear damages or losses (Fig. 17.16). Instead, the progressive structural and faunal decay of the Mauritanian reef appears to have been a long natural process (Colman et al. 2005; Eisele et al. 2011). The decline in coral growth and associated suspension-feeder communities began at the onset of the Holocene, probably as a result of unfavourable environmental conditions. In spite of the high productivity and the adequate salinity and temperature conditions for *L. pertusa*, the low oxygen concentrations and possibly the physical environmental conditions (ongoing acidification and sedimentary dynamics) constitute the limiting factors for the current maintenance of cold-water corals in the Mauritanian slope.

Despite the degradation of the Mauritanian reef, this structure appears as a real physical barrier, a main feature that determines the distribution of the assemblages between shallowest and deepest fauna.

Although the cold-water corals are dead along the entire reef south of Cape Timiris, Colman et al. (2005) and Eisele et al. (2011) found some living polyps of *Lophelia pertusa* and *Madrepora oculata*in several sites. We also found living *L. pertusa*, but only in the southernmost zone (Area 9 in Fig. 17.14), where corals and small specimens of encrusting sponges, hydrozoans, gorgonians, bryozoans, antipatharians and ascidians constitute a typical suspension-feeders assemblage (Annexe 17.3). This zone is out of the influence of the Mauritanian Slide Complex and seems unaffected by the inputs from the Senegal River. The presence of this rich sessile assemblage in the upper slope suggests that a rapid downhill flow of terrigenous sediments to the deep slope must occur. Notably, a high-biomass community of deposit-feeder holothurids was found at the same latitude, for waters deeper than 1500 m.

Arguin and Timiris Canyon Systems (Area 10)

Submarine canyons constitute major topographic features of continental margins worldwide, cutting across the shelf and slope and connecting shelves to deep ocean basins (Harris and Whiteway 2011; De Leo 2012). Canyons are considered as hotspots of biodiversity and biomass and therefore potential areas of interest for fisheries, supporting cold-water coral habitats and other vulnerable ecosystems (FAO 2009; Tyler et al. 2009; Robert et al. 2015). However, canyon ecosystems are one of the most scarcely studied among the hard-bottom habitats in the deep-sea (De Leo et al. 2010; Davies et al. 2014). Until recent years, they have been protected by its own rocky nature but the improvements in technology have enabled trawling in rough bottoms and has placed the canyon benthic communities among those most seriously threatened by fishing activities (Ramírez-Llodra et al. 2011).

The geomorphology of the Arguin canyons system had been previously examined by Krastel et al. (2004) but, until the four *Maurit* cruises, the benthic fauna inhabiting Mauritanian canyons was completely unknown. The multibeam echosounder explorations carried out during the *Maurit* surveys have allowed to obtain a complete map of one of the most spectacular canyon systems of the world, located in front of the Banc d'Arguin. Furthermore, the specific sampling carried out on these structures has provided the first information about the biodiversity and composition of the megabenthos living in the northern Mauritanian canyons.

More than 20 sinuous channels and canyons grouped in four major systems (Tanoûdêrt, Arguin, Louik and Timiris) cut the continental shelf and slope (Fig. 17.14). Some of them reach down to 700 m depth and have walls with slopes of about 50%, in the case of the Arguin canyon extending as far as the middle of the Atlantic (see Chap. 2). Dense communities of suspension-feeders—composed by corals, sponges, hydrozoans, gorgonians, bryozoans, ophiuroids and bivalves were found in the edges of Tanoûdêrt, Arguin North, Louik and Tidra canyons, at depths ranging from 240 to 525 m. The number of species reached 86 in some locations, with sponges as the main biomass component. These assemblages were found over sandstone boulders and rocks completely colonized by incrusting fauna. The scleractinians, *Lophelia pertusa* and *Dendrophyllia cornigera*, the giant oyster *Neopycnodonte zibrowii*and polychaetes belonging to Eunicidae, a family associated to *Lophelia* reefs, were among the most characteristic species of the canyon habitats (Annexe 17.3). Gorgonians were represented by few and small colonies, but antipatharians were completely absent in the canyons. In the remaining inter-canyon sites, diversity was much lower as suspension-feeders were absent and the megabenthos was basically composed by prosobranch molluscs, decapods and other carnivorous and scavenger fauna, typical from soft bottoms.

In all localities of the canyons zone we found high concentrations of dead *L. pertusa* structures, together with rubbles of *Dendrophyllia* sp, *Acesta excavata*, ostreids and other molluscs mixed with different sediments. This type of seabed is the same as the one found on the coral carbonate mounds reef, suggesting that an extensive original cold-water coral reef stretched along the entire Mauritanian coast during past geological periods (see Chaps. 2 and 13). Despite we have found certain abundance of living cold-water corals only in two localities, earlier visual explorations with ROV recorded *Lophelia pertusa* and *Madrepora oculata*alive in Tanoûdêrt canyon (Westphal et al. 2012; Freiwald, Senckenberg Institute, unpublished data, 2015). This record, at latitude 20°14′36″N, exactly matches our northern location in the same canyon and represent the northernmost record of *Lophelia pertusa* in Mauritanian waters.

Wolof's Seamount (Area 11)

Seamounts have been traditionally described as high biodiversity ecosystems which act as island habitats and centres of endemisms (Richer de Forges et al. 2000; Koslow et al. 2001), although these paradigms are currently under discussion (Stocks and Hart 2007). Seamounts host dense sessile suspension-feeders communities, mainly cnidarians that constitute complex three-dimensional habitats for other animals in the deep-sea (Clark et al. 2006; Rogers et al. 2007; Consalvey et al. 2010). In addition, seamounts harbour high fish diversity, including many species of commercial interest that set dense aggregations for spawning or feeding (Clark 2009). However, fish stocks and benthic habitats on seamounts are strongly threatened by human activities, mainly by trawl fishing and, in recent years, by the exploration and exploitation of submarine mineral resources (Clark et al. 2010).

The Wolof's Seamount is a small salt diapir that raises 200 m from the surrounding seabed, having an elongated shape parallel to the edge of the continental shelf, with a conical structure in the centre. It is located on the upper slope, at approximately 90 km south of Nouakchott (17°08′50″N and 16°46′38″W) (Area 11 in Fig. 17.14). Its name is a tribute to the artisanal fishermen that we repeatedly observed in the same location, on board of a small Senegalese canoe 40 nautical miles from shore at night. Thus, we consider fishermen from this ethnic group (Wolof) the real discoverers of this submarine elevation.

Despite the lack of big-size suspension-feeders on the Mauritanian slope, a megabenthic assemblage composed by sponges, mainly belonging to the genus *Geodia*, and the suspension feeder ophiuroid *Ophiothrix maculata*, was surprisingly found over the seamount (Annexe 17.3). Cold-water corals, gorgonians, antipatharians or any other cnidarians were not found. However, the presence of large sponges, like *Geodia megastrella* and *Geodia barretti*, creates a tridimensional habitat able to enhance the biodiversity by providing shelter to a variety of mobile fauna (Consalvey et al. 2010).

Although local fishermen obviously knew the existence of this structure, the small size, rocky-nature and proximity of the seamount to the coral barrier have likely preserved this habitat from the impact of industrial trawling fisheries. The existence of the filter-feeders community in the Wolof's Seamount demonstrates that, despite the intense fishing activity developed on Mauritanian slope, this isolated habitat remains almost undamaged.

Oxygen Minimum Zone

An area with hypoxic conditions was clearly identified in Mauritanian waters, a feature recorded in the continental margins of main upwelling areas worldwide (Helly and Levin 2004; Levin and Sibuet 2012). The OMZ spreads along the entire upper slope, even occupying the canyons depressions, from 400 to 550 m deep. This depth levels correspond to lower central waters, which are waters of very low renovation rate but with a substantial contribution from subtropical regions (Peña-Izquierdo et al. 2012, 2015). Although the minimum dissolved oxygenconcentrations registered during the *Maurit* surveys (1.0–1.3 mL L^{-1}) were not as low as those found in other eastern boundary OMZs (0.2–0.5 mL L^{-1}) (Helly and Levin 2004), their ecological impact seems important.

The diversity in the OMZs is exceptionally low for large taxa (macro- and megabenthos) (Levin and Sibuet 2012; Gooday et al. 2009), to the point that one or a few endemic species can be dominant (Levin and Gage 1998; Levin 2003). According to our observations, in the Mauritanian OMZ, richness values are low for fishes and most megabenthic taxa, some of them—such as the echinoderms—being practically absent (Fig. 17.13). Nevertheless, a particular decapods assemblage inhabits this highly stressed area, with the African spider shrimp *Nematocarcinus africanus* as the dominating species with high values of both density and biomass (see Chap. 9). Although high biomass of decapods in areas with oxygen minimum values have been already reported in the Mediterranean Sea (Fanelli et al. 2013), this Mauritanian decapods assemblage constitutes the first description of an ecologically distinctive community living in a hypoxic habitat off Northwest Africa.

The bathymetric range of the OMZ in the Mauritanian slope is coincident with the distribution of the giant carbonate mounds reef. Although the oxygen conditions in Mauritanian waters do not reach anoxic levels, they are a limiting factor for the development of the cold-water coral*Lophelia pertusa*, whose tolerance limits are between 2.6 and 7.2 mL L^{-1} (Davies et al. 2008; Dodds et al. 2007) (see Chap. 13).

The OMZs are considered among the deep-sea habitats that may be most affected by climate change in the near future, as a result of increasing hypoxia (Ramírez-Llodra et al. 2011). Some authors have pointed out the significant impact that the fluctuations in the extent of the OMZ could have at environmental, ecological and economic level (Helly and Levin 2004). Global warming may drive a reduction of the oxygen content of the world oceans and lead to an expansion of OMZs, producing changes in oceans circulation, temperature and productivity, limiting the population movements, promoting species evolution and directly affecting key fishery resources (Helly and Levin 2004).

Stramma et al. (2008, 2012) have observed a depletion of dissolved oxygen and a vertical expansion of the OMZ in the eastern tropical Atlantic, probably influenced by global warming, which has affected the abundance of large and small pelagic fish. During the last 50 years, the dissolved-oxygen concentrations have decreased in the 300–700 m layer at a rate greater than 1 mm yr^{-1}, what has meant a loss of a 15% of habitat in the Atlantic (0°–25°N, 12°–30°W) (Stramma et al. 2012).

The results of our study on the current extension of the Mauritanian OMZ provide the baseline information for future studies on global warming, OMZ expansion and ocean acidification, necessary to estimate their ecological and economic impact on an area hosting very important ecosystems and fish resources.

Considerations on Conservation

Although humans have used the ocean resources for millennia, the technological advances and the intensive exploitation of living and minerals resources of the last decades are threatening the conservation and sustainable using of marine biodiversity and ecosystems.

The adverse impact of bottom fishing and other human activities over marine ecosystems is a matter of concern for the international community, which has already agreed on a number of important goals and principles to promote their conservation within andbeyond national jurisdiction areas (UNEP 2006). Since 2002, the UN General Assembly, the CBD parties and the FAO members have discussed and adopted a series of resolutions and guidelines calling for urgent actions to protect biological diversity and vulnerable marine ecosystems, to ensure sustainability of fish stocks and to improve fisheries management (UNEP 2006; UNGA 2007; FAO 2008, 2009; CBD 2009a, b, 2011). All 196 coastal states that have endorsed the CDB agreement have been required to review and update their national biodiversity strategies and action plans (NBSAPs) in line with the Strategic Plan for Biodiversity 2011–2020 and the Aichi biodiversity targets (CBD 2011). Among their main goals, this Strategic Plan promotes that at least 10% of coastal and marine areas hosting particular biodiversity or ecosystems shall be conserved by 2020 through a network of protected marine areas (MAPs), ecologically representative and well connected (CBD 2011).

The Islamic Republic of Mauritania started the process for the conservation and sustainable use of biological diversity in 1999 with the development of a Strategic five-year Action Plan (2000–2004) that in 2004 led to the first National Biodiversity Strategy (SNB). Both documents were included in the National Action Plans for the Environment—PANE 2007–2011 and PANE 2012–2016 (MEDD 2005, 2007, 2010, 2012, 2013)—that complement the broad guidelines of the Strategic Framework for the Fight against Poverty, which are reference documents of the national policy of protection of the environment and biodiversity. In August 1994, Mauritania ratified its engagement to the Convention on Biological Diversity (CBD), submitting the corresponding Strategy and Action National Plans of Biodiversity (MEDD 2005, 2007, 2010, 2012, 2013).

In relation to the conservation of marine and coastalbiodiversity, Mauritania currently hosts two marine national parks and two additional sites. The Banc d'Arguin National Park (PNBA), established in 1976, is an entirely protected natural reserve—habitat for a very rich coastal and marine fauna—covering some 1.2 million hectares of the northern littoral between Nouadhibou and Cape Timiris. The Diawling National Park (PND) was established in 1991 with 16,000 hectares on the southern coast along the Senegal River to safeguard domestic and migratory birds and for the conservation of the flora in the lower delta. The two additional sites are the Satellite Reserve of Cape Blanc, created in 1986 under the authority administrative of PNBA to protect one of the last monk seal populations and the Transboundary Biosphere Reserve of the Lower Delta of the Senegal River, classified in 2005 by UNESCO as a site of substantial biological richness and great economic value to local people.

Although the coastal protected areas constitute 12% of the total marine surface of Mauritania, as for most countries, the protected area system has not yet been properly applied for offshore waters (UNEP 2006). During the recent workshop aimed at identifying the EBSAs in the South-Eastern Atlantic Region (UNEP 2014), Mauritania provided descriptions and maps of four areas meeting EBSA criteria (CBD 2009a). Three of these areas—the deep cold-water coral reefs, the Timiris canyons system and the permanent upwelling cell in the Cap Blanc—are located offshore (UNEP 2014).

In relation to cold-water coral) reefs, the CCLME working group identified the inadequacy of current knowledge on the state of offshore habitats and the urgency to fill the scientific gaps in order to categorize actions towards the conservation of this fragile ecosystem (UNEP 2014). As for the cold-water coral reefs, our current knowledge on the characteristics, state and subordinate resources of the Timiris canyon ecosystem are scarce (UNEP 2014).

The objective of this book is to provide scientific information on the main vulnerablemarine ecosystems and the most relevant areas in the Mauritanian slope in order to develop adequate national and regional marine plans, including the establishment of marine protected areas.

Coral Carbonate Mounds Barrier (Areas 8 and 9)

Lophelia pertusa reefs and carbonate mounds are among the most *threatened* or *declining* deep-sea habitats, listed in Annexe V of the Protection of the Marine Environment of the North-East Atlantic (OSPAR) Convention (OSPAR 2008, 2010). Recently, Mauritania proposed the conservation of the cold-water coral reefs off Nouakchott under the EBSA criteria (Area 2, UNEP 2014). We agree with this proposal, with the following considerations:

1. The name of the area is inadequate as it is not a true coral reef but a coral carbonate mounds barrier, fossilized almost in its totality.
2. Although the structure is buried in some areas south of Cape Timiris and cut by the canyons, it runs along the entire Mauritanian slope at 450–550 m depth over 580 km (see Chaps. 2 and 13).
3. This complex structure clearly corresponds to an old cold-water coral reef, belonging to a single province—the *Mauritanian Coral Mound Province*—that includes the previously described Banda and Timiris provinces.

The criterion 1 of the Convention on Biological Diversity (CBD 2009a) (*uniqueness and rarity*) could be applied to protect entirely this biogenic structure. In addition to its giant size, the barrier constitutes a worldwide unique paleoclimatic archive.

At ecological and faunistic levels, the carbonate mounds structure constitutes a physical barrier along the Mauritanian slope, coinciding with the location of the 400–550 m oxygen-depleted layer. Both features add to produce a faunistic discontinuity that separates the shallow and deep assemblages (Figs. 17.11 and 17.12). Moreover, the area hosts a particular decapods assemblage that constitutes the first record of an ecologically distinctive community living in a hypoxic habitat in Northwest Africa (Chap. 9).

Despite the degradation and overall faunistic poverty of the coral barrier, the southern zone (Area 9, Fig. 17.14) constitutes a remarkable habitat in the Mauritanian slope that likely meets several EBSA criteria (CBD 2009a). In this area, despite the unfavourable climatic episodes and current environmental conditions (see Chap. 13), an assemblage of suspension-feeders appears to have survived, maintaining a similar structure to those in well-developed cold-water coral reefs in northern Atlantic latitudes. This zone constitutes the only area where we found many living *Lophelia pertusa*specimens together with black-corals (antipatharians), representing significant assemblages of *endangered, threatened or declining species* (criterion 3). Further, it is a habitat with *vulnerability, fragility, sensitivity and slow recovery* (criterion 4) that *contains a comparatively higher diversity of species* (criterion 6). Moreover, corals and gorgonians are found in the IUCN Red List as vulnerable species to be protected (IUCN 2016).

A comprehensive study is necessary to further increase our knowledge of the Mauritanian Coral Carbonate Mounds Barrier as well as on its possible recolonization processes. This study should include visual surveying along the entire reefstructure with special focus on the southern area where living *Lophelia pertusa* and suspension-feeders have been identified.

Arguin and Timiris Canyons (Area 10)

In addition to the role that submarine canyons play on exchanges between the continental shelf and deep ocean and on the functioning of the benthic and pelagicecosystems, the heads of shelf-incising canyons host unique benthic habitats and biologically diverse communities (Würtz 2012). This is particularly relevant as benthic communities in canyons are threatened by the new fishing technological improvements (Ramírez-Llodra et al. 2011).

Some vulnerableslope ecosystems, as cold-water coral reefs and seamounts, benefit from particular conservation measures but there are no similar protections for submarine canyons. Even though most international organizations agree on the importance of conserving submarine canyons and some protection plans are under development in several areas—for example in the Mediterranean and United Kingdom territorial waters (Würtz 2012; JNCC 2013)—its management is complex. On one hand, the conservation of canyons requires improving scientific knowledge and understanding on the ecological role played by these ecosystems. On the other hand, their governance is not always easy because the canyons' extension covers sometimes waters and seabed under different national and international jurisdictions.

In 2013, Mauritania proposed the protection of the Timiris Canyon System as an EBSA (UNEP 2014). We consider that this protection figure must be extended to the entire canyon systems of northern Mauritania, possibly including the central solitary canyons and southern systems (see Chap. 2) (Fig. 17.14). Other considerations are:

1. The name of used for the Mauritanian proposal, Timiris Canyon, follows Schulz (2003) and Krastel et al. (2004) but does not correspond to its true name. Since 1999, it appears under the name of Arguin Canyon (GEBCO 2003).
2. Although the protection proposal as EBSA only include the Timiris canyon, the Mauritanian slope host more than 70 canyons and large gullies that are grouped into nine canyon systems (see Chap. 2).
3. Although all canyons have been thoroughly mapped and described at the geomorphological level, our current knowledge on their benthic communities is still very scarce and limited to several northern canyons (Westphal et al. 2012) (see Chap. 14). Nevertheless, the discovery of suspension-feeder assemblages of high biodiversity—formed by living cold-water corals (*Lophelia pertusa* and *Madrepora oculata*), the big oyster *Neopyncodonte zibrovii*, the bilvalve *Acesta excavata* and demosponges (Westphal et al. 2012; Chap. 14)—meet with EBSA criteria 3, 4 and 6: *endangered, threatened or declining species*, *vulnerability, fragility, sensitivity and slow recovery* and *contains a comparatively higher diversity of species* (CBD 2009a). The criterion 2—*special importance for life-history stages of species*—can also be applied because canyons harbour source populations of sessile epifauna, such as hydroids, which provide larvae to colonize adjacent soft-bottoms (see Chap. 11). Finally, the pristine suspension-feedersassemblages discovered in the inner walls and edges of the canyons also satisfy the property of *naturalness* contained in criterion 7.

Despite the existence of many deep canyons, the area in front of Banc d'Arguin constitutes the most important fishing ground for artisanal and industrial fleets (Mahfoud et al. 2013; IMROP 2014). Although trawling is not possible at the edges and heads of canyons, where sandstones and outcrop rocks exist, demersal trawlers have operated in this area during decades (FAO 2012; Mahfoud et al. 2013), and during the *Maurit* cruises we also sampled many inter-canyon sites (Chap. 14).

The complex morphology off the North Mauritanian slope hampers the possibility of carrying out comprehensive studies of the entire canyon systems. Nevertheless, the headers and edges of the main canyons can and should be prospected using image techniques in order to identify and map the assemblages and habitats for conservation purposes (Davies et al. 2014).

Wolof's Seamount (Area 11)

Seamounts constitute one of the most characteristic and threatened deep-sea habitats and its conservation is strongly encouraged both in national and international waters (FAO 2008, 2009). Wolof's Seamount was not proposed by Mauritania as an EBSA simply because it was unknown at the time, its scientific discovery resulted from the *Maurit* surveys and its first report ever is provided in Chap. 15 of this volume (Fig. 17.14).

According to the identification guidelines of the CBD (CBD 2009a) this small seamount meets criterion 7 (*naturalness*), applied to areas where there is very low or no disturbance or degradation due to human impact. Its objective is to protect areas with near natural structure, maintaining them as reference sites. Criterion 1 (*uniqueness* and *rarity*) can also be applied to Wolof's Seamount as the particular assemblage Geodidaesponges-ophiuroids is the only one so far recorded off Northwest Africa, with the dense aggregation of *Ophiothrix maculata*—a rare and big-size ophiuroid—never reported before (CBD 2009a). Criterion B of the IUCN for setting a Red List of Ecosystems (*restricted geographic distribution*) is also valid for Wolof's Seamount (Bland et al. 2016). Moreover, the record of *Geodia megastrella* in the Mauritanian seamount constitutes the southernmost report for this specie in the East Atlantic.

Despite its small dimensions, the Wolof's Seamount appears as a *hotspot* of biodiversity in the muddy bottoms of the Mauritanian slope. Taking into account the richness and special faunistic and ecological features of the community of suspension-feeders that inhabits this seamount, it should be considered as an excellent candidate to become a Marine Protected Area. The small size of Wolof's Seamount should facilitate the characterization and mapping of its assemblages and habitats with imagery techniques.

Tongue of the Banc d'Arguin (Area 4)

Criterion 5 for EBSAs identification (CBD 2009a) considers those *areas containing species, populations or communities with comparatively higher natural biological* *productivity*. In Northwest Africa, two offshore areas protecting highly productive oceanic ecosystems have been already designated as EBSA: one of them, called Convergence Region for the Canary and Guinea Currents, is located approximately between 3°–15°N and 12°–25°W, and include the offshore ecosystems and habitats stretching from south Senegal to north Liberia (https://www.cbd.int/ebsa/ebsas, consulted online April 13 2016).

The other EBSA, recently proposed by the CCLME group, is the *Permanent upwellingcell in northern Mauritanian zone* (UNEP 2014). Although the limits of this EBSA are only indicative (UNEP 2014), the *Tongue ofBanc d'Arguin* appears to be located in its southern part and, hence, should also be included within this EBSA (Figs. 17.8 and 17.14). In addition to its peculiar environmental characteristics—sandy bottom, very high carbonate content, elevated organic matter in deepest zone, disruption of oxygen minimum zone—in this area we have located the highest densities, with biomass locally reaching up to 2000 kg per 0.1 km^2. The high abundance of small teleosts, chondrychtyes and cephalopods, would confirm that the elevated productivity of this area also extends to the demersal communities reaching the middle slope waters.

Conclusions

The continental margin of Mauritania is one of the most complex areas of the world's oceans from all geomorphological, hydrological and biological perspectives. Dominated by soft sediments, the Mauritanian slope seabed hosts one of the largest sediment slides and the biggest coral carbonate mounds reef of the world. Moreover, more than 70 submarine canyons are found from north to south, cutting across the continental shelf and slope and, in some cases, extending as far as the middle of the Atlantic.

Soft bottoms habitats between 100 and 2000 m exhibit a high γ-diversity estimated in about 1100 different species. This is a consequence of the transitional character of Mauritanian waters, where temperate and tropical species are mixed. In addition, the high productivity of Mauritanian waters together with the variety of habitats in the slope may have contributed to this great diversity of soft bottoms fauna.

Demersal fishes, decapods, echinoderms, hydrozoans and cephalopods are the most diverse groups, with holothurians, decapods and—to a lesser extent—polychaetes being the most representative taxa in abundance and/or biomass.

The highest diversity was observed on the deep slope at water depths below 1000 m, particularly from the south of Nouakchott (18°N) to near the Senegalese border (16°N), and in front of Cape Blanc and Cape Timiris. Abundances and biomass of main groups (teleosts, elasmobranches, decapods, cephalopods and the total megabenthos) showed a zonation pattern related to depth along the deep shelf and the continental slope. Elasmobranches and megabenthos showed a clear and opposite latitudinal trend, the former being more abundant in the northern area and the latter to the south.

The presence of the coral carbonate mounds barrier and of an oxygen depleted layer at depths between 400 and 550 m causes a faunistic discontinuity and acts as a barrier between the shallowest and deepest assemblages.

A particular decapods assemblage was located inhabiting the oxygen minimum zone, in what constitutes the first description of an ecologically distinctive community living in a hypoxic habitat in Northwest Africa.

We have identified several highly productive areas over soft bottoms of the slope, among which the Tongue of Banc d'Arguin exhibits the highest biomass concentrations.

Hard bottoms are represented in the Mauritanian slope by three important structures: the giant barrier of coral carbonate mounds, the canyon systems of Arguin and Timiris and other southern canyons, and the small Wolof's Seamount. All of them constitute important habitats for suspension-feeders assemblages and vulnerable species currently protected by international regulations.

Efforts should be encouraged in order to improve our scientific knowledge of some particular habitats that are proposed as EBSAs: (i) the coral carbonate mounds barrier, hosting a community of living *Lophelia*, long-time survivor in unfavourable environmental conditions; (ii) the headers and rims of the main canyons of Arguin and Timiris systems, where *L. pertusa* and other corals, sponges and the giant *Neopycnodonte zibrowii* were located; (iii) the small Wolof's Seamount which holds a particular community of Geodidae sponges and suspension-feeder brittle-stars never described before; and (iv) the *Tongue ofBanc d'Arguin* where the highest productivity values were concentrated, linked to the upwelling cell in northern Mauritania shelf waters.

The results exposed in this volume demonstrate the importance and potential value of bottom trawling surveys as a useful platform to improve scientific knowledge on ecosystems in unexplored regions.

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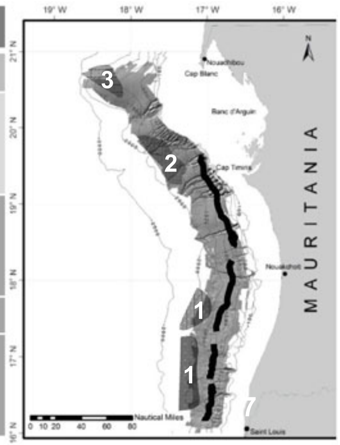
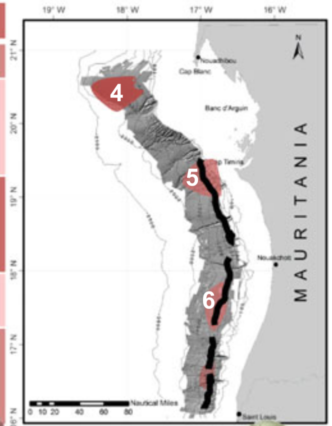
Annexes

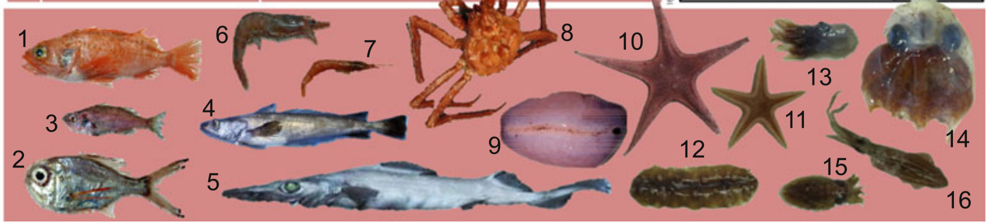
Highly diverse Soft Slope Areas			
	Area 3	**Area 2**	**Area 1**
Location	North Banc d'Arguin Cape Blanc - Tanoûdêrt canyon > 1000 m depth	Between Arguin and Timiris canyon systems > 1000 m depth	South Nouakchott (18ºN) - Senegalese border (16ºN) > 1000 m depth
Features	Muddy bottoms and landslides. Phytodetritus input through canyons	Muddy bottoms and landslides. Phytodetritus input through canyons	Highly unstable muddy bottoms (MSC). Turbiditic currents OM input Senegal River
			Highest diversity
Fauna	Deep teleosts and sharks. Seastars, echinoids, brittle-stars holothurians	Deep teleosteans, cephalopods and echinoids	Deep teleosteans and sharks. Cephalopods, actinians. Holothurians and echinoids



Annexe 17.1 Schematic representation of those areas proposed as EBSAs, which meet the criteria of the Commission for Biodiversity Conservation (CBD), and synthesis of its location, main environmental features and characteristic fauna. Highly diverse Soft Slope Areas (*1–3* in the map). In the pictures: the teleost fishes *Alepocephalus rostratus* (*1*), *Synaphobranchus kaupii* (*2*), *Stomias boa* (*3*) and *Malacocephalus laevis* (*4*); the echinoderms *Enypniastes eximia* (*5*), *Benthothuria funebris* (*6*), *Phormosoma placenta* (*7*), *Hymenaster roseus* (*8*) and *Pseudarchaster gracilis* (*9*); a still unidentified actinia belonging to Hormathiidae family (*10*) and the deep-water cephalopods *Opisthoteuthis agassizii* (*11*) and *Bathypolypus* sp (*12*)

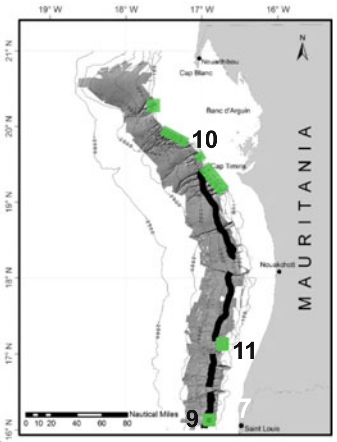
Highly-productive Slope Areas			
	Area 4	**Area 5**	**Area 6**
Location	***Tongue off the Banc d'Arguin*** Between Tanoûdêrt and Arguin canyons system	South of Cape Timiris Between Inchiri and Tioulit canyons	North of 17ºN (17º43'N-17º12'N)
Features	Sandy bottoms to 2000 m. Highest CO_3 and OM Slope upwelling Cape Blanc filament	Narrow shelf, steep slope, sandy bottoms. Barrier. Filament, offshore productivity	Continous barrier. Sandripples, in the limit of MSC. Upwelling
	Highest biomass EBSA propossal		**Highest density**
Fauna	Small teleosteans, medium sharks. Big holothurians, sea-stars Cephalopods, actinians	Decapods and teleosts	Teleosts, decapods and cephalopods

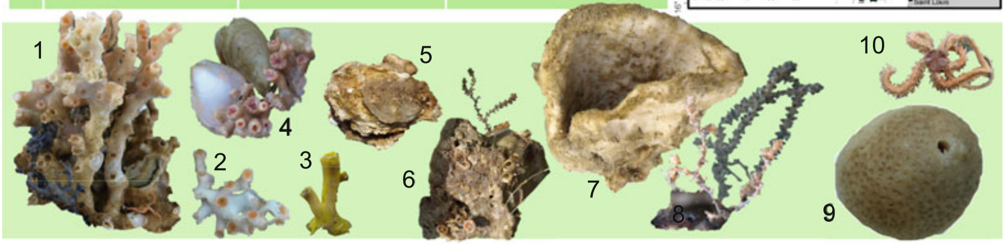




Annexe 17.2 Synthesis of the location, main environmental features and characteristic fauna of the Highly productive Slope Areas (*4–6* in the map). In the pictures: the fishes *Helicolenus dactylopterus* (*1*), *Hoplostethus mediterraneus* (*2*), *Synagrops microlepis* (*3*) and *Merluccius polli* (*4*), among the teleosts, and the demersal elasmobranch *Deania calcea* (*5*); the shrimps, *Parapenaeus longirostris* (*6*) and *Nematocarcinus africanus* (*7*) and a lithodid crab (*8*); the holothurids *Paelopatides grisea* (*9*) and *Parastichopus regalis* (*12*), and the sea-stars *Pseudarchaster gracilis* (*10*) and *Psilaster cassiope* (*12*); the cephalopods *Bathypolypus* sp (*13*), *Opisthoteuthis agassizii* (*14*), *Sepia elegans* (*15*) and the squid *Loligo vulgaris* (*16*)

Vulnerable Areas	Area 9	Area 10	Area 11
Location	Southermost zone of giant carbonate mounds barrier	29 canyons in front Banc 'Arguin. Cape Blanc - Cape Timiris	South of Nouakchott (90 km) (17°08'50"N - 16°46'38"W)
Features	Out of influence of MSC and inputs of Senegal River. Coral bottom	Very steep walls, to 700 m depth. Calcarenite rocks in the edges	Seamount, 200 m high, at 350-450 m depth. Isolated, conical structure, hard bottom
			New discovering
Fauna	*Lophelia pertusa*, corals, sponges, gorgonians, antipa-tharians	*Lophelia*, corals, sponges, gorgonians and big bivalves	Big geodid sponges and suspension-feeders britle-stars





Annexe 17.3 Synthesis of the location, main environmental features and characteristic fauna of the Vulnerable Areas (*9–11* in the map). Suspension-feeders characterize the hard-bottoms habitats from Mauritanian slope. Cold-water corals, mainly *Lophelia pertusa* (*1*), and in some sites *Madrepora oculata* (*2*) and *Dendrophyllia cornigera* (*3*), big bivalves, as *Acesta excavata* (*4*) and the ostreid *Neopycnodonte zibrowii* (*5*), and the gorgonians *Paramuricea* sp and *Acanthogorgia armata* (*6*, *8*) inhabit the southern zone of the carbonate mounds barrier and northern canyons (areas *9* and *10* in the map); sponges were located in the canyons edges (*7*) and Wolof's Seamount. At this last area, a particular assemblage constituted by Geodidae sponges (*9*) and the suspension-feeder brittle-stars, *Ophiothrix maculata* (*10*) was discovered

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