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Occurrence of deep-water corals on the Mid-Atlantic Ridge based on MAR-ECO data

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Abstract

Occurrence of deep-water corals on the Mid-Atlantic Ridge between the southern part of the Reykjanes Ridge and the Azores has been examined based on video surveys using remotely operated vehicles (ROV) and bycatch from longline and bottom trawl. Eight sites were surveyed with ROVs, and the bycatch material came from 16 trawl hauls and nine longline sets. Corals were observed at all sites surveyed with ROVs at depths between 800 and 2400 m, but most commonly shallower than 1400 m. The species richness of corals was high, with a total of 40 taxa recorded. Octocorals dominated the coral fauna with 27 taxa. *Lophelia pertusa* was one of the most frequently observed corals, present at five of the eight surveyed sites. It occurred on basaltic outcrops on the seamounts but always as relatively small colonies (<0.5 m in diameter). Massive live reef structures were not observed. The deepest record of *Lophelia* was at 1340 m, south of the Charlie Gibbs Fracture Zone. Accumulations of dead debris of coral skeletons could indicate a presence of former large *Lophelia* reefs at several locations. The number of megafaunal taxa was 1.6 times higher in areas where corals were present compared to areas without corals. Typical taxa that co-occurred with *Lophelia* were crinoids, certain sponges, the bivalve *Acesta excavata*, and squat lobsters. Signs of destructive fishing and lost gillnets were observed at several locations. The impact of fishing on deep-sea corals is discussed.

Keywords: Deep-water corals; Cold-water corals; Mid-Atlantic Ridge; Fishing impact

1. Introduction

Deep-water corals are widely distributed in the world ocean, and in the North Atlantic the distribution of corals has been reviewed by Zibrowius (1980), Opresko (1980), Cairns and Chapman (2001), and Mortensen et al. (2006). Because surveys in high seas areas are expensive, occurrence of cold-water corals are better documented on the continental margins than on seamounts and mid-oceanic ridges. Taxonomic data on corals of the North Atlantic seamounts are known for the Reykjanes Ridge (Cairns and Chapman, 2001; Keller and Pasternak, 2001; Molodstova, 2006), Meteor Seamounts (Grasshoff, 1972a, b, 1977, 1985; Pasternak, 1985; Zibrowius, 1980; Keller, 1984, 1985), and Horseshoe Seamounts (Cairns and Chapman, 2001; Pasternak, 1985).

The majority of the seamounts in the North Atlantic occur on the Mid-Atlantic Ridge (MAR) (Gubbay, 2002), but there are also seamounts situated some distance from the MAR south west of Rockall Bank, west of Portugal on the Madeira-Tore Rise, and Milne seamounts to the east of the MAR. The seamounts located along MAR have been generated during the past 35 millions years, while the others may be older (Epp and Smoot, 1989).

The special hydrographic conditions with elevated current speeds and good availability of hard bottom are favourable for sessile suspension feeders, which often dominate the community on seamounts (Genin et al., 1986; Rogers, 1994). Corals (Antipatharia, Gorgonacea, Pennatulacea, Scleractinia, Stylasteriidae and Zooantharia) may occur in great abundance, especially along the edges of wide seamounts.

There is increasing concern that fishing in deep water may deplete stocks of long-lived fish species and damage sensitive habitats such as coral reefs and octocoral stands

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(Probert et al., 1997; Vinnichenko, 1998; Krieger, 2001; Fosså et al., 2002; Reed, 2002; Clark and O'Driscoll, 2003; Mortensen et al., 2005). Because of their arborescent growth form and fragile construction deep-water corals seem to be particularly vulnerable to encounters with benthic fishing gear such as bottom trawl and longline (Koslow et al., 2001; Krieger, 2001; Fosså et al., 2002; Mortensen et al., 2005). Recovery of deep-water coral habitats from damage can be expected to be slow because of their low growth rates, generally of the order of $<2\,\mathrm{cm\,yr^{-1}}$ (Wilson, 1979; Mortensen and Rapp, 1998; Andrews et al., 2002; Risk et al., 2002; Mortensen and Buhl-Mortensen, 2005; Gass and Roberts, 2006).

It is well known that coral habitats in deep water represent biodiversity hotspots (Reed et al., 1982; Jensen and Frederiksen, 1992; Buhl-Mortensen and Mortensen, 2005; Mortensen and Fosså, 2006) and commonly house great abundance of fish (Mortensen et al., 1995; Husebø et al., 2002). But, the knowledge is still rudimentary, and in general, less is known about the ecology and associated community of gorgonian deep-water corals, than scleractinian reef-forming deep-water corals. This paper describes the distribution of deep-water corals at some locations along the MAR based on observations with a remotely operated vehicle and bycatch of longlines and bottom trawls. The main goal of this study is to provide a better picture of the distribution of deep-water corals in this area and improve the understanding of the ecology of ridge and seamount communities in the North Atlantic. This is vital for assessing the ecological importance of high seas deep-water coral ecosystems, and to help develop sound scientific advice on habitat and fisheries management issues related to corals.

2. Material and methods

2.1. Study site

Material for this study was obtained from three areas of the northern part of the MAR (Fig. 1). The southern area lies just north of the Azores (around 42°N), while the middle and northern areas were respectively south-east and north-west from the Charlie–Gibbs Fracture Zone (CGFZ) (51°3N–52°N), which separates the southern MAR from the northern MAR and the Reykjanes Ridge. This section of MAR plays a key role in the circulation system of the

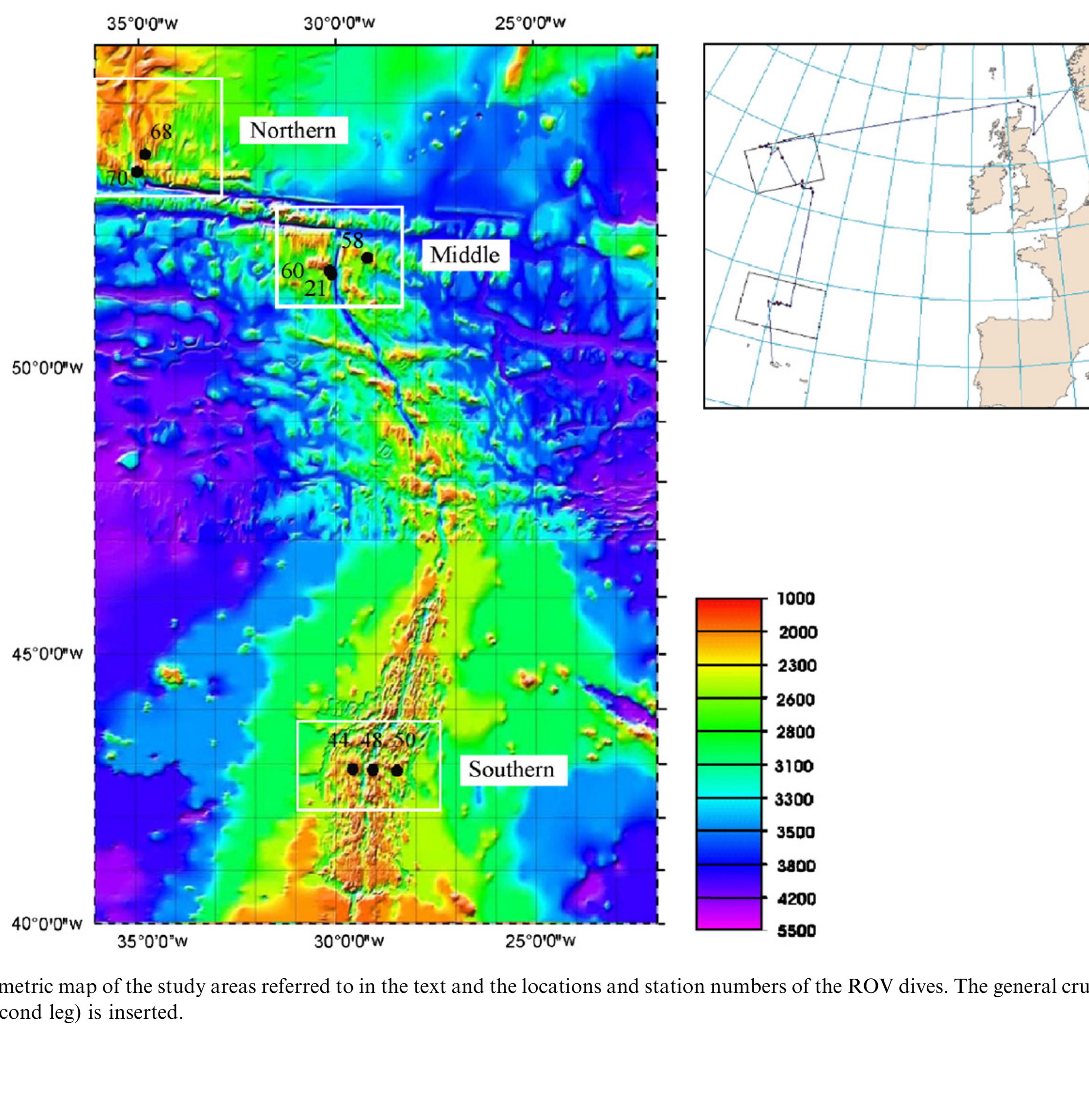

Fig. 1. Bathymetric map of the study areas referred to in the text and the locations and station numbers of the ROV dives. The general cruise track of R.V. G.O. *Sars* (second leg) is inserted.

North Atlantic (Gille et al., 2004; Søiland et al., 2008). There is a flow of deep water between the eastern and western Atlantic basins through the CGFZ that has a maximum depth of 4500 m. The dominating deep-water mass of the region is known as the north atlantic deep water (NADW), which is formed by mixing of the overflowing water masses from the Norwegian and Greenland seas with the Labrador Sea Water. The near-surface circulation is complex, but the main feature is the northeastwards flowing North Atlantic Current, one of the major branches originating from the Gulf Stream (Schmitz and McCartney, 1993). This current carries warm and saline water through the area across the ridge and further onto the European shelf and into the Norwegian Sea.

2.2. ROV observations

ROV surveys were performed during the second leg of the MAR-ECO cruise with the R.V. *G.O. Sars* to the northern MAR in June 2004. Observations were made with the ROVs *Aglantha* (maximum depth 2500 m) and *Bathysaurus* (5000 m) (see Wenneck et al., 2008 for details). Benthic fauna was observed on eight ROV dives (Fig. 1, Table 1), three just north of the Azores and five in the area of the CGFZ. Total time of benthic observations was 25 h 23 min. The dives covered soft and hard substrates and depths ranging from 776 to 2355 m. Video transects were conducted at a constant speed, usually 0.1–0.2 or 0.3–0.4 m s^{-1}, with a field view 2–3 m wide. However, these speeds were difficult to maintain over rough topography. The video records were analyzed using a technique similar to that described by Mortensen et al. (2005). Video records were divided into sequences mainly around 1 min long. These video sequences were shortened when abrupt changes in the habitat occurred. In total, the eight video recorded dives were divided into 736 sequences for analysis. Within these sequences, corals were identified and counted, and the percent cover of substrate types (i.e., sand/mud, pebble, cobble, boulder and outcropping rock) was estimated following the size classes as defined by the Wentworth scale (Wentworth, 1922). Frequency of occurrence of taxa was estimated for transects as the number of video sequences where a taxon occurred divided by the total number of sequences in the transect and normalised to percentages.

2.3. Sampling

Bottom trawl sampling was performed during the second leg of the MAR-ECO expedition in in July 2004 (Wenneck et al., 2008). An otter trawl (modification of the Campelen 1800 shrimp trawl) with an opening between 12 and 17 m wide, and 4.5 m high was used by the R.V. *G.O.Sars* to sample benthic organisms on (see Table 2 for station details). A total of 19 trawl stations were sampled at depths ranging from 826 to 3510 m. The standard duration of each haul was 1 h at ~2 knots (1.03 m s^{-1}) giving a tow distance of ~3.7 km. Material from longlines was obtained from the chartered longliner MS *Loran* that worked in parallel with *G.O. Sars* (Dyb and Bergstad, 2004; Fossen et al., 2008). A total of 37 bottom longline sets were made over a depth-range from 430 to 4300 m. Each set had between 1157 and

Table 1
Information about ROV dives, vehicle (A = Aglantha, B = Bathysaurus), geographical positions as decimal degrees, temperature and salinity (measured by sensors on the ROV), bottom habitats (estimated as average % bottom coverage), and number of coral taxa observed

Area*	Southern			Middle			Northern	
Station	44	48	50	56	60	21	68	70
Dive #	4	3	5	12	10	Lander 2 insp.	15	16
Vehicle	B	B	B	A	A	A	B	B
Latitude (N)	42.94217	42.87333	42.94181	51.75283	51.513	51.52267	53.127	53.01567
Longitude (W)	29.5075	29.1037	28.5009	29.5835	30.3355	30.3325	34.7888	34.8788
Duration (min)	57	104	203	255	192	50	53	609
Min depth	1227	1023	2049	1209	776	862	2337	1167
Max depth	1291	1115	2110	1437	965	899	2355	1516
Temperature	3.5	6.2	3.6	3.6	4.3	4.1	2.9	3.3
Salinity	35.1	35.1	35	35.2	35	35.1	35.1	35.4
Habitat								
Sand/mud	46	21	88	54	23	54	100	55
Pebble	15	0.4	3	9	0	0.2	0	1
Cobble	8	1	3	5	1	3	0	3
Boulder	13	9	3	11	6	1	0	4
Outcrop	5	10	3	14	10	18	0	29
Coral rubble	12	39	0	2	61	24	0	8
Pteropod shell	2	20	0	2	0	0	0	0
Worm tubes	0	0	0	3	0	0	0	0
Coral taxa	10	7	8	14	11	8	1	14

*The study areas are shown in Fig. 1.

Table 2
Geographical positions, depth range and number of coral taxa in 19 bottom trawl hauls

Station	Trawl no.	Coordinates	Depth range	Coral taxa
Southern area				
40	367	42.9152N, 30.3395W	2660–2670	1
42	368	42.8100N, 29.6393W	2270–2290	2
44	369	42.9327N, 29.5362W	1768	2
46	370	42.7633N, 29.2732W	3100–3135	2
48	371	42.8725N, 29.1028W	1300	0
50	373	43.0345N, 28.5518W	2597–2610	3
52	374	42.9220N, 28.1392W	2970–2977	2
Middle area				
53	375	49.8628N, 29.6297W	940–1060	1
54	377	51.3297N 28.8690W	3505–3510	3
56	378	51.7507N, 29.5482W	1930–2000	4
60	379	51.5583N, 30.3110W	1150–1255	0
62	380	51.9180N, 30.4170W	1910–1950	1
64	381	51.5493N, 30.9683W	3462–3464	2
Northern area				
65	382	52.2700N, 31.0143W	826	1
66	383	53.0343N, 33.6117W	3010–3076	1
68	384	53.1387N, 34.7660W	2276–2364	1
70	385	52.9757N, 34.8692W	1640–1650	3
72	386	53.2800N, 35.5342W	2450–2534	2
74	387	53.2933N, 36.7745W	3040–3050	0
			Sum coral taxa	10

Table 3
Geographical positions, depth range and number of coral taxa in the nine out of 37 sets with longline that contained corals

Station	Coordinates	Depth-range	Coral taxa
Southern area			
6	42.63267N, 28.6607W	1572–2340	1
10	42.49733N, 28.9908W	1100–1358	4
21	42.82683N, 29.1162W	972–944	4
Middle area			
30	51.31633N, 29.6078W	3059	1
33	51.80900N, 29.8267W	1327–1570	1
Northern area			
51	54.30333N, 35.4103W	506–519	1
52	54.28050N, 35.4042W	440	1
55	54.29067N, 35.3963W	680	1
58	54.30300N, 35.4090W	540–518	1
		Sum coral taxa	11

3470 hooks. The station numbers and depths of sets where corals were caught are given in Table 3.

Fauna from the bottom trawl was first sorted on deck and then in the laboratory to the lowest possible taxonomical level. Samples were preserved in 80% alcohol or 4% formaldehyde solution depending on the taxon. Representatives of selected taxa were photographed prior to preservation. Coral bycatch on the longline hooks was labelled and frozen in plastic bags.

All collected material has been deposited at the Bergen Museum. Species identifications were provided by taxonomists with expert knowledge on relevant groups.

3. Results

3.1. General habitat description

The seabed surface at the eight surveyed localities was dominated by soft/sandy bottom, or coral rubble (st. 48 and 60). At one site (st. 68) no stones or outcropping rock were observed (Table 1). The seabed surface at five locations consisted of more than 20% hard bottom (stones and outcropping basaltic rock). Examples of these two common habitats are shown in Fig. 2. At some locations (st. 48 and 60) degraded fragments of dead corals (coral rubble) were dominant along several 100 m of a transect (Fig. 3). Pteropod shells covered the seabed entirely over larger areas along three transects (st. 44, 48, and 56) (Fig. 4). The temperature near the seabed varied between 2.9 and 6.2 °C, with the warmest conditions in the southern study area (st. 48) and the coldest in the northern study area (st. 68) (Table 1). Only one coral species (*Flabellum* sp.) was observed at the cold station 68, which also was the deepest surveyed location. At the warmest station 48, seven coral taxa were recorded, and the highest cover of scleractinian coral rubble was observed (Table 1).

3.2. Composition of coral taxa

In total, 41 taxa of corals were recorded from all gears (Table 4). Twenty-two species and eight genera were identified. The remaining 11 taxa were either higher taxonomic units or genera that could not be identified with absolute confidence. Octocorals (Alcyonacea, Gorgonacea, Pennatulacea) were taxonomically richer than hexacorals (Antipatharia and Scleractinia) with 27 versus 14 taxa. Gorgonacea was the most diverse order comprising 14 taxa, whereas Antipatharia and Alcyonacea were represented with the lowest number of taxa (two and three taxa, respectively).

3.3. Distribution of corals

Twenty-five coral taxa were observed in total on all ROV dives (Tables 1 and 5) at depths between 800 and 2400 m (Fig. 5). Fifty-eight percent of the analysed video sequences had one or more coral species. The deepest occurrences were of *Flabellum* and *Acanella* at depths around 2400 and 2100 m, respectively. The highest number of coral taxa was found shallower than 1400 m depth (Fig. 5). However, many of the common species had a wide depth range, and *Antoptilum* sp., *Anthomastus* sp., and *Acanella arbuscula* occurred between 800 and 2100 m. The number of coral taxa was strongly correlated ($R^2 = 0.81$, $p < 0.005$) with the percentage cover of hard bottom (cobble, boulder and basalt combined) (Fig. 6). Most species occurred on the

Fig. 2. Examples of two common habitats along the MAR (A and B) exposed basaltic outcrop at dive # 12 st. 56 with a high abundance of *Anthomastus* sp. (C and D) soft, sandy sediments with scattered shells or pebbles, *Acanella arbuscula* (C), and *Flabellum alabastrum* (D), observed at st. 50.

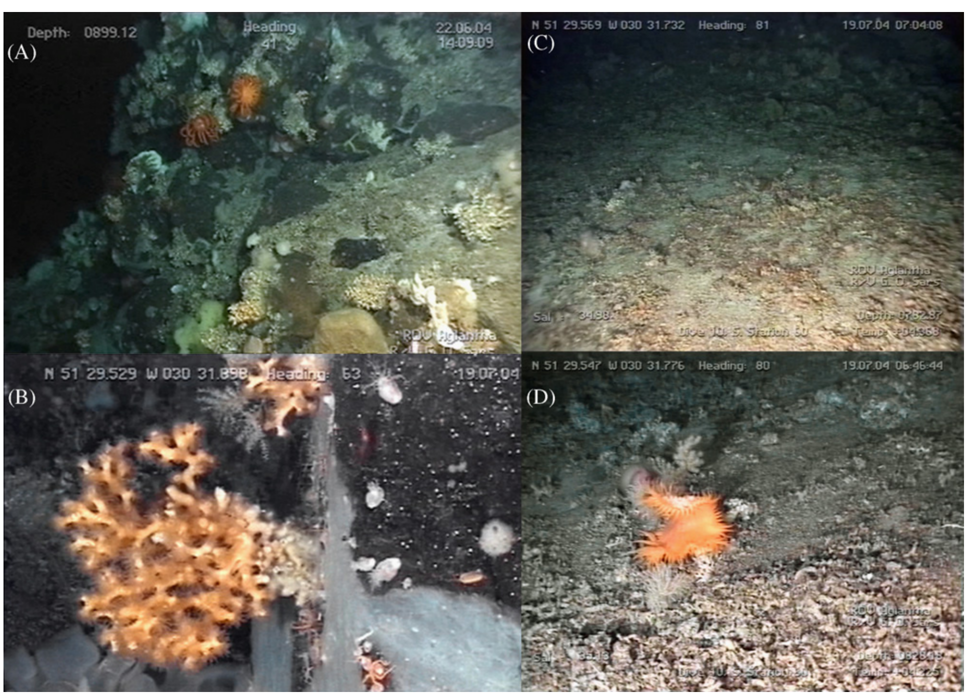

Fig. 3. *Lophelia* habitats observed at dive # 10 st. 60. (A) Small colonies attached to the steep sides of basaltic outcrop. (B) Close-up of a colony (both orange and white colour morphs were observed). (C) and (D) Coral rubble (and an anemone, Actinoscyphiidae indet.) occurring on more level bottom.

steep sides of basaltic outcrops. *Virgularia quadrangularis*, *Acanella* sp., Isididae Indet. and *Flabellum* occurred only on soft sediments. The most common corals observed was unidentified gorgonians, probably comprising several species (Table 5). These were observed in 7% of all video sequences on six dives. The highest frequency of occurrence was at st. 44 where 32% of the video sequences contained unidentified gorgonians. *Lophelia pertusa* or *Solenosmilia*

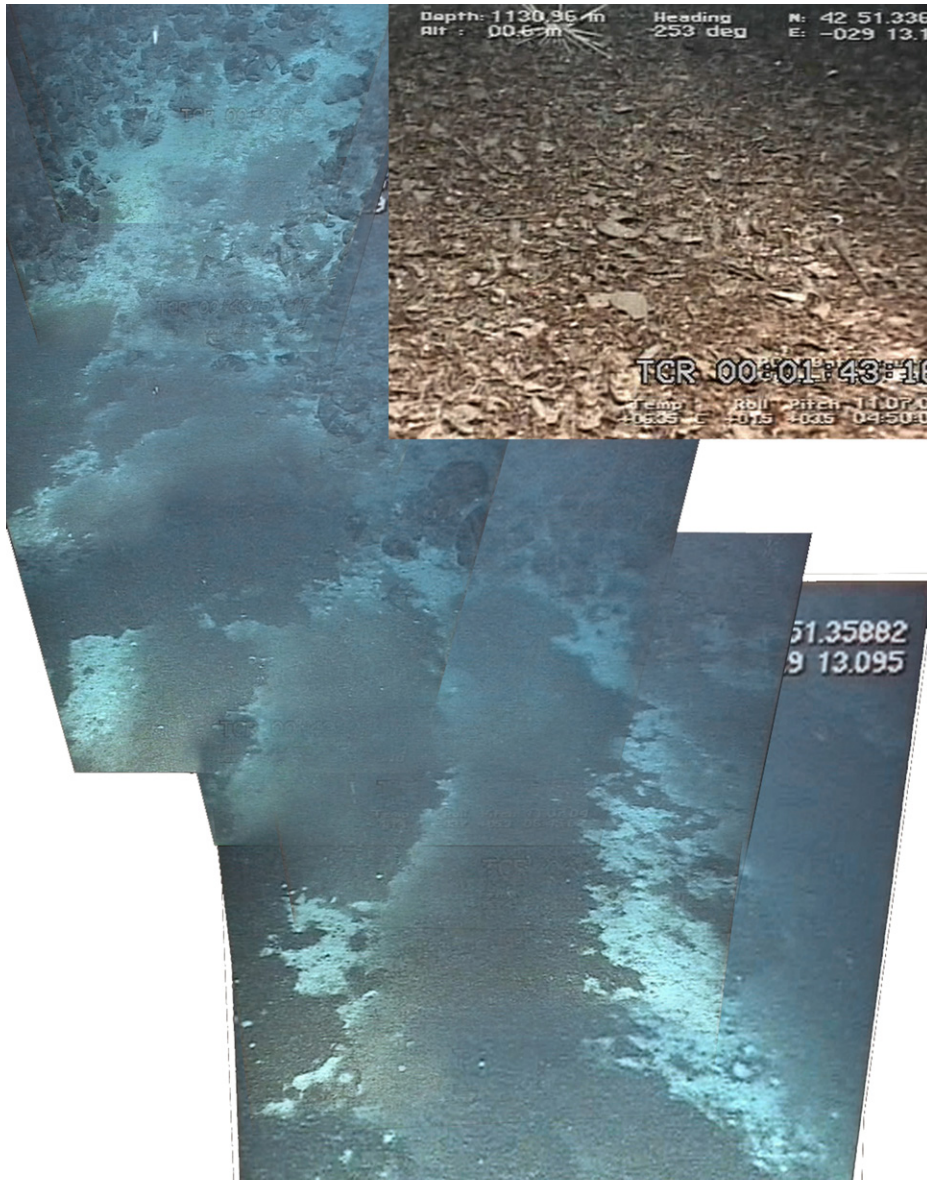

Fig. 4. Mosaic of video frame grabs from dive # 3 st. 48 showing pteropod shells sorted into elongated features at the foot of a local "hill" with boulders. Close-up from the same location is inserted.

variabilis (sometimes hard to distinguish) occurred at five dives with an average frequency of 19%. Highest frequency was observed at st. 60, with occurrence in 66% of the video sequences. Living *Lophelia* was repeatedly observed on the seamounts but always as relatively small colonies. The deepest record was at 1340 m, south of the CGFZ, in the middle study area. We did not observe massive live reef structures, and the largest colony was approximately 0.5 m in diameter. At st. 48, in the southern study area, we observed a seamount with a dense layer of coral rubble on the top and slopes with a few live colonies. *Anthomastus* sp. was almost as common as *Lophelia*/*Solenosmilia* with occurrence in 13% of all video sequences. Its highest frequency (49%) occurred at st. 56, in the middle area. The maximum density at that location was almost 300 col. 100 m^{-2} with a majority of small (diameter < 5 cm) colonies (Fig. 5). Seven taxa were observed only in the Azores area (st. 44, 48 and 50), whereas 13 taxa were restricted only to the CGFZ area (Table 4). Nine taxa occurred only on the eastern side of the MAR, and eight taxa only on the western side. *Acanella* sp. dominated the soft bottom megafauna in the Azores area (st. 48 and 50). The average density of this gorgonian was 4.6 col. 100 m^{-2}, but it reached a maximum of 25 col. 100 m^{-2} at st. 50. In the CGFZ area the most abundant coral taxa were Gorgonacea Gen. sp. (columnar morphotype, Cf. *Radicipes*) (max 30.4 col. 100 m^{-2} at st. 68).

The longliner M/S *Loran* caught 17 specimens of corals on the hooks of the long lines. A total of 11 species (scleractinians, antipatharians and gorgonians) were collected from nine of the shallowest stations.

Table 4
Coral taxa identified from video records made with ROV, and from bycatch on longline and in otter trawl

	Study area			Gear		
	South	Mid.	North	Line	ROV	Trawl
Alcyonacea						
Alcyonacea Indet.		+			+	
Anthomastus spp.		+	+		+	+
Nephtheidae indet.		+	+		+	
Gorgonacea						
Acanella arbuscula	+	+		+	+	
Acanthogorgia sp.	+	+			+	
Chrysogorgia agassizi	+	+			+	+
Gorgonacea Cf. *Radicipes*	+		+		+	
Gorgonacea Indet.	+	+	+	+	+	
Isididae Indet.	+				+	
Cf. *Iridogorgia*	+				+	
Keratoisis sp.	+				+	
Paragorgia arborea	+	+	+	+	+	
Paragorgiidae Indet.	+	+	+	+	+	
Paramuricea sp.	+	+			+	
Paramuricea biscaya		+				
Primnoa resedaeformis			+	+	+	
Primnoidae Indet.	+	+		+		
Pennatulacea						
Anthoptilum sp.	+	+	+		+	
Anthoptilum murrayi		+				
Funiculina quadrangularis		+			+	+
Kophobellemnon macrospinosum		+				
Pennatula sp.1 (cf. phosphorea)		+	+			+
Scleroptilum grandiflorum	+					
Umbellula durissima		+				+
Umbellula encrinus		+				
Umbellula thompsoni		+				
Pennatulacea Indet.	+	+	+		+	+
Antipatharia						
Antipatharia (Cf. *Bathypathes arctica*)	+		+		+	
Antipatharia Indet.	+	+	+	+	+	
Scleractinia						
Caryophyllia ambrosia	+		+			+
Caryophyllia cornuformis		+				+
Desmophyllum dianthus	+	+	+	+	+	
Flabellum alabastrum	+	+	+		+	+
Flabellum spp.	+	+	+		+	
Flabellum angulare	+		+			+
Fungiacyathus fragilis	+	+	+			+
Lophelia pertusa	+		+	+		+
Lophelia/Solenosmilia	+	+	+		+	
Madrepora oculata	+			+	+	
Solenosmilia variabilis	+			+		
Stephanocyathus moseleyanus	+					+
Sum coral taxa	28	28	20	11	25	13
Unique for area or gear	7	8	1	3	13	7
Total number of coral taxa	41					

Presence of corals is indicated in relation to geographical areas (see Fig. 1), and sampling gear.

Corals were caught in 16 of the 20 trawl hauls. These were mainly solitary scleractinians and seapens, two groups that are not easily caught on longline or difficult to identify on video records. The dominant corals in trawl catches were *Stephanocyathus moseleyanus* and *Pennatula* cf. *phosphorea*.

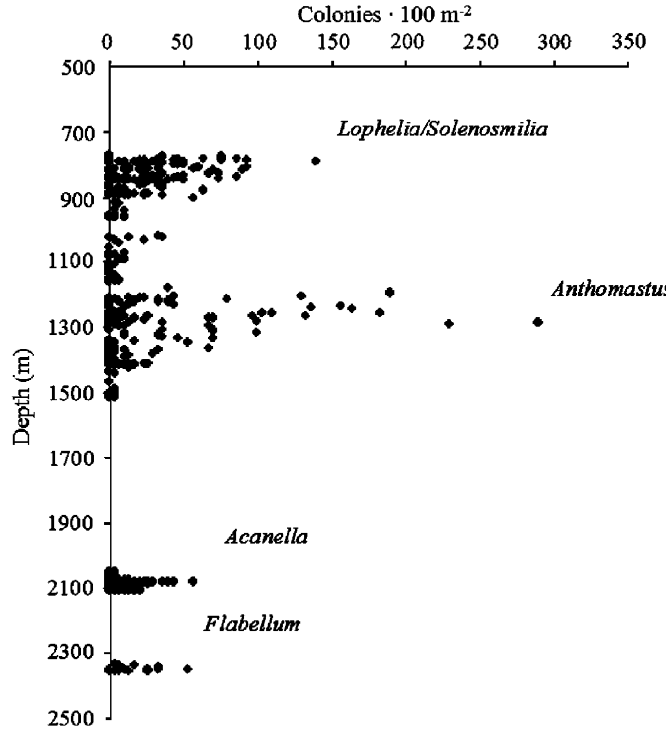

Fig. 5. Density of observed coral colonies and individuals plotted against depth. Peaks of dominating species are indicated on the plot.

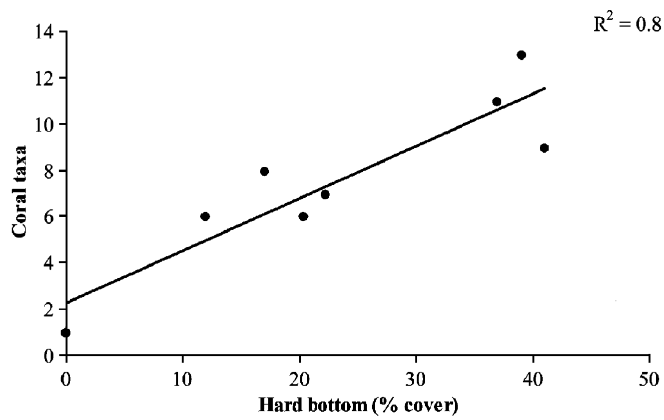

Fig. 6. The relationship between number of coral taxa and percentage cover of hardbottom (cobble, boulder and outcropping bedrock combined).

3.4. Other invertebrates

In total, 30 megafaunal invertebrate taxa other than corals were observed during the ROV dives. Twenty-nine of these taxa occurred in video sequences containing corals, and only 18 taxa occurred in video sequences where no corals were observed. The most common taxa that occurred close to, or directly on *Lophelia* colonies were

Table 5
Frequency of occurrence (percentage of video sequences) of coral taxa observed during dives with the ROVs Aglantha and Bathysaurus

Station #	44	48	50	56	60	21	68	70
Alcyonacea								
Alcyonacea Indet.						2		
Anthomastus sp.			2	49	13	12		22
Nephtheidae indet.						2		2
Gorgonacea								
Acanella arbuscula	4	13	51		3	3		
Acanthogorgia sp.	2				42			
Chrysogorgia agassizi			1	3				
Gorgonacea Cf. *Radicipes*			0.5					48
Gorgonacea Indet.	32	6		2	5	4		8
Isididae Indet.	19							
Cf. *Iridogorgia*	2		0.5					
Keratoisis sp.		11						
Paragorgia arborea	4			5	1			
Paragorgiidae Indet.		3		2	1	2		2
Paramuricea sp.	13			2				
Primnoidae Indet.	4				1			
Pennatulacea								
Anthoptilum sp.			0.5	11	5			2
Funiculina quadrangularis				6	1			
Pennatulacea Indet.		2	0.5	1				3
Antipatharia								
Antipatharia (Cf. *Bathypathes arctica*)	8							2
Antipatharia Indet.	17			2				2
Scleractinia								
Desmophyllum dianthus				8	2	2		4
Flabellum alabastrum				1				2
Flabellum spp.			0.5	1			64	2
Lophelia/Solenosmilia		11		14	66	49		18
Madrepora oculata		2						

crinoids, certain sponges, the bivalve *Acesta excavata*, and squat lobsters. In the CGFZ area dominant taxa were Syringamminidae (Foraminifera) (218 ind. $\cdot$ 100 m^{-2}, and 40.7 × 100 m^{-2} , at sts 70 and 56, respectively) and Hyocrinidae (Crinoidae) (16.4 ind. $\cdot$ 100 m^{-2} at st. 60).

3.5. *Signs of fisheries impact*

At dive 16 (st. 70) one net (pelagic gillnet) was found in a small mound filled with dead coral skeleton pieces (Fig. 7A). Another sign of human contact was bottles (rubbish from ships) observed along st. 50. Ropes from fishing gear were found on the seabed and entangled in a large and partly broken colony of *Paragorgia arborea* at st. 60 (Fig. 7B). There were no clear marks in the seabed from contact with heavy fishing gear such as trawl doors.

4. Discussion

The non-hydrothermal hard bottom areas of oceanic ridges are often colonised by erect megafauna such as gorgonians, sponges, hydroids, and black corals (Grigg, 1997). To a large degree, the topography of the seabed seems to control the distribution of habitats along the MAR by providing different settings for sedimentation and retention of particulate matter. This is illustrated by the accumulation of coral rubble near the bases of volcanic ledges, and deposits of pteropod shells on level sandy bottom some 10 m away from rocky obstructions where currents will not sweep the light shells away. The topography also controls the current patterns and velocity (Genin et al., 1986), and hence the transport rate and concentration of food particle for suspension feeders.

Corals were observed at all locations and depths surveyed with ROV. The discontinuous bathymetric distribution of corals reflects the uneven coverage of depths by the ROV dives, rather than the distribution of corals. The corals with the deepest occurrence were species associated with soft bottom (*A. arbuscula* and *Flabellum* spp.). This also reflects the lack of hard substrates at the deepest sites surveyed with the ROVs. The material for this study is too limited, and the taxonomic resolution of the video records too poor to demonstrate geographical gradients in coral distribution along the ridge. One example of this was the occurrence of *L. pertusa* and *Madrepora oculata,* which could not be separated when observed at a distance. Only when examined closer (<1 m away) was it possible to positively identify the species. Another factor that blurs possible patterns of geographic distribution is that the depth range of the ROV dives differed between the study areas. The number of coral taxa recorded in this study is comparable to what has been reported in other studies in the North Atlantic (Brattegard and Holthe, 1997; Mortensen et al., 2006), but given the uncertainties of some species identifications resulting from poor visual resolution and the lack of sampling with adequate gear (e.g. epibenthic sledge or beam trawl) in this study, it is probable that the species richness of corals on the MAR is higher than in high latitude areas within continental margins.

Clearly the diversity of megafauna was higher in areas with corals than without. This has also been shown for deep-water coral reefs and areas with octocoral stands (e.g., Jensen and Frederiksen, 1992; Buhl-Mortensen and Mortensen, 2004). However, this relationship is partly explained by the presence of hard bottom substrate, which is favourable not only for corals but also for many other sessile suspension feeders. Old degraded colonies of scleractinians may form a layer of debris that accumulates over hundreds and thousands of years. Such coral rubble can be a pronounced feature of the habitat on the tops of seamounts, and may represent an important habitat for various attached and cryptic invertebrate species.

4.1. *Evidence of fishing impact*

Remains of former large *Lophelia* reefs were observed at several locations. The degradation of these reefs could be

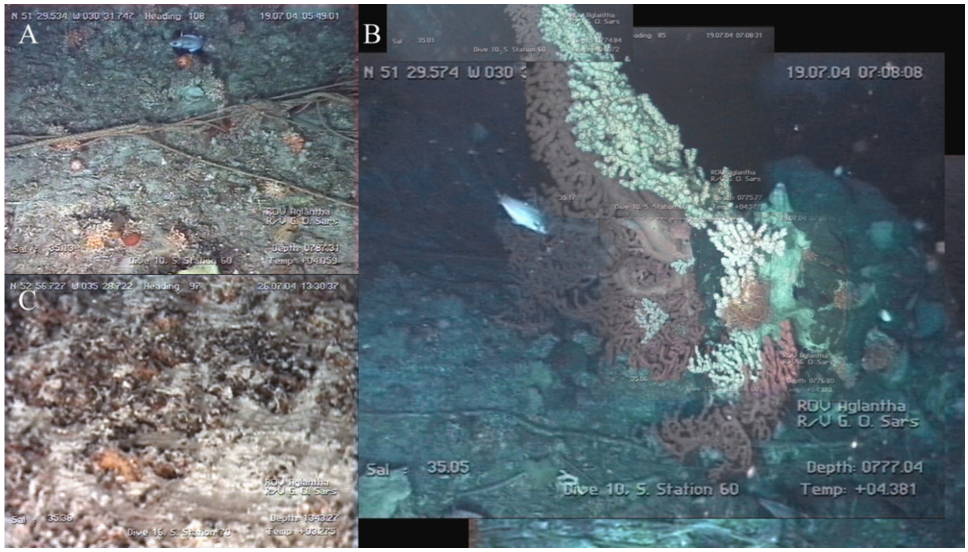

Fig. 7. Evidence of fishing impact. Ropes (A) and video mosaic of damaged *Paragorgia arborea* (B) from dive # 10 st. 60. (C) A net, probably from a pelagic trawl lying over coral rubble at dive # 16 st. 70.

due to either natural factors such as changed current patterns, reduced food supply, or destructive fisheries. If the oceanographic setting of this area has been little changed since the last deglaciation then there are no obvious natural causes to account for a dramatic reduction of the extent of reefs at the MAR. Unfortunately, no samples of dead coral skeletons were collected. This could have resolved the uncertainty on the age of these skeletons. There has been a commercial fishery on the MAR since the early 1970s (Gordon et al., 2003). The international fishery has mainly targeted near-bottom fishes such as roundnouse grenadier, alfonsino, orange roughy and redfish. The primary gear has been trawl, both demersal and pelagic, but longlines and gillnets were also used. The true scale of the operations has proven hard to document. It is assumed that the activity has declined in recent years following introduction of regulatory measures by the Northeast Atlantic Fisheries Commission (www.neafc.org).

The small (<ca 30 cm) living *L. pertusa* colonies occurring in the area correspond to approximately 30–60 years of normal growth with rates of 0.5 to 1 cm yr^{-1} (Wilson, 1979; Mortensen and Rapp, 1998). This could fit with recovery after early damage when the fisheries started in the 1970's. However, the huge areas with small pieces of dead and old (coated with micro epibiota and detritus) *Lophelia* skeletons do not support that theory.

Furthermore, the absence of clear marks caused by trawl doors also indicates that possible impact from bottom trawling has been much less in the surveyed area compared with certain areas off the Norwegian coast (Fosså et al., 2002). Marks observed on the pteropod bottom (Fig. 4) are more irregular than could be expected from trawl doors and are probably rather caused by hydrodynamic related processes, such as sediment sorting and ripple-mark formation in bands.

There is limited documentation of human induced impacts to benthic habitats on seamounts in the open Atlantic Ocean. The observations of lost trawl netting and longlines presented here are some of the few direct evidences of fishing impacts on benthic habitats in Atlantic high sea areas. The chartered longliner *MS Loran* that operated in the same areas at the same time also caught lost longlines when fishing on these hills (Dyb and Bergstad, 2004). In other parts of the North Atlantic fishing with longlines has been documented to impact on gorgonian coral stands (Mortensen et al., 2005). Compared with other studies of coral habitats and impacts from fishing, the results presented here are inconclusive. Therefore, these results must be regarded as a first glance at the status of deep-sea corals along the MAR.

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