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Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic

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The effects of deep-sea bottom longlining on fish communities and the benthic ecosystem, as well as the interactions between fishing and seabirds, were studied based on data collected from a joint collaboration between the Spanish Institute of Oceanography and a longliner, carried out on the Hatton Bank area (north-east Atlantic) in 2008. A total of 38 longline sets were distributed mainly along the rugged bottom of the rocky outcrop at depths ranging from 750 to 1500 m. Deep-water sharks and lotids were predominant in the catches contributing respectively 80.4% and 13.1% in terms of weight. Deep-water sharks were predominant in the discards. By-catch of cold-water corals and small glass sponges occurred along the western flank of the Hatton Bank, while large hexactinellids were found along the eastern flank. Longlines fished the adult fraction of vulnerable deep-water sharks and lotids. High catches per unit effort values for these species were obtained in coral areas. A combination of seabird-scaring streamer lines and other measures of preventing seabird by-catch were used. Only one fulmar was captured and it survived. Data on distribution of marine litter and derelict deep-sea gillnets are also presented.

Keywords: benthic impact, by-catch, cold-water corals, deep-water sharks, Hatton Bank, litter, longline, lotids, mitigation, seabirds, vulnerable marine ecosystems

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INTRODUCTION

Deep-sea bottom longline fisheries of the Hatton Bank

Deep-sea bottom longline fisheries are conducted both on the deep-sea slopes and shallower waters of the Hatton Bank, targeting deep-water sharks, Greenland halibut and gadoids (Bensch *et al.*, 2008). Accordingly, the North East Atlantic Fisheries Commission (NEAFC) and the European Union (EU) have closed a part of the Hatton Bank to bottom fishing (EC, 2009; NEAFC, 2010), in order to protect vulnerable marine ecosystems (VMEs) threatened by deep-sea fisheries (FAO, 2009). Catch limitations for most deep-water species were also implemented by the EU and currently no directed fisheries for deep-water sharks are permitted for Community vessels (EC, 2008a). Deep-water sharks *Centrophorus squamosus* (Bonnaterre, 1788) and *Centroscymnus coelolepis* (Bocage & Capello, 1864) have conservative reproductive strategies that suggest that they may not sustain intensive commercial exploitation (Clarke *et al.*, 2001). Both were included in the list of threatened and/or declining species and habitats of the OSPAR Convention for the protection of the marine environment of the north-east Atlantic (OSPAR, 2008).The first is also included under the 'vulnerable category' (White, 2003) by the International Union for Conservation of Nature (IUCN) and the second one is considered to be 'near threatened' (Stevens & Correia, 2003). *Molva dypterygia* (Pennant, 1784) and *Brosme brosme* (Ascanius, 1772), are gadoid species belonging to the family Lotidae (lotids). The first grows much faster than most deep-water species but it is particularly vulnerable to fishing because spawning aggregations can be targeted (ICES, 2008a), meanwhile the second one is more vulnerable due to a slow growth rate and a higher age at first maturity (ICES, 2008b).

Longline impacts

There appears to be little information on impacts of static gears on the Hatton Bank. But VMEs could be negatively affected by bottom longlining (Bavestrello *et al.*, 1997; Krieger, 2001; Fosså *et al.*, 2002; Reed, 2002). Moreover the mortality of seabirds in bottom longline fisheries (Brothers *et al.*, 1999), particularly *Fulmarus glacialis* (Linnaeus, 1761), could be large. However, in the north-east Atlantic, longlines are not currently regarded as a serious threat for the fulmar (Tasker *et al.*, 2000), since their populations are now large. The species is listed as being of 'least concern' by IUCN (BirdLife International, 2008). Nevertheless, reduction of seabird by-catch, as well as conservation of VMEs, discard research and impact assessments are issues addressed

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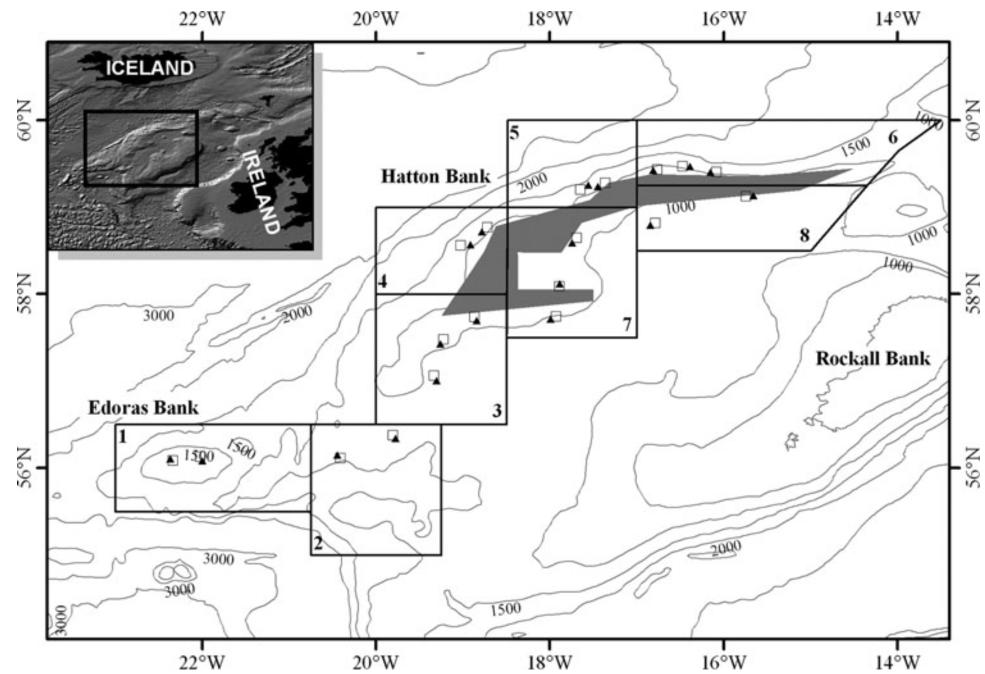

Fig. 1. Map of the study area showing the boundaries of the sampling blocks (solid line) and the start positions of the longline hauls (white squares, multifilament gear; black triangles, monofilament gear). Longlines were deployed outside the NEAFC/EU closed area (shadow area).

by the United Nations General Assembly resolution 61/105 on sustainable fisheries (UNGA, 2006).

Aim of the survey

The objective of the survey was to study the potential for a sustainable longline fishery over the rocky outcrop of the Hatton Bank area (unusual ground for the Spanish longliners) and furthermore to describe the effects of longlining on fish communities and the benthic ecosystem, as well as the interactions between fishing and seabirds. In addition, the survey provided a chance to collect extra data on marine litter and derelict deep-sea gillnets. Collaborative research with longline fishermen provided an opportunity to target large predators and scavengers in rugged terrain and hard substrate (Fossen *et al.*, 2008) and offered a cost-effective means of gaining valuable insight into the longlining techniques. The working hypothesis is that longlining, regarded as a more selective fishing method than trawling (Bjordal & Løkkeborg, 1996), could produce impacts in sensitive species when their distributions overlap with fishing grounds. The purpose of this paper is to contribute to the understanding of the deep-sea fishery and to provide input to advisory processes. The inclusion of data collected in collaboration with stakeholders into the process, will improve stakeholder comprehension, the degree of acceptance and potential for success of conservation measures.

MATERIALS AND METHODS

Study area

The study area (Figure 1) in international waters of the north-east Atlantic, occurs within the NEAFC Regulatory Area (ICES Subdivision VIb_1 and Division XIIb), on the Hatton Bank area (750–1500 m depth). Hatton Bank is a large offshore bank, situated to the west of the European continental shelf. Its geophysical setting has been recently summarized by Sayago-Gil *et al.* (2010). Evidence of outcropping bedrock, coral carbonate mounds and cold-water coral assemblages were reported (Roberts *et al.*, 2008; Howell *et al.*, 2010) in the shallowest area of the bank (<1000 m depth). Along the deep western flank (>1000 m depth), the habitats (Durán Muñoz *et al.*, 2009) are located on two distinct geomorphological domains, namely: (i) the contouritic sedimentary seabed of the Hatton Drift (McCave & Tucholke, 1986), a ground frequented by trawlers; and (ii) the rugged seabed of the Hatton Bank outcrop, a ground feasible for longlining. The term outcrop, *sensu stricto*, refers to those parts of the bank that project from the seabed surface and which are not covered—or slightly covered, up to 15 m—by sedimentary deposit (drift). Three areas of cold-water corals have been identified by Durán Muñoz *et al.* (2009) along the outcrop in the western deep slopes of the bank.

Survey methodology

The experimental survey was developed by the Spanish Institute of Oceanography (IEO) in collaboration with fishermen. The study was carried out over twenty days during the summer of 2008, on-board a Spanish bottom longliner (336 gross tonnage) predominantly used to fish hake in European waters. The study area was divided into eight sampling blocks, based on the previous knowledge of the seabed morphology (Sayago-Gil *et al.*, 2010) and the fishing grounds (Durán Muñoz *et al.*, 2009). Three blocks were delineated within the western slope, considering the main outcrop areas (as given in ICES, 2008c): (i) Central Area (block 4); (ii) Ridges and Mounds Area (block 5); and (iii) North-western Area (block 6). The remaining represent (iv) the eastern flank of the bank (blocks 3, 7 and 8), (v) the adjacent Edoras Bank (block 1), and a transitional area between both banks (block 2). The objective of this sampling scheme (Figure 1; Table 1) was to study

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Table 1. Characteristics of the longline hauls. Sampling block (Block), date, monofilament gear (Mn), multifilament gear (Mt), start position (Lat, latitude; Long, longitude), average start depth (m), and hooks deployed (number). For each set, catch in weight (kg) of deep-water sharks, lotids and vulnerable marine ecosystems indicator taxa are given (values <0.1 are noted as +). SG, sponges; GO, gorgonians; SP, sea pens; SF, soft corals; BC, black corals; CC, cup corals; SC, stony corals; LC, lace corals.

			Start				Fish		VMEs indicator taxa							
Block	Date	Gear	Lat (N)	Long (W)	Depth	Hooks	Sharks	Lotids	SG	GO	SP	SF	BC	CC	SC	LC
1	29 July	Mn	560622	222205	1107	1235	86.7		0.1	+					0.9	
1	29 July	Mt	560469	222033	1103	1455	503.1			0.5			0.1			
1	30 July	Mt	560735	220180	1288	1475	15.6							0.1		
1	30 July	Mn	560475	220000	1263	1610	4.4									
2	31 July	Mn	560864	202668	1460	1660	14.5		+	+				0.1		
2	31 July	Mt	560640	202485	1485	1440	15.8									
2	1 August	Mt	562230	194845	1348	1440	83.6									
2	1 August	Mn	562025	194647	1369	1640	65.0		0.1							
3	2 August	Mn	570027	191828	1145	2045	502.0	7.0		+				0.1		
3	2 August	Mt	570340	192017	1108	1795	840.5						+	+		
3	3 August	Mt	572841	191370	925	1430	165.4	88.1						0.1		
3	3 August	Mn	572569	191556	943	1610	314.3	101.0	0.1	+				0.2	+	
3	4 August	Mn	574150	185039	731	1610	489.2	71.2							+	
3	4 August	Mt	574402	185229	743	1420	269.3	27.8					+		4.5	
4	5 August	Mt	583326	190159	1067	2190	870.9	37.6	+					+	0.2	
4	5 August	Mn	583416	185483	970	1640	724.3	119.6	0.1					+		
4	6 August	Mt	584578	184320	986	1805	241.0	86.0	0.2	0.1		0.1		0.2	37.5	+
4	6 August	Mn	584302	184692	953	1660	403.0	200.4	+	0.1		+		+	10.3	
5	7 August	Mn	591529	173349	1067	1650	484.0	135.4	+	+		+	1.2	0.1	6.3	0.8
5	7 August	Mt	591204	173915	1105	1460	321.9	32.6								
5	8 August	Mt	591650	172188	911	1470	209.3	44.4	+	0.2				+	0.4	
5	8 August	Mn	591434	172687	910	1630	243.8	194.2	0.2	0.1		+	0.2	0.2	50.9	+
6	9 August	Mt	592574	164603	845	1065	206.1	26.8			0.1					
6	9 August	Mn	592543	164851	847	1215	116.4	37.9		+					0.9	
6	11 August	Mn	592800	162341	1226	1630	225.1	27.8								
6	11 August	Mt	592800	162844	1134	2200	491.9	47.8			0.1					
6	12 August	Mt	592400	160511	1199	2210	370.4	41.5	+		+			+	+	
6	12 August	Mn	592400	160926	1116	1640	168.1	124.5						+		
8	13 August	Mn	590789	153927	1080	1640	197.9	85.8	1.0	0.3	0.9			0.3		
8	13 August	Mt	590735	154477	1096	2200	241.9	12.1	0.1		0.2					
8	14 August	Mt	584896	164748	1167	2220	136.6		0.7		+	+				
8	14 August	Mn	584766	165050	1159	1660	76.5	6.9	0.4		+					
7	15 August	Mn	583522	174457	833	2480	469.4	35.8			0.3				0.4	
7	15 August	Mt	583878	174165	852	2200	305.1	38.3	0.2						2.1	
7	16 August	Mt	580518	175344	775	2200	334.5	4.6								
7	16 August	Mn	580714	175333	792	1640	160.8	72.1							0.5	
7	17 August	Mn	574260	175964	1010	1650	211.2	22.8	0.3		0.1			0.2		
7	17 August	Mt	574436	175593	988	2210	107.9	7.2			0.1			0.1		

Table 2. Technical characteristics of the bottom longlines. (Mn, monofilament gear; Mt, multifilament gear). Average values ± SD of the mean soak time are given. Presence of safety line (SL), weighs (W) and alternate floats and weights (AFW) is noted as +.

	Mn	Mt	Total
Mean soak time (hour)	8.4 ± 2.3	9.2 ± 2.5	8.8 ± 2.4
Lines deployed (number)	19	19	38
Hooks deployed (number)	31,545	33,885	65,430
Hooks	7/0 J	9/0 EZ	
Hook spacing (m)	2.5	1.33–1.45	
Bait	Sardine	Sardine	
Mainline/snoods	Nylon-multifilament	Synthetic-multifilament	
Main line diameter (mm)	2.0	2.5	
Snoods diameter (mm)	1.1	2.0	
SL	+	+	
W	+	+	
AFW	+		

mainly the zones of the rocky outcrop open to bottom fishing activities. With this aim, 19 fishing stations were distributed outside the cold-water coral protection area (EC, 2008b; NEAFC, 2007, 2008). At each station, two different experimental bottom longlines (monofilament type and multifilament type; Table 2) were deployed at similar depths, by means of a manual longlining method (Bjordal & Løkkeborg, 1996). The choice of the gears is related with the objective to sample fish distributed at various depths near the bottom. The monofilament longline was designed modifying a gear to catch hake while a multifilament one was designed modifying a gear to catch deep-water species (Piñeiro *et al.*, 2001). With the aim to reduce negative impact of the study, a relatively limited number of longlines (38) and hooks (65,430) were deployed. Hooks of relatively small size were used with the purpose to sample a wide size-range of fish. Gears were adapted for deep-water fishing on hard substrates: longlines were attached to a safety line in order to avoid loss of gear if it gets stuck and breaks. The lines were weighted in order to reduce the effects of bottom currents and also to increase sink speed to minimize seabird by-catch. Coordination of deployment of two different gears in the same station was complex, making difficult to obtain the same soak times for both gears. Several seabird by-catch mitigation strategies were used in a combined manner (Figure 2; Table 3). Most of them have been described in the EU regulation applicable to Antarctic fisheries (EC, 2004). Control settings without any means of preventing seabird by-catch were not carried out, because the objective was to avoid by-catch using simple solutions (Hall *et al.*, 2000), not to assess their effectiveness, which has been already described (Løkkeborg, 1998, 2003; Weimerskirch *et al.*, 2000; Løkkeborg & Robertson, 2002; Bull, 2007). Longlines were deployed just before dawn (night-setting): one seabird-scaring streamer line was used in combination with minimum lighting, line weighting, thawed baits and appropriate discard management. In order to prevent entanglement due to strong winds, eight longlines were deployed without any scaring strimmer line. Longlines were hauling during the day (day-hauling): an experimental curtain, based on the 'Brickle curtain' (Brothers *et al.*, 1999) was always used in combination with appropriate discard management.

Data collection and analysis

Two scientific observers experienced in deep-water fisheries were onboard the vessel. At each station, they recorded information on: (i) longline characteristics, number of hooks deployed, location, time and depth for setting and hauling; (ii) landings and discards in weight (iii) fish length; (iv) by-catch of benthic invertebrates; and (v) behaviour/by-catch of seabirds. Any litter and gillnets found were also recorded. Fish and seabirds were identified at the lowest possible taxonomic level using available literature. Photographs were taken for subsequent verification. Invertebrates (hooked/entangled) were recorded, including the epifauna over the substrata collected by the gear. Samples were photographed and preserved in ethanol as 'voucher' specimens for subsequent final identification at the laboratory. Standard measurements of fish species were taken by sex (total length, in the case of deep-water sharks and lotids). In each set, all the individuals of the target species were measured, except when the numbers were excessively large or the individuals were damaged. In this case, a sample was taken randomly. Total catch per unit of effort (CPUE) was calculated as a relative index of abundance, following the equation: CPUE = catch in kg/1000 hooks on the longline. Average depth of each longline was calculated as the arithmetic mean of depth at start, middle and end positions. Despite expected

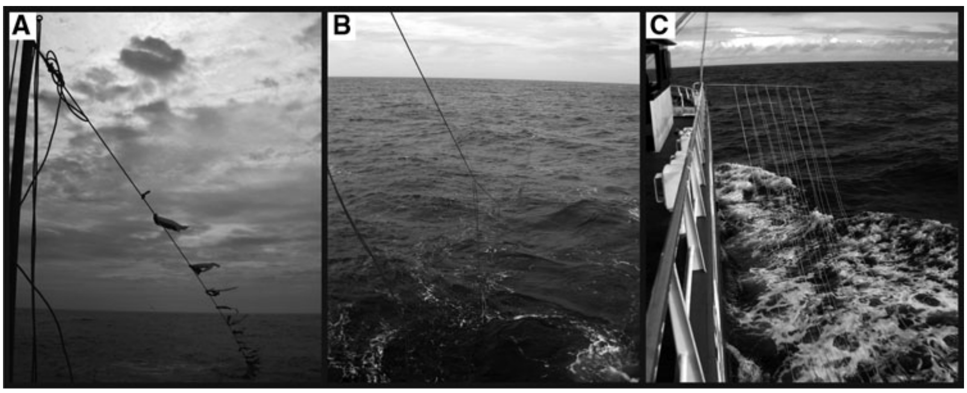

Fig. 2. Photographs showing the seabird mitigation devices. (A) Towed streamer line rigged with tapes; (B) towed streamer line rigged with ropes; (C) experimental curtain for hauling.

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Table 3. Seabird by-catch mitigation strategies used during the survey.

Description	Objective	Comments
Seabird-scaring streamer line: towed scaring line rigged with synthetic brightly coloured tapes	To discourage seabirds from settling on baits during setting	Easier operated than the line of ropes. With strong winds, it could get entangled with the gear
Seabird-scaring streamer line: towed scaring line rigged with synthetic ropes	To discourage seabirds from settling on baits during setting	With strong winds, it could get entangled with the gear
Experimental curtain: steel arm rigged with synthetic ropes forming a curtain around the hauling area	To prevent seabirds from approaching the hooks during hauling	Easy to use, but needs technical improvement
Night-setting and use of minimum vessel lighting required for navigation and safety	To make the vessel less attractive to seabirds during setting	Easy to carry out, at least in summertime south of 60°N
Appropriate discard management: not discharge fish, offal, or spent bait while setting the gear; discharge discards offal or spent bait on the opposite side of the hauler, while hauling	To make the vessel less attractive to seabirds during setting and hauling	Complex to be carried out due to the vessel's traditional configuration
Use of completely thawed baits	To reduce line buoyancy and availability of baits to seabirds during setting	
Line weighting: weights attached to the gear	To increase sink speed of line and to reduce availability of baits to seabirds during setting	The main aim was to reduce the effects of bottom currents

differences in catchability, catch data from the two gears were pooled in order to simplify analyses. Spanish multidisciplinary surveys (undertaken between 2005 and 2007) on the western slope of Hatton Bank (Durán Muñoz *et al.*, 2009) provided data used in this study.

RESULTS

Catch composition and discards

Catch composition is presented in Tables 1, 4, 5 & 6. Deep-water sharks (Scyliorhinidae, Pseudotriakidae, Dalatiidae and Centrophoridae) dominated the catches and contributed with 80.4% in terms of weight. This was due mainly to the predominance of *Centrophorus squamosus* and *Centroscyllium fabricii* (Reinhardt, 1825). Lotids (Lotidae), *Molva dypterygia* and *Brosme brosme*, were the predominant teleosts in terms of weight (13.1%). Cnidarians were the clearly dominant invertebrates, particularly the stony corals (colonial Scleractinea), *Madrepora oculata* (Linnaeus, 1758), *Lophelia pertusa* (Linnaeus, 1758) and to a lesser extent *Solenosmilia variabilis* (Duncan, 1873). They contributed 0.9% in terms of weight. In terms of catch composition by gear (Table 4), 53.6% of the catches of sharks in weight were obtained with the multifilament longline. In the case of lotids and stony corals, catches from the monofilament longline represented 71.5% and 61.1% of the total weight captured of these taxa respectively.

Table 4. Values of catch per unit effort (CPUE) (kg/1000 hooks) obtained in the Hatton Bank area, by taxa and sampling block. For each taxon, the contribution to the total catch in weight (kg) and percentage (%) is presented. Percentages of total catch obtained with monofilament gear (%Mn) and multifilament gear (%Mt) are also given. Values < 0.1 are noted as +. Taxa are listed by weight.

		CPUE (kg/1000 hooks)								Catch			
		1	2	3	4	5	6	7	8	Kg	%	%Mn	%Mt
Elasmobranchs	Deep-water sharks	105.6	28.9	260.4	306.9	202.7	158.4	128.3	84.6	10,686.5	80.4	46.4	53.6
	Skates	1.1	2.6	11.9	2.5	1.0	1.2	0.2	1.6	192.3	1.4	69.5	30.5
Teleosts	Lotids			29.8	60.8	65.5	30.7	14.6	13.6	1,736.4	13.1	71.5	28.5
	Morids	2.0	2.8	0.8	8.7	27.1	6.5	1.2	0.1	350.0	2.6	79.8	20.2
	Others	3.0	12.6	4.2	0.1		0.4	0.5	0.1	147.9	1.1	96.1	3.9
Holocephals	Chimerids				0.3	0.9	0.5	0.3	1.3	27.2	0.2	58.4	41.6
Total fish		111.7	47.0	307.1	379.4	297.2	197.8	145.1	101.2	13,140.2	98.9	51.5	48.5
Cnidarians	Stony corals	0.2		0.5	6.6	9.3	0.1	0.2		114.9	0.9	61.1	38.9
	Cup corals	+	+	+	+	0.1	+	+	+	1.8	+	66.1	33.9
	Sea pens						+	+	0.1	1.8	+	70.0	30.0
	Black corals	+		+		0.2				1.5	+	93.8	6.2
	Gorgonians	0.1	+	+	+	0.1	+		+	1.3	+	35.3	64.7
	Soft corals				+	+			+	0.2	+	21.3	78.7
	Lace corals				+	0.1				0.8	+	97.8	2.2
	Others	+	0.2	+	+	+	+	0.1	0.1	3.1	+	85.5	14.5
Molluscs			+	0.1	0.1		0.2	0.1	0.3	8.0	0.1	73.0	27.0
Arthropods		0.5	0.2	+	+	+	0.2			6.5	+	87.9	12.1
Sponges		+	+	+	+	+	+	+	0.3	3.5	+	65.8	34.2
Echinoderms		0.1	0.1	+	+	+	+	+	0.1	2.8	+	60.4	39.6
Others				+	+	+	+		+	0.1	+	81.0	19.0
Total invertebrates		0.9	0.6	0.7	6.9	9.8	0.5	0.5	1.0	146.3	1.1	64.0	36.0

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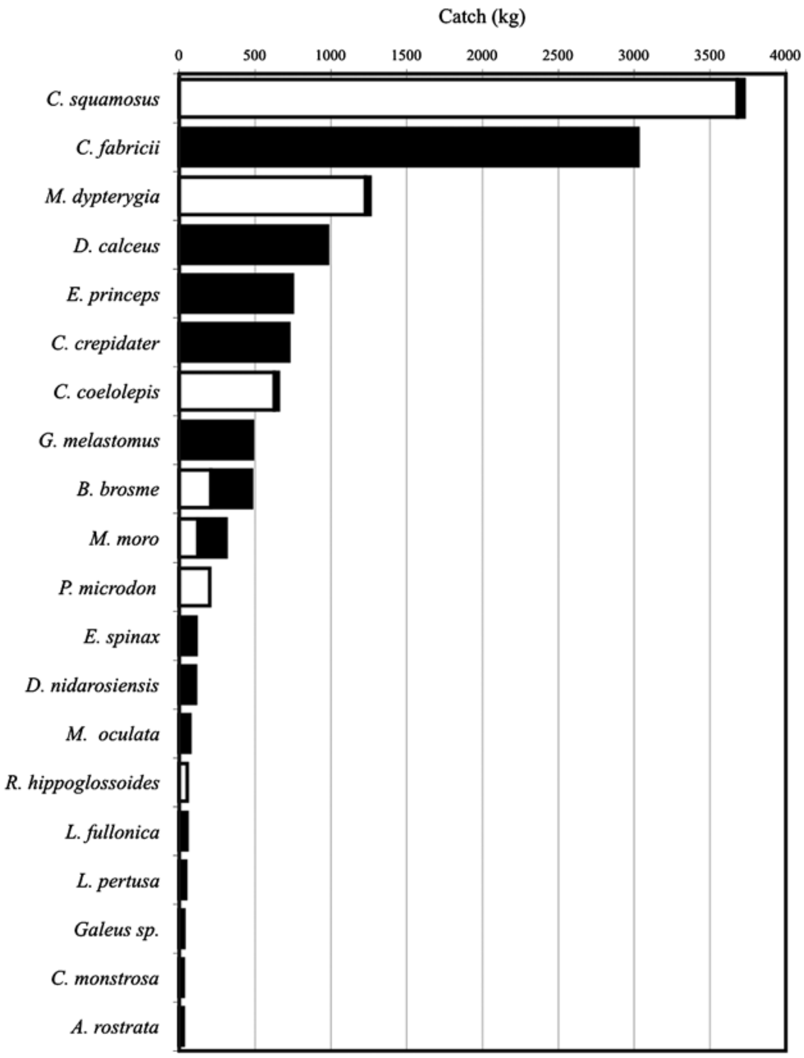

Fig. 3. Discarded (white) and retained (black) fractions for the main species (total catch >25 kg) in terms of weight. The species are listed by total catch.

Discards represented 54% of the total catch in terms of weight. The discarded and retained fractions for the species with total catch greater than 25 kg are presented in Figure 3. Discards were dominated by deep-water sharks that contributed nearly 84% of total weight discarded. Discards were composed of non-commercial species as well of individuals from the commercial ones, discarded due to damages caused by amphipods and predators.

Distribution patterns of vulnerable, threatened and/or declining fish species

Table 4 and Figure 4 present CPUE values for main taxa. Deep-water sharks and lotids show high values along the western slope and south-eastern flank of the Hatton Bank. Morids (Moridae) and holocephals (Chimeridae) were abundant along the western slope, while skates (Rajidae) were caught along the whole study area. All other species were pooled in a group of 'others'. It was more abundant in the south. *Centrophorus squamosus* and *Centroscymnus coelolepis* occurred along the study area in deep waters (Figure 5). The first was caught predominantly on the western slope of the Hatton Bank (blocks 4, 5 and 6) at depths ranging from 750 to 1200 m, while the second was more abundant on the south-eastern flank (block 3) and Central Area (block 4) at depths from 1000 to 1200 m, being absent in shallow depths (<1000 m). *Molva dypterygia* and *Brosme brosme*, were also more abundant along the Hatton Bank (Figure 5), but *Brosme brosme* was absent on the north-eastern flank (block 8). Lotids were not found south to 57°N (blocks 1 and 2). Highest CPUE values for both species were obtained at shallow depths (<1000 m) on the western slope (blocks 4, 5 and 6). Length-range and mean length for these four vulnerable species are presented in Table 5, showing that longline catches were composed of large individuals.

Distribution patterns of vulnerable benthic invertebrates

Deep-water sponges (demosponges and hexactinellids) and cold-water corals (reef builders and coral garden components) were identified in longline by-catch (Tables 1, 4 & 6; Figure 6). According to the FAO (2009), these are examples of taxa which may contribute to forming VMEs. Coral by-catch occurred when longlines were deployed along the western flank of the Hatton Bank. Stony corals (colonial Scleractinia) were recorded in the Central Area (block 4) and the Ridges and Mounds Area

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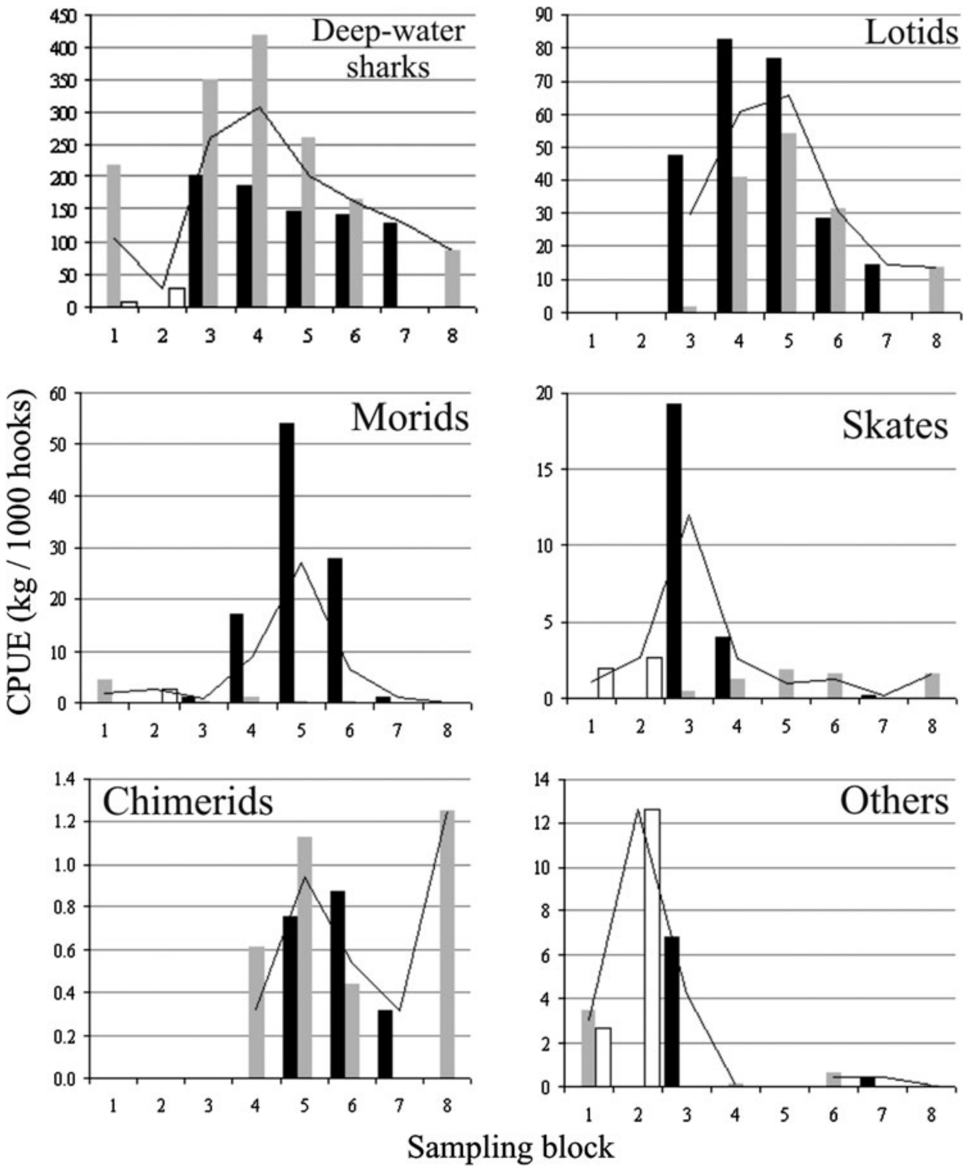

Fig. 4. Values of catch per unit of effort (kg × 1000 hooks) for the main taxa of fish, by depth strata (black bars, <1000 m; grey bars, 1001–1200 m; white bars, >1201 m; black line, total) and sampling block.

(block 5). Cup corals (solitary Scleractinia), gorgonians such as bamboo corals and seafans (Gorgonacea), soft corals (Alcyonacea), black corals (Antipatharia), and lace corals (Stylasteridae), were also captured. Although corals occurred between 850 and 1150 m depth, stony corals by-catch was higher at shallow depths (<1000 m). In the North-western Area (block 6) stony corals were also recorded, in addition to gorgonians and cup corals. The strict outcrop was a suitable hard substratum to most vulnerable species, but some of them are associated with a sandy-mud deposit (drift) that sometimes slightly covers the outcrop (Sayago-Gil *et al.*, 2010). This is possibly why sea pens (Pennatulacea) were observed in this area. Here, corals were obtained at depths from 850 to 1200 m. Stony corals, cup corals and sponges were captured also in the southern part of the bank (block 3). Large hexactinellid sponges that characterize sponge-dominated biotopes (Barthel *et al.*, 1996) on sandy-muddy grounds were recorded in the eastern slopes (blocks 7 and 8) at depths ranging from 800 to 1200 m. Sea pens and cup corals also occurred in such areas at similar depth-range. A small demospongid species was found in block 8 (1100 m depth) while fragile and small hexactinellid glass sponges were found in shallow waters (<1000 m) of the western slopes (blocks 4 and 5). Stony corals, black corals, sponges and particularly gorgonians occurred in the Edoras Bank (block 1) at depths ranging from 1000 to 1200 m. Cup corals were also recorded in this zone (>1200 m depth).

Seabirds

Ten seabird species were identified and their behaviour was recorded (Table 7). *Fulmarus glacialis* was sighted during 23 night-setting operations (61% of the total) flying near the stern end of the vessel, and looking for baited hooks just behind the streamer line. Seabirds were not observed in the remaining night-setting operations: this does not necessarily indicate absence of seabirds, since sightings were very difficult due to darkness in the absence of vessel lights. Seabirds, particularly *Fulmarus glacialis*, were observed near the

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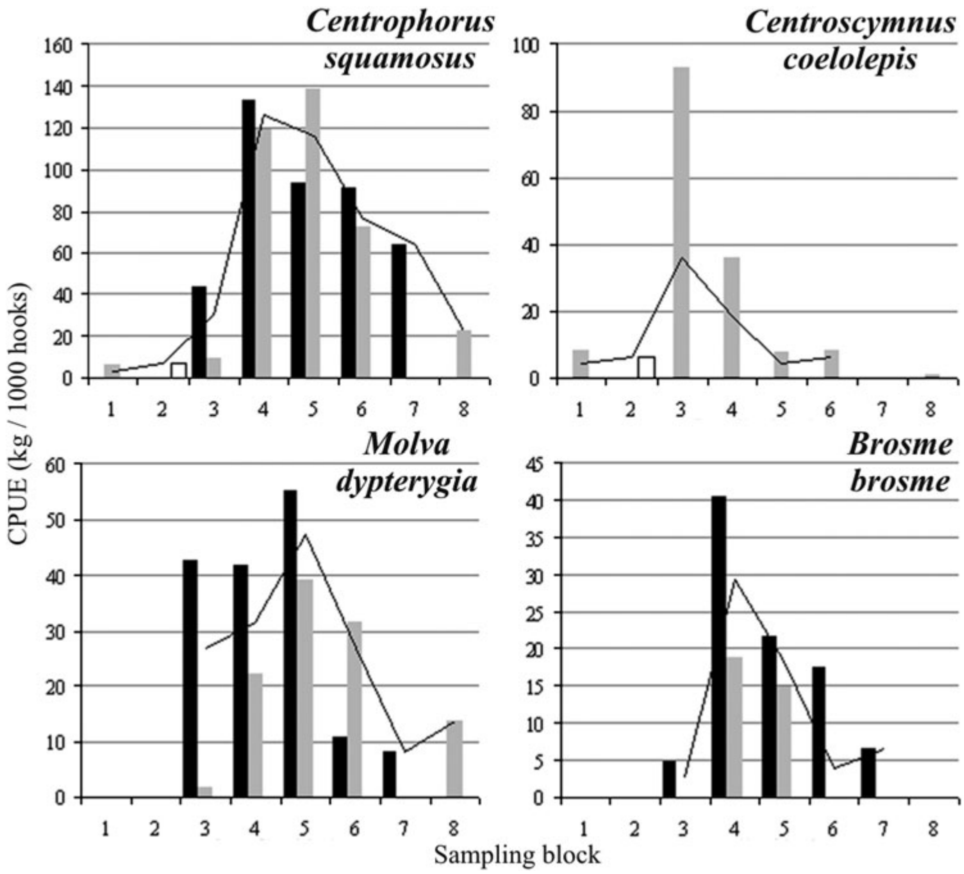

Fig. 5. Values of catch per unit of effort (kg × 1000 hooks) for the main vulnerable deep-water sharks and gadoid species, by depth strata (black bars, <1000 m; grey bars, 1001–1200 m; white bars, >1201 m; black line, total) and sampling block.

vessel during the day-hauling operations. This species was always present during the hauling (sometimes more than 300 estimated individuals). Seabirds waited on the opposite side of the hauler (close to where offal, spent baits and discards were discharged) or were near the line-hauler side, swimming or waiting for fallen fish or fallen bait. One individual of *Fulmarus glacialis* was captured during haul-in operations within block 6. The seabird was freed and it survived.

Extra data on marine litter and derelict deep-sea gillnets

A variety of litter items weighing 13 kg were recovered in the longlines, including some fishery-related items: (i) glass; (ii) plastic; (iii) steel and other metals; and (iv) textile. Fragments of derelict deep-sea gillnets were fished in north-western (block 6) and southern parts of the bank (block 3), a fragment of longline was captured in the north-eastern part (block 8) and a piece of steel rope (trawl rope?) was recovered in shallow block 7. Moreover, an abandoned gillnet was observed in block 7 (800 m depth).

DISCUSSION

Effects on vulnerable fisheries resources

Effects of the longline fishery on fish species are strictly related to the size of hooks, the particular type of longline, the bait, and the feeding behaviour of fish (Bjordal & Løkkeborg, 1996). Here, the catch composition was dominated by deep-water sharks as in previous studies (Clarke *et al.*, 2005; Fossen *et al.*, 2008) suggesting that large deep-water chondrychthyes have high catchability to bottom longlining, in particular in complex coral habitats such as the Hatton Bank outcrop. Sharks and gadoids species may be more abundant in cold-water coral habitats (Table 4) than elsewhere (Husebø *et al.*, 2002; Costello *et al.*, 2005; Ross & Quattrini, 2007; Buhl-Mortensen *et al.*, 2010). The length distributions observed in the catches when compared with minimum size of sexual maturity, indicates that in the study area, summertime longline catches of both *Centrophorus squamosus* and *Centroscymnus coelolepis*, were mainly composed of large individuals. Longlines were rigged with relatively small hooks, but small individuals of both shark species were not caught as in previous studies based upon trawl and longline catches (Girard & Du Buit, 1999; Clarke *et al.*, 2002; Bañón *et al.*, 2006). *Centrophorus squamosus* ranged in length from 82 to 138 cm (ML = 104.5 cm, N = 516). Only two individuals were larger than 128 cm, the size of female maturation, but 70% of the individuals measured were larger than 101 cm in length, the size of male maturation (Clarke *et al.*, 2002). With regard to *Centroscymnus coelolepis* (LR = 74–116 cm, ML = 104.8 cm, N = 59), 72% of the individuals were larger than 102 cm in length, the size of female maturation (Girard & Du Buit, 1999). Length-ranges of sharks captured with longlines were narrower than those reported previously based upon trawl catches (Girard &

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Table 5. Deep-water sharks and lotids captured with longlines in the Hatton Bank area. For each species, the number of longline sets (S) where the species was encountered and the catch in weight (kg) in each sampling block are given (values < 0.1 are noted as +). For the vulnerable species referred to in the text, information on length-range (LR) and mean length (ML) in cm, and number of individuals measured (N) is presented.

		1		2		3		4		5		6		7		8		Total				
		S	kg	S	kg	S	kg	S	kg	S	kg	S	kg	S	kg	S	kg	S	kg	LR	ML	N
Scyliorhinidae	*Galeus melastomus*					2	271	2	1	2	11	2	7	4	193			12	483			
	Galeus sp.	1	+			3	5	4	6	3	3	1	1	5	5	4	11	21	31			
	Apristurus sp.					1	6											1	6			
Pseudotriakidae	*Pseudotriakis microdon*							1	200									1	200			
Dalatiidae	*Centroscyllium fabricii*	4	257	4	62	4	838	4	586	2	136	4	621	3	145	4	381	29	3026			
	Centroscymnus coelolepis	1	23	2	41	2	357	2	137	1	25	3	65			1	7	12	654	74–116	104.8	59
	Centroselachus crepidater					5	119	3	233	4	173	4	59	6	60	4	79	26	723			
	Etmopterus sp.	3	314	4	36	4	207	3	119	3	90	3	14	4	78			24	858			
Centrophoridae	*Centrophorus squamosus*	2	16	3	39	6	304	4	920	4	723	6	759	6	791	4	174	35	3726	82–138	104.5	516
	Deania calceus					4	474	3	37	2	98	2	52	5	318			16	979			
Lotidae	*Molva dypterygia*					5	266	4	230	4	292	6	266	6	99	3	105	28	1259	70–136	95.1	356
	Brosme brosme					2	29	4	213	3	114	2	40	3	82			14	478	50–94	66.9	104

Du Buit, 1999; Clarke *et al.*, 2005). Catches of lotids were also preferentially composed of large and adult individuals. 80% of *Molva dypterygia* (LR = 70–136, ML = 95.1 cm, N = 356) were larger than 88 cm in length, the size of female maturation (Magnusson & Magnusson, 1995). In the case of *Brosme brosme* (LR = 50–94, ML = 66.9 cm, N = 104), all of the individuals were larger than 45 cm, the maturity size for both sexes (Magnusson *et al.*, 1997). Longlines appear to select for larger lotids than commercial trawls (ICES, 2009).

The high discard ratio observed during the experimental survey, was a consequence of the longline catch composition in the outcrop area: catches were largely dominated by deep-water sharks, which have low market interest, except *Centrophorus squamosus* and *Centroscymnus coelolepis*, the main retained species. Among teleosts, only *Molva dypterygia*, *Brosme brosme* and a few other species captured such as *Mora moro* (Risso, 1810), *Reinhardtius hippoglossoides* (Walbaum, 1792), *Lophius piscatorius* (Linneaus, 1758) and *Aphanopus carbo* (Lowe, 1839) have currently commercial interest in longline fisheries. The current ban of deep-water shark fisheries, as well as the restrictive quotas for other commercial deep-sea species (EC, 2008a) suggests that bottom longlining in the Hatton Bank cannot be profitable now because the main catch can no longer be marketed.

Effects on benthic habitat

Chuenpagdee *et al.* (2003) indicate that the level of by-catch and the habitat impact associated with demersal longlines is moderate. However, the present longline survey agrees with previous studies (Bavestrello *et al.*, 1997; Butler & Gass, 2001; Krieger, 2001; Witherell & Coon, 2001; Fosså, *et al.*, 2002; Krieger & Wing, 2002; Reed, 2002; Gass & Willison, 2005; Mortensen *et al.*, 2005, 2008; Orejas *et al.*, 2009) suggesting that bottom longlining has negative impact on VMEs when their distributions overlap with the fishing grounds. In the presence of strong currents, large weights were required for bottom longlining, and such weights can also damage corals as Reed (2002) suggests. Equally, weighting lines to increase sink speed to minimize seabird by-catch can also contribute to entangling on corals. In the present study, movements of the longlines over the seabed were often recorded. This suggests bigger impacts of strong currents dragging the lines across the bottom causing coral entangling, as was indicated previously by Clark & Koslow (2007). Even though bottom longlines are expected to be much less damaging to corals than trawls, it may still represent a threat if fishing intensity is high (Bavestrello *et al.*, 1997; Mortensen *et al.*, 2005). An additional concern is the ability to use longlines to fish rocky areas that are inaccessible to trawls. The present survey indicates that the Hatton Bank outcrop is a key area for VMEs indicator species (cold-water corals and sponges; Table 6) as was reported in previous studies (Roberts *et al.*, 2008; Durán Muñoz *et al.*, 2009; Howell *et al.*, 2010). By-catch data confirm the presence of VMEs within the current NEAFC cold water coral protection area (EC, 2009; NEAFC, 2010), but also suggest some areas of VME indicator species close to the current closure boundary, further suggesting some revision of closure boundaries should be considered.

Table 6. Vulnerable marine ecosystems indicator species captured with longlines in the Hatton Bank area. For each species, the number of longline sets (S) where the species was encountered and the catch in weight (kg) in each sampling block are given (values < 0.1 are noted as +).

		1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**Total**	
		S	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**	**S**	**kg**
Porifera	Porifera indeterminate	1	+	2	+	2	+	4	+	2	+	1	+	2	+	4	1	18	2
	Tentorium sp.	1	+															1	+
	Radiella sp.															1	+	1	+
	Pheronema carpenteri													1	+	2	1	3	1
	Euplectella sp.			1	+					1	+							2	+
	Aphrocallistes sp.							1	+	3	+							4	+
Gorgonacea	Gorgonacea indeterminate	1	+	1	+			1	+									3	+
	Acanthogorgia sp.									1	+							1	+
	Acanella sp.							1	+									1	+
	Isidae indeterminate	1	1							1	+							2	1
	Plexauridae indeterminate	1	+			1	+	1	+	2	+					1	+	6	1
	Callogorgia verticillata					1	+					1	+					2	+
	Primnoa resedaeformis							1	+									1	+
Pennatulacea	Pennatulacea indeterminate													1	+	1	+	2	+
	Anthoptilum murrayi											1	+					1	+
	Halipteris sp.											1	+	2	+	2	1	5	1
	Pennatula sp.											1	+			1	+	2	+
	Umbellula sp.													1	+	2	+	3	+
Alcyonacea	*Capnella florida*							2	+	2	+							4	+
	Nephtheidae indeterminate									2	+					1	+	3	+
Antipatharia	Antipatharia indeterminate	1	+			1	+			2	1							4	1
	Stichopathes sp.					1	+			1	+							2	+
Scleractinia	Scleractinia indeterminate													1	1			1	1
	Caryophyllia sp.					3	+	4	+	3	+	2	+			1	+	13	+
	Desmophyllum sp.					1	+	2	+	2	+							5	+
	Lophelia pertusa					3	+	2	35	3	6			2	2			10	43
	Madrepora oculata					1	4	3	13	3	52	1	1	1	1			9	70
	Solenosmilia variabilis	1	1									1	+	1	+			3	1
	Stephanocyathus moseleyanus					3	+	1	+	2	+			2	+	1	+	9	1
	Flabellum alabastrum	1	+	1	+													2	+
Hydrozooa	Stylasteridae indeterminate							1	+	2	1							3	1

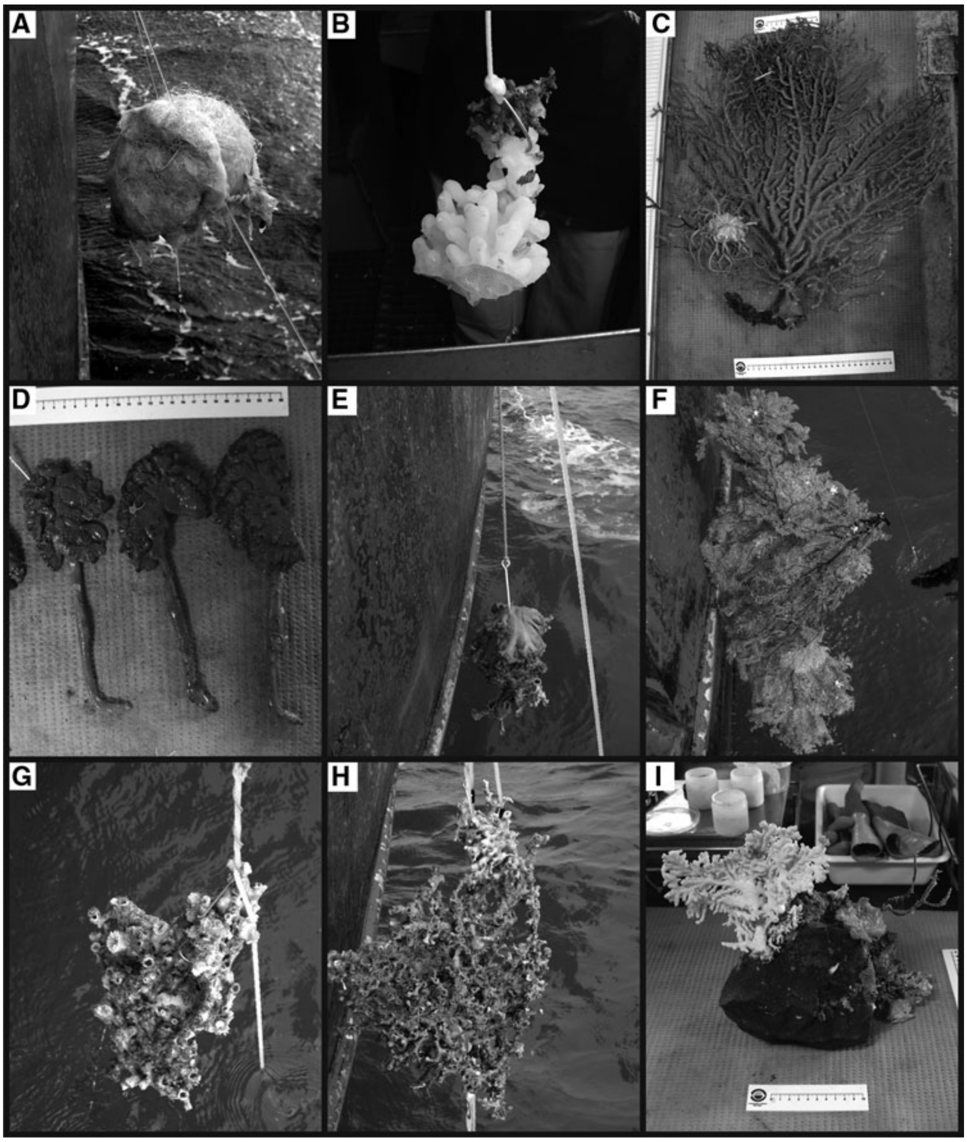

Fig. 6. Photographs showing some examples of vulnerable marine ecosystems indicator species captured. (A) Large hexactinellid sponge; (B) small glass sponge; (C) gorgonian; (D) sea pens; (E) soft coral; (F) black coral; (G) cup corals over coral skeletons; (H) stony corals; (I) lace coral.

Table 7. Seabirds observed in the Hatton Bank area and interactions with longlining. For each species the setting/hauling operations in which the species was observed are presented, in number (N) and percentage (%). Seabird behaviour during hauling is summarized: feeding fishing waste and generally in front of the hauling area feeding fall fish/baits (very active), feeding fishing waste following the vessel (moderately active), feeding fishing waste following the vessel, but generally far away (few active), interaction was not observed (no interaction). Seabird by-catch and other observations are also given (no by-catch is noted as *).

	Setting		Hauling				
Species	N	%	N	%	Seabird behaviour	By-catch	Comments
Fulmarus glacialis	23	61	38	100	Very active	1 individual	Captured during hauling and released live
Larus fuscus			23	61	Moderately active	*	
Puffinus griseus			11	29	Few active	*	
Puffinus gravis			4	11	Few active	*	
Rissa tridactyla			4	11	Few active	*	
Stercorarius skua			4	11	Very active	*	
Larus hyperboreus			3	8	Moderately active	*	
Morus bassanus			1	3	No interaction	*	
Stercorarius longicaudus						*	Sighted during navigation
Hydrobates pelagicus						*	Sighted during navigation

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Interactions with seabirds

As in previous studies (Bertellotti & Yorio, 2000; Weimerskirch *et al.*, 2000), here it was observed that discharged discards and offal are attractive as a food source for seabirds (particularly scavengers) and possibly have a positive effect on population size trends as Furness (2003) suggests. But by-catch can cause direct mortality in *Fulmarus glacialis* and reduce their abundance. The survey showed that seabirds can also be accidentally captured during hauling (however they can be easily released alive). Nevertheless, seabird scaring-strimmer lines and curtains used in combination with the operational measures described in the literature (Bull, 2007) can reduce seabird by-catches. Most of these mitigation strategies used have been successfully implemented in other high seas areas (e.g. the Antarctic), and could be used in the NEAFC Regulatory Area. Mitigation devices are simple, economic to manufacture by the crew, and easy and safe to use, at least in summertime south of 60°N. The traditional longliner configuration needs to be improved in order to manage discards and offal better (the ability to discharge offal on the opposite side of the hauler is recommended).

Other environmental issues

Most of the encounters with litter were recorded on the eastern slope of the Hatton Bank. Litter, particularly plastics, can produce damage on diverse marine fauna (Hutton *et al.*, 2008; Graham & Thompson, 2009). Hess *et al.* (1999) suggest that distribution of benthic litter possibly may be due to hydrodynamic circulation and human activity patterns. Despite the ban of gillneting in deep-waters of the NEAFC Regulatory Area (NEAFC, 2006; EC, 2007), a derelict deep-sea gillnet was observed there. This suggests that retrieval exercises to recover gillnets would be welcome in order to prevent 'ghost fishing' (Matsuoka *et al.*, 2005) on the rocky bottoms of the Hatton Bank, but gillnet-retrieval gears (Large *et al.*, 2009) could produce damage to vulnerable benthos.

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