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Distribution of deep-water corals of the Flemish Cap, Flemish Pass, and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): interaction with fishing activities

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The distribution of deep-water corals of the Flemish Cap, Flemish Pass, and the Grand Banks of Newfoundland is described based on bycatch from Spanish/EU bottom trawl groundfish surveys between 40 and 1500 m depth. In all, 37 taxa of deep-water corals were identified in the study area: 21 alcyonaceans (including the gorgonians), 11 pennatulaceans, 2 solitary scleractinians, and 3 antipatharians. The greatest diversity of coral species was on the Flemish Cap. Corals were most abundant along the continental slope, between 600 and 1300 m depth. Soft corals (alcyonaceans), sea fans (gorgonians), and black corals (antipatharians) were most common on bedrock or gravel, whereas sea pens (pennatulaceans) and cup corals (solitary scleractinians) were found primarily on mud. The biomass of deep-water corals in the bycatches was highest in previously lightly trawled or untrawled areas, and generally low in the regularly fished grounds. The information derived from bottom-trawl bycatch records is not sufficient to map vulnerable marine ecosystems (VMEs) accurately, but pending more detailed habitat mapping, it provides a valuable indication of the presence/absence of VMEs that can be used to propose the candidate areas for bottom fishery closures or other conservation measures.

Keywords: deep-water corals, fishing impact, Marine Protected Areas, NAFO, Northwest Atlantic Ocean, vulnerable marine ecosystems.

Introduction

Deep-water corals can be found worldwide along shelf breaks, on continental slopes, seamounts, and mid-ocean ridges (Freiwald *et al*., 2004) and, because they increase habitat complexity, they are important components of deep-water ecosystems (Tissot *et al*., 2006). Increased complexity provides feeding and spawning sites (Mortensen *et al*., 2005; Etnoyer and Warrenchuk, 2007) and sources of shelter for invertebrates and fish (Fosså *et al*., 2002; Krieger and Wing, 2002; Reed, 2002); hence, some deep-water corals are considered to be essential fish habitats (EFHs; Etnoyer and Morgan, 2003). In general, coral habitats in deep water represent biodiversity hotspots for invertebrates (Jensen and Frederiksen, 1992; Fosså *et al*., 2002; Reed, 2002; Jonsson *et al*., 2004; Buhl-Mortensen and Mortensen, 2005), and commonly support a high abundance of fish (Breeze *et al*., 1997; Koenig, 2001; Husebø *et al*., 2002; Costello *et al*., 2005; Stone, 2006; Edinger *et al*., 2007b).

The most vulnerable marine ecosystems (VMEs) are ones that are both easily disturbed and very slow to recover, or may never recover. Vulnerable ecosystem features may be physically or functionally fragile. According to this definition (FAO, 2009), and taking into account their fragile, three-dimensionally complex structure, some deep-water corals constitute VMEs (Fuller *et al*., 2008). The structural characteristics, slow growth rates, and long-lived nature of corals (Stone and Wing, 2001; Risk *et al*., 2002; Andrews *et al*., 2009; Sherwood and Edinger, 2009) make them especially vulnerable to damage by the mechanical impacts of bottom fishing activities (Watling and Norse, 1998; Koslow *et al*., 2001; Krieger, 2001; Hall-Spencer *et al*., 2002; Heifetz *et al*., 2009). Therefore, deep-sea coral populations damaged by fishing gear will take many decades or centuries to recover (Andrews *et al*., 2002; Althaus *et al*., 2009; Sherwood and Edinger, 2009).

There is international consensus that fisheries management needs to be based on an ecosystem approach. An ecosystem approach requires that fisheries managers consider the interactions between fish populations and their habitats, and wider ecosystem effects of fishing operations. The most effective ecosystem-based fisheries management systems have mechanisms whereby basic knowledge of ecosystems is communicated effectively to decision-makers and stakeholders (George *et al*., 2007). The United Nations General Assembly calls for Member States and Regional Fisheries Management Organizations (RFMOs) to take measures to protect vulnerable ecosystems in the high seas, by instituting conservation measures, such as Marine Protected Areas (MPAs) (UNGA, 2005, 2006). These may be essential to protect marine biodiversity and ensure sustainable fisheries (Laffoley, 2008).

To protect deep-sea corals effectively, their distribution patterns must be understood. Records of deep-sea corals in Atlantic Canada have been collected since the late nineteenth century, but only recently have researchers and conservationists taken an interest in this group of species (Breeze *et al*., 1997; MacIsaac *et al*., 2001; Mortensen and Buhl-Mortensen, 2004; Gass and Willison, 2005; Watling and Auster 2005; Bryan and Metaxas, 2006; Mortensen *et al*., 2006; Edinger *et al*., 2007a; Gordon and Kenchington, 2007; Wareham and Edinger, 2007; Cogswell *et al*., 2009). Managing the deep-water ecosystems by RFMOs is difficult, as most of the studies have been undertaken in the Canadian Economic Exclusive Zone (EEZ), with scarce information from international waters (Edinger *et al*., 2007a; Wareham and Edinger, 2007).

In this paper, the distribution, biomass, and species richness of deep-water corals of the Flemish Cap, Flemish Pass, and the "tail" and "nose" of the Grand Banks of Newfoundland has been studied. Our research is based on bycatch data from 2005 to 2007 bottom-trawl Spanish/EU surveys, and fills some gaps in the knowledge on the deep-water coral distributions in the international waters of the Northwest Atlantic Ocean. Currently, and pending a proper habitat mapping exercise, the information presented in this document is already being used, along with Canadian data, by the Northwest Atlantic Fisheries Organization (NAFO) as baseline data to identify candidate VME areas in the NAFO Regulatory Area (NAFO, 2008a, b), for the subsequent adoption of suitable habitat conservation measures to preserve deep-water corals.

Material and methods

Study area

The Flemish Cap is a plateau of approximately 200 km width with depths of <150 m in its centre, situated eastward of the Grand Banks of Newfoundland and separated from them by the approximately 1200-m-deep Flemish Pass (Figure 1). The Grand Banks of Newfoundland are on the Canadian continental shelf and they stretch beyond 200 nautical miles (Canadian EEZ) off the coastline.

The Flemish Cap is located within an area of transition between cold subpolar waters, influenced by fluctuations in the Labrador Current and in the North Atlantic Current (Gil *et al*., 2004). The Grand Banks shelf is separated from the Flemish Cap by the cold southward flow of the Labrador Current (Colbourne and Foote, 2000). Compared with the Grand Banks, the Flemish Cap can support a higher primary and secondary production as a result of its hydrodynamic conditions (Maillet *et al*., 2005).

Most of the Flemish Cap is covered with muddy sand and sandy mud, although in its centre a patch of sand is found. Stones are scattered in the entire area. The Flemish Pass has sandy mud with accumulations of pebbles and stones apparently deposited by icebergs floating along this course. The Grand Banks shelf is <100 m deep and has a sandy and gravelly or pebbly bottom; the eastern slope has sand to 200–250 m, muddy sand to 700–800 m, and sandy mud deeper than 1500 m (Litvin and Ravchev, 1963).

Data sources: surveys

Data used in this study came from four different bottom-trawl groundfish surveys carried out by the Instituto Español de Oceanografía (IEO) and the European Union (EU): (i) the Spanish 3NO survey sampled the "tail" of the Grand Banks of Newfoundland (NAFO Divisions 3NO) between 40 and 1500 m; (ii) the EU Flemish Cap survey sampled all the Flemish Cap (NAFO Division 3M), and currently a depth range between 130 and 1450 m; (iii) the Spanish 3L survey sampled the "nose" of the Grand Banks of Newfoundland and the Flemish Pass (NAFO

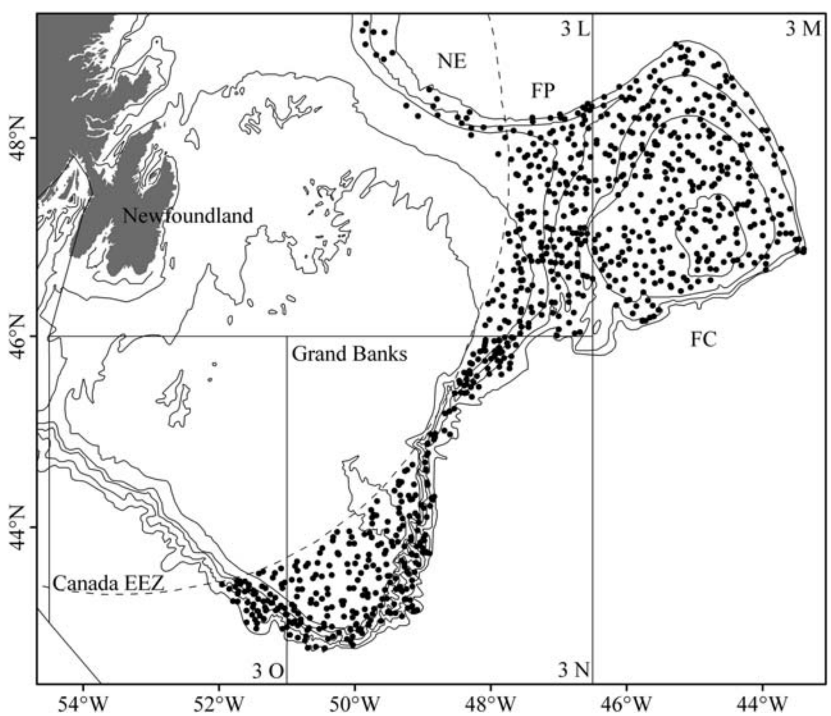

Figure 1. Map of sampling locations on the eastern Canadian continental shelf and slope (NAFO Divisions 3LMNO). Bathymetric curves were obtained from the General Bathymetric Chart of the Oceans (IOC *et al*., 2003). The depth contours indicate 50, 100, 200, 500, 1000, and 1500 m. FC, Flemish Cap; FP, Flemish Pass; NE, northeastern slope of the Grand Banks.

Division 3L) between 110 and 1450 m; (iv) the exploratory survey in NAFO Division 3L (inside Canada's EEZ) sampled part of the continental slope of the northeast of the Grand Banks within the Canadian EEZ between 300 and 1500 m depth. These surveys were carried out between spring and summer, using a random-stratified sampling design with standardized 30-min tows and vessel speed of 3 knots. Since the start of these multiannual efforts, several different oceanographic vessels have been used. Since 2003, however, all surveys were run on the Spanish RV "Vizconde de Eza".

A Campelen 1800 bottom-trawl gear was used in the Flemish Pass and the Grand Banks of Newfoundland (Divisions 3LNO) with a 20-mm codend mesh size and a 24-m swept width, whereas a Lofoten bottom-trawl gear was used in the Flemish Cap (Division 3M) with a 35-mm codend mesh size and 14-m swept width. The mean swept area for the Camplen trawl is 6.7 ha and for the Lofoten is 3.9 ha. Catchabilities for fish species have been described (Vázquez, 2002), but no studies for sessile species are available. Despite the different nature of the groundrope between gears, the behaviour of the gear in a coral encounter seems to be similar. Because a comparative study of catchability of the gears for sessile species was not available, we assumed that this difference did not affect significantly the catchability of corals. Difference in mesh size within the codend (20 mm for the Campelen, and 35 mm for the Lofoten) is unlikely to be important for most of the coral species considered, except the smaller sea pens and smaller cup corals. The most important factor influencing the catchability of corals is the different path swept by the gears, and to remove this effect from the analyses, the results were expressed as biomass per area swept by the gear (kg ha^{-1}). We caution that measurements of coral biomass per unit seabed area will require *in situ* observations (Edinger *et al.*, 2007b), and these data are expressed in this way to pool the data from both gears for analytical purposes only.

Analyses were based on deep-water corals recorded during 2005–2007 on the "tail" of the Grand Banks, 2006–2007 on the Flemish Cap, Flemish Pass, and "nose" of the Grand Banks, and 2007 within Canadian waters on the northeastern slope of the Grand Banks. In all, 910 tows were carried out in the area and period considered (Figure 1) as follows: 349 for the "tail" of the Grand Banks (Divisions 3NO), 355 for the Flemish Cap (Division 3M), and 180 for the Flemish Pass and "nose" of the Grand Banks (Division 3L). Finally, 26 tows carried out within Canadian waters in 2007, along the continental slope (Division 3L) were examined.

Coral data matrix

Corals were recorded and weighed on board, and some samples were preserved for later examination in 2005 and 2006. A more detailed invertebrate sampling was undertaken during the 2007 surveys, under the IEO-ECOVUL/ARPA interdisciplinary project, and corals were recorded, weighed, and preserved as vouchers for subsequent definitive identification in the laboratory. To show all the data at the same level, we have grouped all the deep-water corals into five groups: soft corals (Alcyonacea), gorgonians (Alcyonacea), sea pens (Pennatulacea), black corals (Antipatharia), and cup corals (Scleractinia). For convenience, the order Alcyonacea was divided into soft corals and gorgonians to study their distribution separately, because they have different structural characteristics and vulnerability to fishing activities. Depth ranges were recorded by five depth intervals: <300, 300 to <600, 600 to <900, 900 to 1200, and >1200 m. Coral samples from 2007 were identified to species level whenever possible, and these data were used to study the richness of the coral species in the study area. The location of the coral records was assigned to the start position of the survey fishing tows.

Table 1. Substratum types based in Wentworth grade classification.

Type	Description	Criteria
Mud (M)	Clay and silt	<0.062 mm
Sand (S)	Fine sand to medium clean sand	0.062–0.5 mm
Sand–Shell (SS)	Fine sand to medium sand with shells	0.062–0.5 mm with shell fragments
Sand–Granules (SG)	Fine sand to medium sand with granules	0.062–0.5 mm with granules (2–4 mm)
Coarse sand (CS)	Coarse sand to granules	0.5–4 mm
Pebbles–Cobbles (PC)	Pebbles and cobbles	4–256 mm

Substrata

Substrata of the bottom trawled were studied in 2007 surveys by a sediment collector consisting of a stainless steel cylinder (30 × 14 cm) with one end closed that was incorporated into the trawl, and a modified version (60 × 14 cm) was used in 2008. No changes in sediment distribution between 2007–2008 and 2005–2006 are assumed. The sediment collector was tested in several places with both trawls. The best results were obtained when the collector was placed behind the delta plate of the Campelen groundrope, and after the bumper bobbin in the Lofoten groundrope. A preliminary visual classification was carried out in accordance with an approximation to the Wentworth grade classification (Buchanan, 1985). The substrata identified are listed in Table 1.

Fishing activities

Currently, there are four bottom fisheries in the study area (Bensch *et al.*, 2008): a fishery for Greenland halibut, the main fishery, distributed along the continental slope (700–2000 m depth) of the Flemish Cap, Flemish Pass, and "nose" and "tail" of the Grand Banks (Campanis *et al.*, 2008); a skate fishery takes place primarily on the continental shelf on the "tail" of the Grand Banks (Del Río *et al.*, 2003), a shrimp fishery mainly between 300 and 700 m depth in the north of Flemish Cap and 300–400 m depth in the "nose" of the Grand Banks (Casas, 2008), and a redfish fishery in a small portion of the area southeast of the Grand Banks (Vinnichenko and Sklyar, 2008). These international fisheries are conducted in Divisions 3LMNO of the NAFO Regulatory Area (NRA).

To study the interactions between fishing activities and deep-water corals, the Spanish commercial fishing effort (footprint) corresponding to the bottom-trawl fishery in NAFO Regulatory Area (Divisions 3LMNO) was analysed for the period 2001–2006. The fishery information comes from NAFO Observers data. These data represent almost all the total Spanish effort in the study period and the data used here correspond to the bottom fishing activity data recently submitted by all flag States for 2003–2007 (NAFO, 2009a). The Spanish data may be considered a subset of the total fishery effort in the study area. The area of study was divided into 0.05 × 0.05° squares. In all, 48 552 records were used. All the starting tow positions per

Table 2. Bottom-trawl fishing level classification.

Category	Tows per cell	Trawl level
1	0–1	Lightly/never trawled
2	2–20	Moderately trawled
3	>20	Heavily trawled

rectangle were counted, and rectangles resulting were classified into three categories (Table 2).

All the maps were drawn with ArcGIS 9.1 and geographical databases were referenced to the World Geodetic System 1984 (WGS84). Bathymetric curves were exported as shapefiles (ArcMap format) from the General Bathymetric Chart of the Oceans (IOC *et al.*, 2003).

Results

Coral distribution

At least 37 different taxa of deep-water corals were identified (Appendix): 21 alcyonaceans, 11 pennatulaceans, 2 solitary scleractinians, and 3 antipatharians. Deep-water corals were recorded in 627 of the tows (69% of the total tows conducted), mainly between 600 and 1300 m, representing in this depth range more than 75% of the total coral biomass. The mean number of species recorded per tow was 3, and the greatest number of species (14) was obtained in one tow on the northern edge of the Flemish Cap.

Soft corals (order Alcyonacea) were the most common deep-water corals in the area, and occurred in 58% of the tows. They were quite widespread in the area studied (Figure 2a), but most abundant at the shelf break and on the continental slope of the Flemish Cap, the Flemish Pass, and on the northeastern slope of the Grand Banks, between 600 and 900 m depth (Figure 3a). This was because of the presence of *Duva florida* and to a lesser extent *Anthomastus* spp. and some organisms belonging to family Nephtheidae. Main bycatch of soft corals was recorded in the north of the Flemish Cap, around 600–700 m depth, where biomass values between 2 and 5.5 kg ha^{-1} of soft corals were observed. Moreover, in the shallower part (<200 m depth) of the Flemish Cap, *Duva florida* was found in the bycatches reaching more than 2.5 kg ha^{-1} in one tow.

Gorgonians (order Alcyonacea) occurred in 14% of the tows. They were not widely distributed in the study area (Figure 2b). However, they reached the highest average values in the Flemish Pass and northeastern slope of the Grand Banks (Figure 3b) because of high bycatches of some large species with an important structure-forming role, such as *Paragorgia arborea*, *Paragorgia johnsoni*, *Primnoa resedaeformis*, *Paramuricea* spp., and *Keratoisis* sp. The greatest biomass of deep-water gorgonian corals was found between 1200 and 1300 m (Figure 3a) at the south of the Flemish Pass, where *Keratoisis* sp. was recorded in two consecutive tows (10.20 and 1.87 kg ha^{-1}), and two big 1-m-long basal fragments of *Paragorgia arborea* were recorded in another tow. A second area is localized inside the Canadian EEZ, on the northeastern slope of the Grand Banks (Figure 3b), around 700 m depth (Division 3L), where a large number of different gorgonian species (*Paragorgia arborea*, *Primnoa resedaeformis*, and *Paramuricea* spp.) were recorded in a single tow (9.85 kg ha^{-1}). In the southeastern part of the Flemish Cap (Figure 2b), bycatch of gorgonians was lower in terms of biomass than in zones previously mentioned, but large colonies of *Paragorgia johnsoni* and *Paramuricea* spp. (approximately 1 m long) occurred in three consecutive tows. Other smaller gorgonians such as *Acanthogorgia armata*, *Acanella arbuscula*, *Radicipes gracilis*, *Anthothela grandiflora*, *Placogorgia* sp., and *Swiftia* sp. were distributed mainly along the Flemish Cap around 600 and 1000 m depth.

The order Pennatulacea (sea pens) occurred in 36% of the tows, mainly in the northern part of the Flemish Cap and the Flemish Pass (Figure 2c), in the 900–1200-m-depth strata (Figure 3a). They were also abundant in a small area in the southeast of the Grand Banks, where 0.85 kg ha^{-1} of different pennatulaceans were recorded. The most common species found were *Anthoptilum grandiflorum*, *Funiculina quadrangularis*, *Pennatula aculeata*, and *Halipteris finmarchica*.

Antipatharia (black corals) was the order least represented in terms of presence and biomass in the tows analysed (Figure 3b), although some species could also play an important structure-forming role. Three taxa were recorded: *Stauropathes arctica*, *Stichopathes* sp., and *Leiopathes* sp. They were present between 600 and 1200 m depth along the Flemish Cap and Flemish Pass (Figure 2d).

The order Scleractinia was represented only by solitary scleractinians (cup corals). Cup corals occurred in 145 tows (14%) and showed a similar distribution to that of pennatulaceans (Figure 2e). The highest bycatches of cup corals (1.64 kg ha^{-1}) were recorded in the southeast of the Grand Banks, in the tow mentioned above (where pennatulaceans were found), and in another tow nearby at 1028 m depth (0.29 kg ha^{-1}). Except for a few tows in the Flemish Pass and Flemish Cap with presence of *Desmophyllum dianthus*, all the other records were *Flabellum alabastrum*.

The greatest coral species richness was around the Flemish Cap (Figure 4), between 600 and 1200 m depth (Figure 5a), where between 9 and 14 species were recorded in several tows, and to the southeast and northeast of the Grand Banks around 800 m depth. The Flemish Cap (Division 3M) appears to support the highest average of coral species (Figure 5b) and the highest diversity (Appendix), with 34 species recorded, followed by the Flemish Pass and "nose" of the Grand Banks (Division 3L), with 22. To the southeast of the Grand Banks (Division 3NO), 17 species were recorded, most in a small area close to the Canadian EEZ (Division 3O), with notable records of pennatulaceans and *Flabellum alabastrum*. However, because total richness depends on sampling effort, these results have to be used with caution. For example, the northern slope of the Grand Banks (inside the Canadian EEZ, Division 3L), which was the area with the lowest coral species richness (11), was sampled only with 26 tows (3%) during the study period.

Substratum types

Figure 6 shows the substrata identified visually in the study area. The shallower areas of the Flemish Cap have a mix of fine or medium sand, sometimes with large amounts of granules and coarse sand. The north and deep Flemish Cap and Flemish Pass have mainly mud. In some deep areas of the southern Flemish Cap, pebbles and cobbles were found. The continental shelf of the Grand Banks has mainly fine or medium sand, with shell fragments in the "tail" of the Bank. The continental slope has mud and in some areas of the southeast coarse sand, pebbles, and cobbles.

Soft corals were found on all substrata, from mud to coarse sand, pebbles and cobbles. Gorgonians were predominant in mud and in pebbles and cobbles, whereas cup corals and pennatulaceans were mainly on mud and sand bottoms. Antipatharians

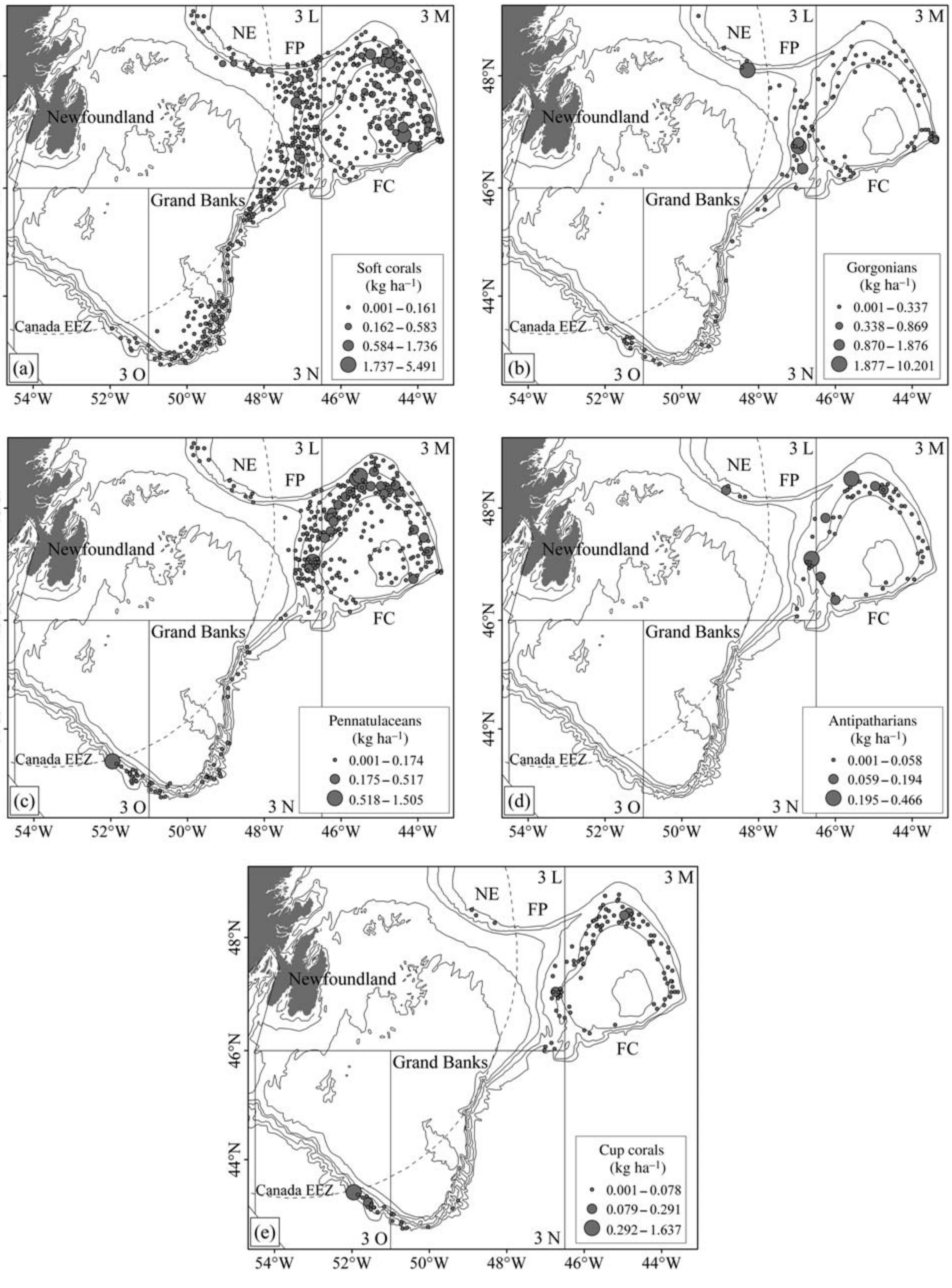

Figure 2. Distribution of deep-water coral biomass in the study area (NAFO Divisions 3LMNO). (a) Soft corals; (b) gorgonians; (c) pennatulaceans; (d) antipatharians; (e) cup corals. The size of the symbols (dots) represents the biomass per swept area (kg ha^{-1}). Note that the scale is not the same in all the maps. Intervals were obtained by Jenks' natural breaks from ArcGIS 9.1 classification. The depth contours indicate 50, 100, 200, 500, 1000, and 1500 m. FC, Flemish Cap; FP, Flemish Pass; NE, northeastern slope of the Grand Banks.

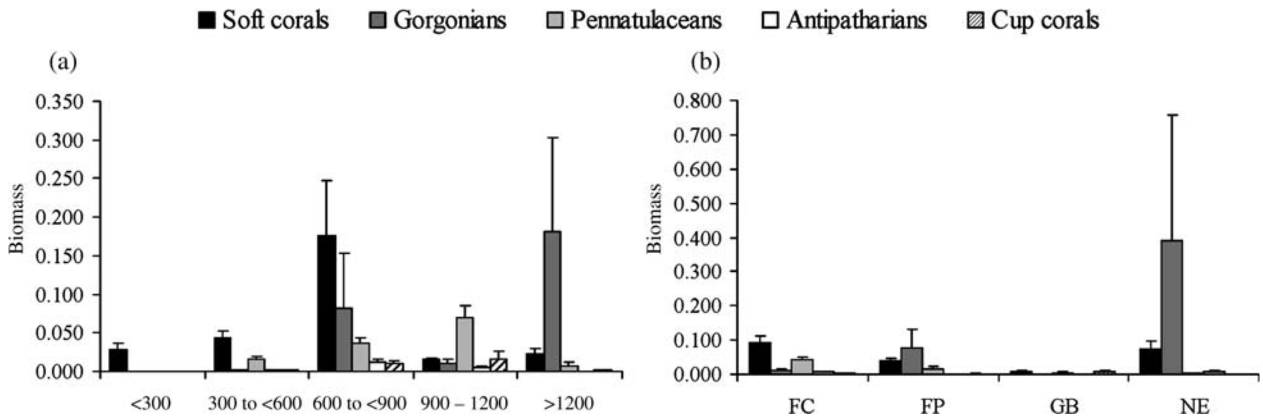

Figure 3. Average biomass ($\pm$ s.e. of the mean) per swept area (kg ha^{-1}) of each coral group considered per depth (a) and per geographic area (b). FC, Flemish Cap; FP, Flemish Pass; GB, Grand Banks; NE, northeastern slope of the Grand Banks.

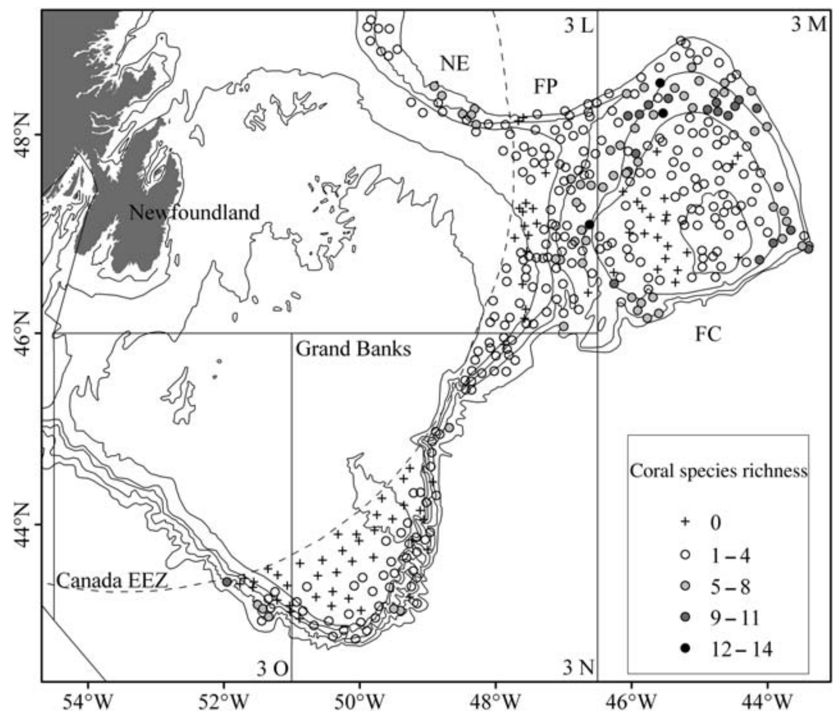

Figure 4. Coral species richness. Number of deep-water coral species recorded per tow in the study area (NAFO Divisions 3LMNO). The depth contours indicate 50, 100, 200, 500, 1000, and 1500 m. FC, Flemish Cap; FP, Flemish Pass; NE, northeastern slope of the Grand Banks.

were not so widely distributed, and appeared on sand, pebbles and cobbles, (Figure 7a). Higher mean species richness was found on mud, pebbles and cobbles, and coarse sand, whereas there were almost no corals on sand with shell debris (Figure 7b).

Fishing activities

The Spanish fishery footprint is shown in Figure 8. This map presents a general view of the areas where the effort of the commercial vessels is higher. There is a well-trawled area in the north of the Flemish Cap, in some regions of the Flemish Pass and along the continental slope of the east of the Grand Banks of Newfoundland. This area fits with that normally used by the Greenland halibut fishery (González-Costas and González-Troncoso, 2009). Since 2001, the distribution of the Greenland halibut fishery has been quite constant (see more details on the evolution of the fishing effort distribution in González-Troncoso *et al.*, 2007; Campanis *et al.*, 2008). The shallower area of the Grand Banks and the Flemish Cap around 400–500 m are moderately trawled; these areas fit with the thorny skate and the shrimp fishery, respectively (González-Costas and González-Troncoso, 2009). The remaining areas seem to be untrawled or slightly trawled. Superimposing the relevant information on deep-water coral bycatches from groundfish surveys (Figure 8), it is clear that most of the bycatches of deep-water corals, particularly large gorgonians, and the areas of highest species richness, were in lightly and untrawled grounds. The highest mean biomass of all coral groups (excluding

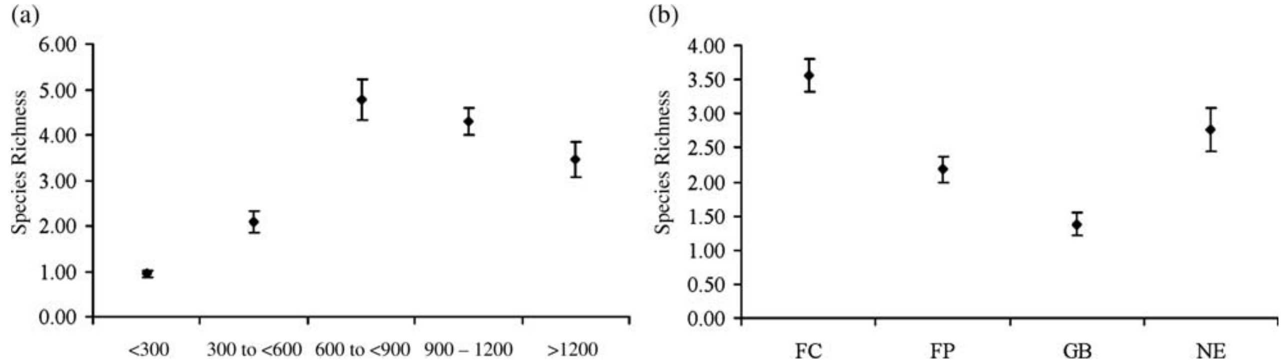

Figure 5. Average coral species richness (±s.e. of the mean) per (a) depth (m) and (b) geographic area. FC, Flemish Cap; FP, Flemish Pass; GB, Grand Banks; NE, northeastern slope of the Grand Banks.

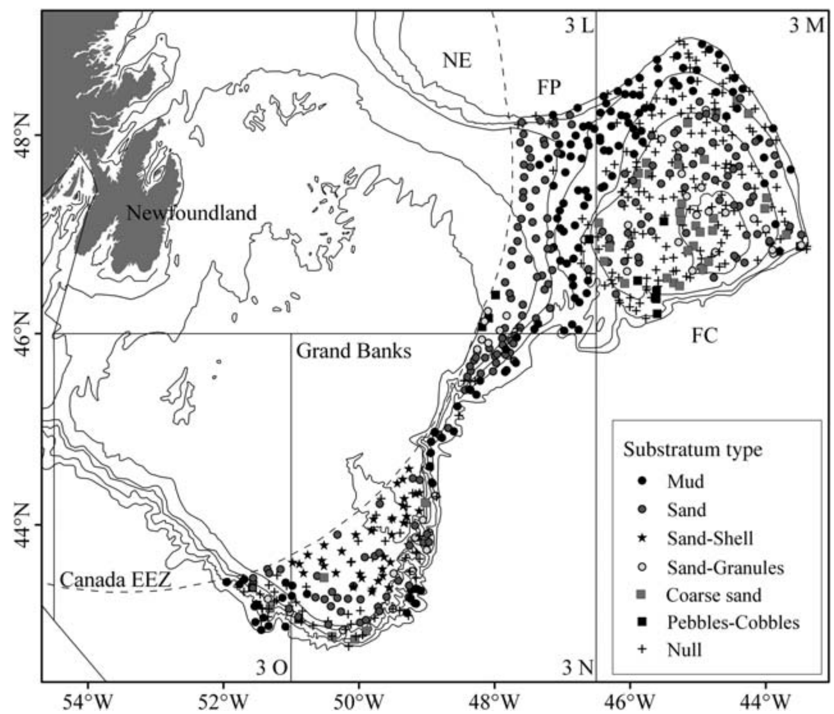

Figure 6. Substratum types in the study area (NAFO Divisions 3LMNO) based on sediment collector sampling from 2007 to 2008. The depth contours indicate 50, 100, 200, 500, 1000, and 1500 m. FC, Flemish Cap; FP, Flemish Pass; NE, northeastern slope of the Grand Banks.

pennatulaceans) was found in lightly or never trawled grounds (Figure 9a). In moderately trawled grounds, some pennatulaceans and soft corals were abundant, whereas in heavily trawled grounds low average biomass of all corals was recorded (Figure 9a). The average number of coral species was similar in the three categories considered, between two and three species per tow (Figure 9b); however, the total coral species was greater in the lightly or never trawled grounds, where 33 different coral species were recorded compared with the 21 species recorded in the heavily trawled grounds (Figure 9c).

Discussion

Coral distribution

In all, 37 taxa of deep-water coral have been identified during this study, dominated by 21 species of alcyonaceans. If compared with data from larger areas such as the east coast of the United States and/or Atlantic Canada compiled by other authors (Gass and Willison, 2005; Watling and Auster, 2005; Mortensen *et al*., 2006; Wareham and Edinger, 2007; Cogswell *et al*., 2009; Wareham, 2009), the species richness in the study area is high. The species richness in the area will probably still be higher than that shown by our data, however. Although species living on rocks were occasionally obtained, only trawlable substrata were sampled; more species are expected on hard, consolidated substrata, particularly scleractinians [11 species are quoted by Cairns and Chapman (2001), from the cold-temperate Canadian coast] and gorgonians. In addition, the taxonomy of the octocorals in the Northwest Atlantic is problematic and modern revisions are lacking for several groups; for example, those that we identified as Clavulariidae indet., Nephtheidae indet., *Paramuricea* spp., and *Anthomastus* spp. consist of several taxa each. The area of the

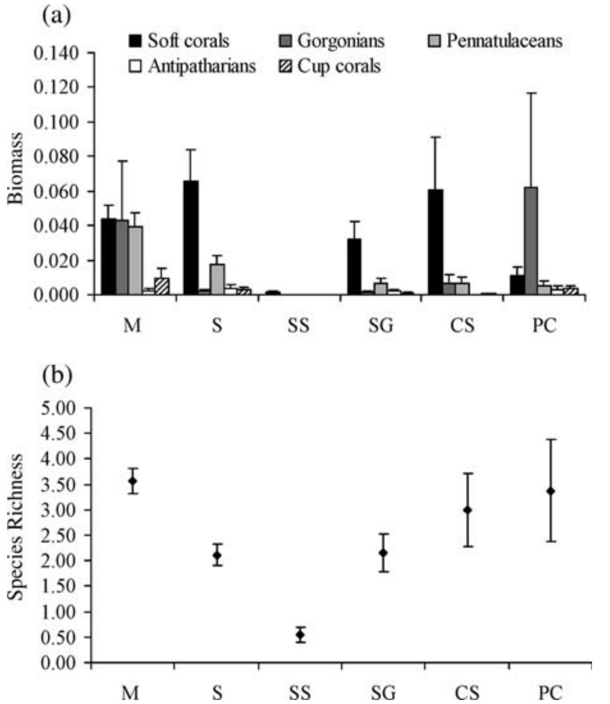

Figure 7. (a) Average biomass ($\pm$ s.e. of the mean) per swept area (kg ha^{-1}) of each coral group considered per substratum type. (b) Average coral species richness ($\pm$ s.e. of the mean) per substratum type. M, Mud; S, sand; SS, sand with shell debris; SG, sand with granules; CS, coarse sand; PC, pebbles and cobbles.

Grand Banks and their cold-water coral communities are the subject of intensive ecological research, and clarifying the taxonomic status of the octocorals is essential to an accurate evaluation of the biodiversity.

In the study area, there are some regions with high biomass and diversity of deep-water corals. The highest average coral biomass area was between 600 and 900 m depth on the northeastern slope of the Grand Banks, in the Flemish Pass, and around the Flemish Cap. Except some soft corals such as *Gersemia rubiformis* or *Duva florida*, and some pennatulaceans, all the corals were found deeper than 600 m. The highest species richness was found on the Flemish Cap, where almost all the coral species recorded in this study were present. Coral species recorded are similar to those found by other authors in adjacent areas (Breeze *et al*., 1997; Watling and Auster, 2005; Mortensen *et al*., 2006; Edinger *et al*., 2007a; Wareham and Edinger, 2007; Cogswell *et al*., 2009). Nevertheless, the Flemish Cap had species not usually recorded in Canadian deep water, such as *Parastenella atlantica* and *Telestula septentrionalis*, and the species richness was high compared with more extensive areas nearby. The deep Flemish Pass, which separates the Flemish Cap from the Grand Banks, the mix of different currents in the area (Gil *et al*., 2004), the highly oxygenated environment rich in nutrients (Stein, 2007), and the greater substratum heterogeneity on the Flemish Cap compared with adjacent areas (Figure 6) could explain these differences in the fauna present.

That the greatest diversity of coral species (Appendix) was recorded on the Flemish Cap seems to be in line with the assumption that the differences between gears in terms of codend mesh size (20 mm for the Campelen 1800, and 35 mm for the Lofoten trawl) did not affect these results severely.

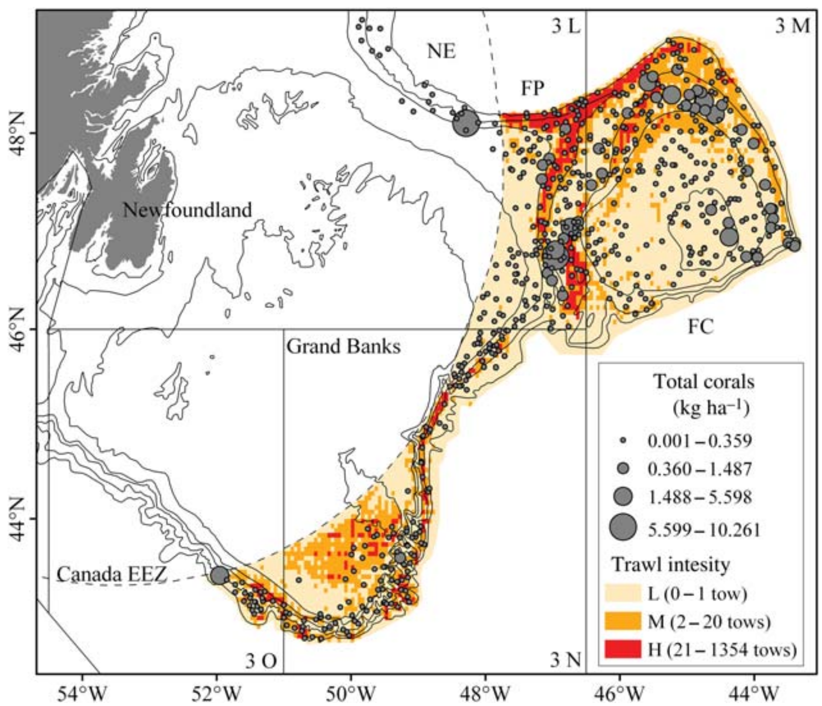

Figure 8. Spanish fishery footprint based on NAFO observers (2001 – 2006) superimposed on total deep-water coral biomass per swept area (kg ha^{-1}) recorded during Spanish/EU groundfish surveys. The depth contours indicate 50, 100, 200, 500, 1000, and 1500 m. L, Lightly – never trawled (0 – 1 tow per cell); M, moderately trawled (2 – 20 tows per cell); H, heavily trawled (21 – 1354 tows per cell). FC, Flemish Cap; FP, Flemish Pass; NE, northeastern slope of the Grand Banks.

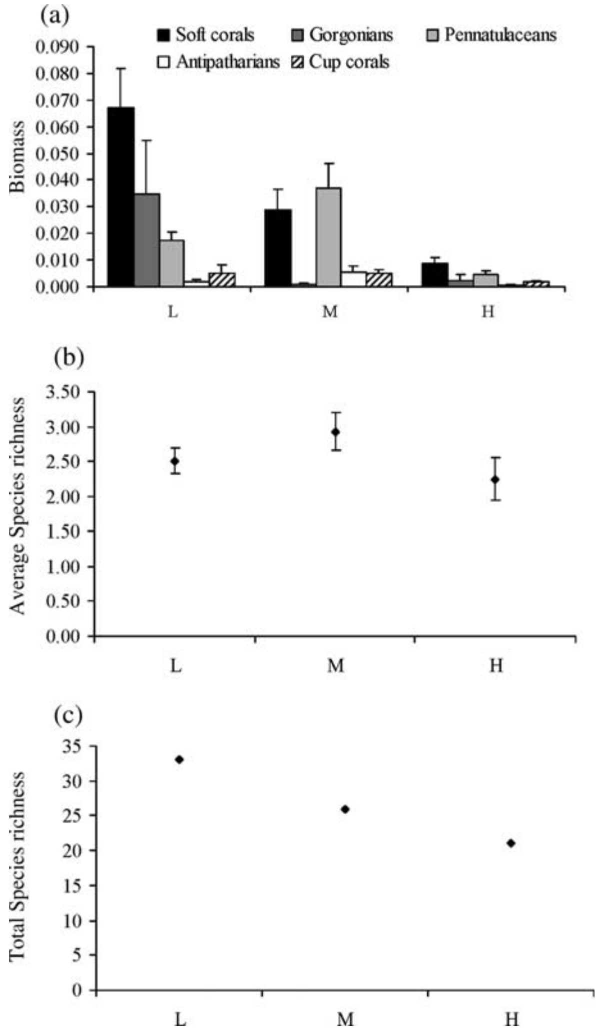

Figure 9. (a) Average biomass ($\pm$ s.e. of the mean) per swept area (kg ha^{-1}) of each coral group considered per trawl intensity based on NAFO observers. (b) Average coral species richness ($\pm$ s.e. of the mean) per trawl intensity based on NAFO observers. (c) Total coral species richness per trawl intensity based on NAFO observers. L, Lightly–never trawled (0–1 tow per cell); M, moderately trawled (2–20 tows per cell); H, heavily trawled (21–1354 tows per cell).

The northeastern slope of the Grand Banks seems to be an important location for corals because they were found in all 26 tows there. A high biomass of large gorgonians was obtained. The "tail" of the Grand Banks was sampled more intensely than the other areas considered, but had fewer coral species and lower biomass than on the Flemish Cap and Flemish Pass.

In an area of the "tail" of the Grand Banks (Division 3O), close to the Canadian Economic Exclusive limit, pennatulaceans and cup corals were abundant; this area is next to the area closed in 2007 to all fishing activity involving bottom contact gear to protect deep-water corals (NAFO, 2007).

No colonial scleractinians were recorded as bycatch during the study period. This observation concurs with the maps of structural habitats compiled in 2008 by the ICES-NAFO WGDEC (see ICES, 2008). Davies *et al*. (2008) consider that this area is a suitable habitat for *Lophelia pertusa*, but the northern record in the Atlantic Canada comes from the Scotian margin (Gass and Willison, 2005; Mortensen *et al*. 2006; Cogswell *et al*., 2009). Further research is needed on hard grounds to check if such colonial scleractinians occur in the area.

Substratum characteristics

Development of new technologies, such as research submersibles and remotely operated vehicles, along with new seabed mapping technologies, such as multibeam bathymetry and sidescan sonar with visual ground truthing, have made *in situ* research of deep-water coral habitats possible. However, in bottom-trawl surveys, this is not feasible, so the sediment collector is an economic and simple tool to obtain sediment samples in such surveys. Despite the limitations of this methodology to study the substratum affinities of the different coral species (i.e. many coarse substrata will not be sampled), it provides a general idea of the sediment present in the area sampled, allowing an approximation of the corals recorded related to the substratum type in each area. Furthermore, these data are similar to those obtained by other authors from the same area (Litvin and Ravchev, 1963).

Visual ground truthing surveys document most of the alcyonaceans and antipatharians living attached to pebbles, cobbles, and glacial deposits (Krieger and Wing, 2002; Mortensen and Buhl-Mortensen, 2005; Mortensen *et al*., 2006), whereas pennatulaceans and *Flabellum* spp. seems to be restricted to finer sediments, such as silt and clay (Williams, 1995; Mortensen *et al*., 2006; Buhl-Mortensen *et al*., 2007). Soft corals occurred in all types of substratum. Soft corals can have different affinities; for example, Nephtheidae species were found attached to pebbles, shells, or coarse sand, whereas *Anthomastus* sp. and *Anthomastus* spp. were found in mud or sand bottoms and also attached to pebbles or others organisms, such as sponges. Gorgonian corals were found on mud bottoms and bottoms with the presence of pebbles and cobbles. Some gorgonians, such as *Acanella arbuscula* or *Radicipes gracilis*, dwell in mud bottoms, whereas most others, such as *Paragorgia arborea, P. johnsoni*, *Paramuricea* spp., or *Primnoa resedaeformis*, are restricted to hard bottoms. Pennatulaceans and cup corals were dominant on mud and sand bottoms, whereas antipatharians were present in small catches in mud, sand, or pebbles. The mix of corals with different substratum affinities in some of the tows suggests that the gear sweeps different types of substratum in one tow.

Fishery interactions

The biomass of deep-water corals was generally low in the fishing grounds used regularly. That may reflect past trawling activity or varying habitat suitability for the corals. Most corals were recorded in lightly or never trawled bottoms. Fisheries information indicates that at present these areas are not considered suitable for bottom trawling or are not worth using for fishing (although they could be suitable in the future). That the areas with higher coral biomass and diversity of corals are not being used for fishing could facilitate the establishment and operation of possible protection measures, such as MPAs that would reduce the bycatch and destruction of habitat-forming corals.

Conservation and management measures

Some large gorgonians (Isididae, Paragorgidae, Plexauridae, and Primnoidae) and antipatharians (Leiopathidae, Schizopathidae) recorded in this study are important habitat-forming species and considered EFH (Etnoyer and Morgan, 2003). Given their size, the age of the species involved, and their vulnerability to physical damage, these habitats probably constitute VMEs as defined by FAO guidelines (FAO, 2009). The results derived from Spanish/EU surveys have identified at least three areas with large catches of sizeable gorgonians. Some of these areas have already been mentioned in the literature, and closures have recently been established (NAFO, 2009b). The northeastern slope of the Grand Banks of Newfoundland (Division 3L) fits with those found by Gass and Willison (2005), Edinger *et al*. (2007a), and Wareham (2009), and the area at the South of Flemish Pass (Division 3M) fits with those mentioned by Edinger *et al*. (2007a) and Wareham (2009). However, this is the first time that corals on the deeper Flemish Cap (Division 3M) have been documented. The maximum coral biomass (69 and 68.9 kg) obtained in two tows in the northeastern slope of the Grand Banks and Flemish Pass was slightly higher than the highest values (10–50 kg) obtained by Edinger *et al*. (2007b) with Campelen 1800 gear and 15-min tows in adjacent waters.

Sea-pen fields can also be important for fish and may provide significant structural relief in habitats dominated by sand or mud (Tissot *et al*., 2006). Since 2003, sea-pen communities have been included in the OSPAR list of threatened and declining habitats (OSPAR, 2003). Recently, the OSPAR convention (OSPAR, 2008) has included "coral gardens", which are relatively dense aggregations of colonies or individuals of one or more coral species, supporting a rich associated fauna of benthic and epibenthic species (ICES, 2007).

There are no internationally accepted criteria to define VMEs based on bycatch, although in recent years some efforts have been made to do so (NAFO, 2008b; Rogers *et al*., 2008; Parker *et al*., 2009; Penney *et al*., 2009). Following a semi-quantitative approach, there are two areas (southeast of the Grand Banks and north of the Flemish Cap) with important bycatches of sea pens and other corals (soft corals, cup corals, small gorgonians) in terms of biomass and diversity (Figures 2 and 4). However, it is not clear whether these bycatches indicate the presence of VMEs.

The cold-temperate North Atlantic scleractinian fauna is characterized by having a high percentage of widespread species and low degree of endemism (Cairns and Chapman, 2001; Hall-Spencer *et al*., 2007). Rejuvenation of subareas with greatly reduced abundance is likely to happen by influx of larvae from adjacent subareas, and this mechanism may facilitate some stability in the overall occurrence patterns. This also seems to happen with other corals recorded in this study that appear cosmopolitan or amphi-Atlantic species (see Sanmartín, 2004). Nevertheless, given that the rates of recruitment and growth of the species in the study area are unknown, the time-scale over which a population could be re-established is unpredictable.

The use of vulnerable organism bycatch information to define VMEs has many limitations (Durán Muñoz *et al*., 2008). Organisms that are killed on the seabed may not be retained by the gear or may be destroyed and lost from the gear before they are returned to the deck of the vessel, resulting in underestimates of bycatch and ultimately in the interaction of the gear with VMEs (Edinger *et al*., 2007a). Therefore, a lack of bycatch of species that comprise VMEs is not definitive evidence that they are not present in an area that is fished (Rogers *et al*., 2008), although presence is indicative of some VME existence. Hence, without a properly planned habitat mapping exercise (superposing multibeam echosounder, dredge, visual ground truthing, and other relevant data layers), complemented with information on fishery footprint, it is not possible to map accurately the location of VMEs and to define exactly, for example, areas to be closed to protect the habitats and implement the 2006 UNGA resolution 61/105.

The analysis of bycatch data from Spanish/EU conventional groundfish surveys have identified some priority areas for interdisciplinary research surveys to verify where VMEs and EFHs could exist. During the years 2009–2010, a multidisciplinary collaborative project on board the Spanish RV "Miguel Oliver" will be carried out to study the VMEs in the NAFO Regulatory Area. This and *in situ* observations undertaken on board the Canadian RV "Hudson" during the summer of 2009 and 2010 will improve the knowledge of the VMEs in the area.

The information presented in this document, along with additional Canadian data, has been used by the NAFO Working Group on Ecosystem Approach to Fisheries Management as baseline data to identify candidate VMEs areas in the NAFO Regulatory Area (NAFO, 2008a, b) for the subsequent adoption of suitable habitat conservation measures to preserve deep-water corals (NAFO, 2009b).

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Appendix

Appendix Table 1. List of coral taxa recorded by the Spanish/EU groundfish survey in 2007 per geographic area, and the occurrence of each coral taxon expressed as a percentage.

		FC	FP	GB	NE	Occurrence (%)
Alcyonacea						
	Alcyonacea indet.	X				1.23
Clavulariidae	Clavulariidae indet.	X		X		1.47
	Telestula septentrionalis	X				2.70
Alcyoniidae	*Anthomastus* spp.	X	X	X		4.17
	Anthomastus sp.	X	X	X		14.22
Nephtheidae	*Duva florida*	X	X	X	X	62.25
	Gersemia rubiformis		X	X		6.13
	Nephtheidae indet.	X	X	X	X	25
Anthothelidae	*Anthothela grandiflora*	X				0.74
Paragorgiidae	*Paragorgia arborea*		X		X	0.49
	Paragorgia johnsoni	X				0.98
Acanthogorgiidae	*Acanthogorgia armata*	X	X			2.70
Plexauridae	*Paramuricea* sp.	X				0.25
	Paramuricea spp.	X	X		X	3.68
	Placogorgia sp.	X				0.49
	Swiftia sp.	X				0.74
Chrysogorgiidae	*Radicipes gracilis*	X	X	X		4.66
Isididae	*Acanella arbuscula*	X	X	X	X	12.5
	Keratoisis sp.	X	X	X		1.23
Primnoidae	*Parastenella atlantica*	X				0.25
	Primnoa resedaeformis	X			X	0.74
Pennatulacea						
Kophobelemnidae	*Kophobelemnon stelliferum*	X				2.7
Funiculinidae	*Funiculina quadrangularis*	X	X	X		12.5
Protoptilidae	*Distichoptilum gracile*	X	X	X		1.23
	Protoptilum sp.	X				0.25
Umbellulidae	*Umbellula lindahli*	X	X	X		8.09
Anthoptilidae	*Anthoptilum grandiflorum*	X	X	X	X	29.9
Halipteridae	*Halipteris finmarchica*	X	X	X		13.48
	Halipteris cf. *christii*	X				3.43
Virgulariidae	*Virgularia* sp.	X				0.25
Pennatulidae	*Pennatula aculeata*	X	X	X	X	12.01
	Pennatula grandis	X	X	X	X	7.6

Continued

Continued

		FC	FP	GB	NE	Occurrence (%)
Antipatharia						
Antipathidae	*Stichopathes* sp.	X				0.25
Leiopathidae	*Leiopathes* sp.		X			0.49
Schizopathidae	*Stauropathes arctica*	X	X		X	6.62
Scleractinia						
Caryophylliidae	*Desmophylllum dianthus*	X	X			0.25
Flabellidae	*Flabellum alabastrum*	X	X	X	X	13.48
Total corals (37)		34	22	17	11	

FC, Flemish Cap; FP, Flemish Pass; GB, Grand Banks; NE, northeastern slope of the Grand Banks.