Distribution of deep-sea corals in the Newfoundland and Labrador region, Northwest Atlantic Ocean

Vonda E. Wareham and Evan N. Edinger

Abstract

Deep-sea corals were mapped using incidental by-catch samples from stock assessment surveys and fisheries observations. Thirteen alcyonaceans, two antipatharians, four solitary scleractinians, and 11 pennatulaceans were recorded. Corals were broadly distributed along the continental shelf edge and slope, with most species found deeper than 200 m; only nephtheid soft corals were found on the shelf. Large branching corals with robust skeletons included *Paragorgia arborea* (Linnaeus, 1758), *Primnoa resedaeformis* (Gunnerus, 1763), *Keratoisis ornata* (Verrill, 1878), *Acanthogorgia armata* (Verrill, 1878), *Paramuricea* spp., and two antipatharians. Coral distributions were highly clustered, with most co-occurring with other species. Scientific survey data delineated two broad coral species richness hotspots: southwest Grand Bank (16 spp.) and an area of the Labrador slope between Makkovik Bank and Belle Isle Bank (14 spp.). Fisheries observations indicated abundant or diverse corals off southeast Baffin Island, Cape Chidley, Labrador, Tobin's Point, and the Flemish Cap. Corals on the Flemish Cap comprised exclusively soft coral, sea pens, and solitary scleractinians. Most coral-rich areas were suggested in earlier research based on stock assessment surveys or Local Environmental Knowledge (LEK). Currently there are no conservation measures in place to protect deep-sea coral in this region.

Deep-sea corals can be found worldwide (Freiwald and Roberts, 2005), but until recently data on their distributions in the Northwest Atlantic Ocean were limited (Collins, 1884; Deichmann, 1936; Miner, 1950; Nesis, 1963; Tendal, 1992, 2004; Breeze et al., 1997; MacIsaac et al., 2001; Gass and Willison, 2005; Watling and Auster, 2005; Mortensen et al., 2006). Within the last decade, knowledge of corals in eastern Canada has increased dramatically, with attention being primarily focused on the Scotian Shelf (Breeze et al., 1997; MacIsaac et al., 2001). The continental shelf and slope of Newfoundland and Labrador have received very little attention (Nesis, 1963; Tendal, 1992; Gass and Willison, 2005). This study presents deep-sea coral distribution patterns and diversity data in an area that has, up to now, received only exploratory treatment.

In Atlantic Canada, deep-sea corals have been found at depths > 200 m primarily along the continental shelf edge and continental slope, particularly near submarine canyons or saddles where the shelf has been incised (Breeze et al., 1997; MacIsaac et al., 2001; Gass and Willison, 2005; Mortensen and Buhl-Mortensen, 2005b). Such bathymetric features are considered good habitat for corals because they are associated with strong currents that winnow away fine sediment, exposing harder substrates, and provide a reliable source of fine particulate organic matter for suspension feeding corals (Hecker et al., 1980; Harding, 1998). Conversely, increased sedimentation can be hazardous to

George, R. Y. and S. D. Cairns, eds. 2007. Conservation and adaptive management of seamount and deep-sea coral ecosystems. Rosenstiel School of Marine and Atmospheric Science, University of Miami.

corals, congesting polyps and inhibiting feeding processes (Hecker et al., 1980). Hard substrates are believed to be important, especially to larger gorgonian corals such as *Primnoa resedaeformis* and *Paragorgia arborea*; two species that are typically found attached to cobbles, boulders, or bedrock (Mortensen and Buhl-Mortensen, 2004, 2005a; Mortensen et al., 2006). Other corals have a calcareous holdfast for anchoring in soft sediment (e.g., *Acanella arbuscula*). Many solitary Scleractinians such as *Flabellum alabastrum* simply lie on the ocean floor, while others, e.g., *Desmophyllum dianthus* usually retain a holdfast.

Deep-sea corals are slow-growing and long-lived (Lazier et al., 1999; Andrews et al., 2002; Risk et al., 2002; Roark et al., 2005; Sherwood et al., 2006), and can reach heights up to 2.5 m (Miner, 1950; Tendal, 1992; Breeze et al., 1997; Mortensen and Buhl-Mortensen, 2005). Large corals increase complexity of benthic environments through their arboreal growth and robust skeletons (Krieger and Wing, 2002); in turn, these structures can create habitat for other benthic organisms during some stages of their life history (Auster, 2005). Large sessile organisms, however, are more susceptible to anthropogenic disturbances, especially fishing gear in contact with the ocean floor (Watling and Norse, 1998; Krieger, 2001; Fosså et al., 2002; Hall-Spencer et al., 2002; Thrush and Dayton, 2002; Anderson and Clark, 2003). The Northeast Newfoundland Shelf, southern Labrador Shelf, and the Grand Banks of Newfoundland have been subject to intense bottom trawling, (Kulka and Pitcher, 2002). As shelf stocks were depleted, fishing effort shifted to deeper waters on the slope, with potentially severe consequences for deep-water ecosystems (Koslow et al., 2000).

The goal of this study is to map the distribution and diversity of deep-sea corals off the coasts of Newfoundland, Labrador, and southeast Baffin Island using incidental by-catch from scientific surveys and fisheries observations aboard commercial vessels. General information on the distribution patterns of deep-sea corals and their diversity in the region is limited, and the extent to which they have been impacted by fishing activities in the Newfoundland and Labrador region is unknown. This study presents distributions and depth ranges of individual coral species and highlights areas with high diversity and abundance of deep-sea corals in waters off Newfoundland and Labrador, Canada. The study area in question encompasses the continental shelf and slope of the Grand Banks of Newfoundland, Northeast Newfoundland Shelf, the Flemish Cap, Labrador Shelf, Davis Strait, and Baffin Basin. It is our hope that this work will add to the growing information on deep-sea corals in Atlantic Canada (Cairns and Chapman, 2001; Gass and Willison, 2005; Mortensen et al., 2006) and provide necessary data to help conserve coral habitat in the Northwest Atlantic.

Materials and Methods

Coral data was gathered opportunistically from three sources, commencing in 2002 up to and including May 2006. The Canadian Department of Fisheries and Oceans (DFO) Multispecies Stock Assessment Surveys covered central and southern Labrador as well as northeast to southwest Newfoundland, but excluded the Gulf of St. Lawrence. The Northern Shrimp Stock Assessment Survey, co-sponsored by the Northern Shrimp Research Foundation and DFO, covered the southeast Baffin Island and northern Labrador. Observations from the Fisheries Observer Program (FOP) were the third source of data, and covered a broader area, extending from Baffin Basin to the Grand Banks and the Flemish Cap. Each data source encompassed different management zones and incorporated slightly different sampling techniques. Therefore, each source is discussed separately.

Multispecies stock assessment surveys and the northern shrimp survey.—DFO multispecies stock assessment surveys (2002–2006) consisted of an annual spring and fall survey aboard the Canadian Coast Guard Ship (CCGS) Wilfred Templeman and the CCGS Teleost. Survey tows followed a stratified random survey design and covered NAFO (Northwest Atlantic Fisheries Organization) divisions 2HJ (southern Labrador), and 3KLMNOP (northeast-southern Newfoundland, and The Grand Banks). The CCGS Wilfred Templeman conducted shallow water tows < 700 m, while the CCGS Teleost conducted both shallow and deep water tows < 1500 m. Research Vessels (RV) used in the study were equipped with a Campelen 1800 shrimp trawl with rockhopper footgear: tight rubber disks (102 × 35 cm diameter) with spacers along the footrope. The 16.9 m wide net had four panels constructed of polyethylene twine: wing panel 80 mm mesh size, the square and first belly 60 mm mesh size, the second belly and cod end 40 mm mesh size with a 12.7 mm liner in the cod end (cf. McCallum and Walsh, 1996). Tow duration was 15 min at 3 kt (± 1 kt); average tow length was 1.4 km (0.79 nmi), and tows were conducted along a consistent depth contour. The area swept was calculated by multiplying net wing span by tow distance for an average swept area per tow of 0.025 km^2 (0.073 nmi^2). The total area that can be surveyed by DFO per year for all NAFO divisions in the region was 690,676 km^2. However, not all NAFO divisions were surveyed each year: divisions 2J and 3KLNOP were surveyed in each year from 2002–2005, but not consistently; divisions 0B and 2G were surveyed in 2005; division 2H was surveyed in 2004. Each catch was sampled for fish species, and sub-sampled for invertebrate by-catch. Individual coral species were assigned a numerical species code with the exception of pennatulaceans, which were grouped. All suspected corals were assigned a species code, bagged, labelled with locator number, and frozen. DFO technicians and scientific crew were provided with coral identification guides produced by the Bedford Institute of Oceanography and by the authors. Training workshops for DFO crew and fisheries observers were organized in 2004 and 2005 by the authors. All specimens were forwarded to Memorial University (MUN) and identified by the authors using gross morphology (shape, size, hardness, color, and presence/absence of horny axis), polyp morphology, and, in some cases, sclerite description using Scanning Electron Microscopy. Photographs of coral species are presented in Figure 1.

The Northern Shrimp Survey was conducted from late July to early September 2005 on the Fisheries Products International vessel MV Cape Ballard. This was the first of five annual research deployments scheduled for the Artic Region. Survey tow methods were standardized with DFO surveys and followed a random stratified sampling program at depths of 100–750 m in NAFO divisions 0B (southeast Baffin Island) and 2G (northern Labrador). All research surveys were standardized with the assumption that each catch was searched meticulously; therefore any coral caught within a given set was assumed to be almost always recovered by the RV technicians, and lack of corals in a given set was interpreted as absence of coral in that sample.

Fisheries observer program.—Fisheries observers are deployed aboard Canadian and Foreign fishing vessels and are responsible for monitoring compliance to fisheries regulations and for the collection of scientific and technical data related to fishing operations (Kulka and Firth, 1987). Fisheries managers and scientists use these data to manage and study fisheries. Observers are deployed in most fisheries in the region covering a broad array of depths extending from Baffin Basin to southern Newfoundland and the Flemish Cap. Prior to collecting corals, all observers were equipped with the same identification guides as the RV technicians, and participated in coral identification workshops in 2004 and 2005 organized by the authors. Coral data were collected between April 2004 and May 2006. Observer coverage at sea varied between 0–100% depending on the fishery, quota allocation, gear type and NAFO division. Sampling protocol required each observer to submit at least one sample of each coral species encountered on each trip, and to record all other occurrences of each coral species on set/catch data sheets. Samples and records were tracked to assess accuracy of data from each observer. Coral distribution data from fisheries observers presented here include identified samples and records that could be compared with an identified sample previously submitted by the individual observer reporting the record. Data from fisheries observers had several limitations. First, distribution data from observers were biased by fishing effort. Second, unlike the RV surveys, observer coral data were not standardized for variations in tow length, gear type, and search time. Finally, observers may not have had sufficient search time to locate all corals within a catch, especially in high volume fisheries such as shrimp. Given these limitations, observer data were treated as presence, but not absence, of coral species.

Definition of coral species richness hotspots and abundance peaks.—Coral species richness hotspots were identified qualitatively in the scientific survey data as areas with higher species richness per tow than surrounding sets. Observer data were not used to identify coral species richness hotspots, but were used to describe the range of individual species, and to characterize coral distributions in areas not covered by the scientific surveys.

***Mapping of deep-sea coral*.—**Data from research surveys (Multispecies and Northern Shrimp Surveys), and samples and records from observers were combined into a master database and mapped in MapInfo Professional 8.0 Software. Bathymetry data were obtained from the General Bathymetric Chart of the Oceans (GEBCO, 2003). Distribution maps were verified visually for accuracy and cross checked with data points plotted on Canadian Hydrographic Service bathymetry charts. Any discrepancies were investigated and adjusted appropriately.

Results

Multispecies stock assessment surveys and northern shrimp survey.—Thirty-five research surveys carried out between December 2002 and January 2006 were explored: 2002 (1), 2003 (2), 2004 (10), 2005 (19), and 2006 (3). The 34 multispecies surveys yielded 1968 tows from NAFO divisions 2HJ and 3KLMNOP. The one Northern Shrimp Survey yielded 227 tows from NAFO divisions 0B and 2G. The total area swept was 52.75 km^2, or approximately 0.00685% of the survey area. NAFO divisions 3Pn (2002 only) and 3Ps (2005 only) were the only divisions within the region in which surveys covered > 0.01% of area within the time frame of this study. One area was not adequately surveyed, a small area adjacent to Hudson Strait in the Labrador Sea (~61°20´N, 62°30´W). It was excluded because of the high probability of gear damage due to rough substrates and the reported concentrations of large gorgonians (e.g., *P. arborea*, *P. resedaeformis*) found in this particular area (D. Orr, DFO, pers. comm.). In total, 976 coral specimens were collected from 622 scientific survey sets that captured at least one coral specimen per set. See Table 1 for a summary of each species frequency, mean depth, and range.

Fisheries observer program.—From January 2004 to May 2006 fisheries observers documented 1304 coral occurrences from nine of the 25 directed fisheries operating in the region: 397 occurrences were from submitted samples and 907 were from records only (Table 1). The Greenland halibut (*Reinhardtius hippoglossoides*) fishery had the highest frequency of coral by-catch (n = 677) and fished the deepest depths (average depths 889–1070 m depending on gear type) on the continental slope (Table 2). Fishing effort was concentrated in deep waters off the southeastern slope of the Baffin Island Shelf, the southeast Labrador slope, the Northeast Newfoundland Shelf, and in a deep water trough of the Northeast Newfoundland Shelf called Funk Island Deep (Fig. 2A). Mobile gear used in this fishery included Otter trawls (1 net) and twin trawls (2 nets), with the main difference between these being the number of nets hauled per vessel. Fixed gear was also used, benthic longline and gillnet, but mainly off the southwest Grand Bank, in areas unsuitable for trawling.

The northern shrimp (*Pandalus borealis* and *Pandalus montagui*) fishery had the second highest frequency of coral by-catch (n = 226) with effort concentrated on the Labrador Shelf edge (average depths 349–415 m depending on gear type; Table 2). Three trawl types were utilized: shrimp, twin, and triple trawls. Mandatory Nordmore Grate bycatch reduction devices (22–28 mm bar spacing) were used in conjunction with each gear type to help reduce by-catch of mobile species. The grate allows shrimp to pass through and into the net, while oversized by-catch are redirected out through an exit door in the top panel of the net.

Both the shrimp and Greenland halibut fisheries deployed multiple gear types but only the latter used both mobile and fixed gear classes. Overall, mobile gear captured 943 coral occurrences (samples and records), compared to 363 occurrences by fixed gear (Table 3). The Otter Trawl had the highest frequency of coral by-catch (n = 636) of all gear types. Other fisheries in the region captured corals as well and are summarized in Table 2. Further analysis of coral by-catch patterns among directed fisheries and gear types will be published separately.

Deep-sea coral distribution and diversity patterns.—Twenty-eight deep-sea coral species were identified in the region, with two additional forms represented that have not been identified to species level. In total, there were 13 alcyonaceans, two antipatharians, four solitary scleractinians, and 11 pennatulaceans (Table 1; Figs. 1, 2).

The order Alcyonacea was subdivided into three informal groups: soft corals with polyps contained in massive bodies, gorgonians with a consolidated axis, and gorgonians without a consolidated axis (Bayer, 1981). See Figure 2A for alcyonacean distributions.

Soft corals consisted of one alcyoniid (*Anthomastus grandiflorus*) and at least two nephtheids (*Gersemia rubiformis*; *Capnella florida*), however, a third nephtheid species was suspected. Because of uncertainty in identifying nephtheid corals to species, all nephtheids were mapped as a single group.

Nephtheids (n = 898) had the highest frequency of all species documented. *Gersemia rubiformis* (Fig. 1X), was the only species in the study that was consistently distributed on the continental shelf (n = 308). Depth for this species ranged between 47–1249 m with average depths < 174 m. Individual colonies were < 5 cm high (when frozen and con-

Table 1. Summary of coral occurrences by species from DFO Multispecies Stock Assessment Surveys (RV) 2003–2006, the Northern Shrimp Stock Assessment Survey (RV) 2005, records (fisheries observations with no samples; FOP_r), and samples (fisheries observations with samples; FOP_s) from fisheries observations April 2004–January 2006. (?) = species suspected but not confirmed: Nephtheid soft corals are represented by *Capnella florida*, *Gersemia rubiformis*, and at least one other form of nephtheid, which has yet to be identified. *Paramuricea placomus* and *Paramuricea grandis* may both be represented, spicule mounts suggest presence of both species, but some specimens are not yet determined. *Stauropathes arctica* is confirmed, but the identity of a second growth form of antipatharian assigned *Bathypathes* sp., has not yet been determined, partly due to uncertainty in the taxonomy of this group. Sea pens 4 and 12 are two distinct forms yet to be identified; sea pen spp. refers to pennatulaceans too poorly preserved to be identifiable beyond order.

	Coral frequencies (#)				Mean depth and range (m)		
Order/Family/Species	RV	FOP_s	FOP_r	Total	RV	FOP_s	FOP_r
Alcyonacea							
Nephtheidae							
Capnella florida (Verrill, 1869)	284	118	97	499	444 (47–1,404)	615 (230–1,287)	552 (269–1,087)
Gersemia rubiformis (Ehrenberg, 1834)	166	31	111	308	174 (41–722)	286 (51–1,249)	547 (56–1,249)
Nephtheids (?)	88	3	–	91	253 (67–1,398)	717 (399–1,135)	–
Alcyoniidae							
Anthomastus grandiflorus (Verrill, 1878)	49	15	1	65	913 (171–1,404)	834 (302–1,277)	821
Primnoidae							
Primnoa resedaeformis (Gunnerus, 1763)	11	6	11	28	402 (162–676)	559 (357–1,157)	432 (380–592)
Paragorgiidae							
Paragorgia arborea (L.)	8	10	9	27	573 (370–846)	719 (448–1,277)	481 (402–576)
Anthothelidae							
Anthothela grandiflora (Sars, 1856)	2	–	–	2	723 (528–918)	–	–
Isididae							
Keratoisis ornata (Verrill, 1878)	6	8	16	30	491 (195–664)	786 (302–1,100)	879 (403–1,262)
Acanella arbuscula (Johnson, 1862)	81	50	187	318	822 (154–1,433)	827 (344–1,277)	893 (302–1,244)
Acanthogorgiidae							
Acanthogorgia armata (Verrill, 1878)	30	19	25	74	873 (171–1,415)	819 (278–1,260)	513 (302–1,207)

Table 1. Continued.

	Coral frequencies (#)				Mean depth and range (m)		
Order/Family/Species	RV	FOP_s	FOP_r	Total	RV	FOP_s	FOP_r
Chrysogorgiidae							
Radicipes gracilis (Verrill, 1884)	11	4	13	28	1052 (785–1,337)	997 (384–1,491)	981 (419–1,207)
Plexauridae							
Paramuricea grandis (Verrill, 1883)	22	16	11	49	810 (152–1,415)	800 (457–1,193)	594 (402–773)
Paramuricea placomus (L.)	22	16	11	49	810 (152–1,415)	800 (457–1,193)	594 (402–773)
Antipatharia							
Schizopathidae							
Stauropathes arctica (Lütken, 1871)	2	14	21	37	1,075 (1,013–1,136)	1,027 (745–1,287)	1,069 (872–1,228)
Bathypathes sp. (Brooke, 1889) (?)	2	14	21	37	1,075 (1,013–1,136)	1,027 (745–1,287)	1,069 (872–1,228)
Scleractinia							
Flabellidae							
Flabellum alabastrum (Moseley, 1873)	53	19	69	141	819 (218–1,433)	629 (353–1,135)	833 (339–1,200)
Dasmosmilia lymani (Pourtalès, 1871)	1	–	–	1	457	–	–
Caryophlliidae							
Desmophyllum dianthus (Esper, 1794)	–	2	–	2	–	883 (713–1,052)	–
Vaughanella margaritata (Jourdan, 1895)	1	3	–	4	1,320	1,199 (1,163–1,252)	–
Pennatulacea							
Virgulariidae							
Halipteris finmarchia (Sars, 1851)	29	11	336	577	749 (113–1,433)	745 (344–1,028)	699 (182–1,244)
Pennatulidae							
Pennatula grandis (Ehrenberg, 1834)	16	16	336	577	876 (488–1,404)	633 (320–1,018)	699 (182–1,244)
Pennatula phosphorea (L.)	36	9	336	577	823 (96–1,345)	713 (146–1,223)	699 (182–1,244)

Table 1. Continued.

Order/Family/Species	Coral frequencies (#) RV	Coral frequencies (#) FOP_s	Coral frequencies (#) FOP_r	Coral frequencies (#) Total	Mean depth and range (m) RV	Mean depth and range (m) FOP_s	Mean depth and range (m) FOP_r
Pennatula aculeata (Koren and Danielsen, 1858)	1	–	336	577	229	–	699 (182–1,244)
Funiculinidae							
Funiculina quadrangularis (Pallas, 1766)	18	–	336	577	1,018 (346–1,433)	–	699 (182–1,244)
Umbellulidae							
Umbellula lindahli (Kölliker, 1875)	4	3	336	577	463 (145–620)	870 (723–984)	699 (182–1,244)
Protoptilidae							
Distichoptilum gracile (Verrill, 1882)	2	2	336	577	921 (794–1,048)	750 (346–1,154)	699 (182–1,244)
Anthoptilidae							
Anthoptilum grandiflorum (Verrill, 1879)	47	19	336	577	796 (171–1,433)	833 (320–1,072)	699 (182–1,244)
Kophobelemnidae							
Kophobelemnon stelliferum (Müller, 1776)	1	1	336	577	1,235	1,154	699 (182–1,244)
sea pen sp. 4	2	–	336	577	647 (493–801)	–	699 (182–1,244)
sea pen sp. 12	2	–	336	577	1,224 (1,135–1,313)	–	699 (182–1,244)
sea pen spp.	3	18	336	577	775 (212–1,200)	697 (277–1,063)	699 (182–1,244)
Total coral specimens	976	397	907	2,281			
Total sets sampled	2,192	45,566		47,758			
Total sets with at least one coral specimen	622	864		1,477			
Total sets without coral	1,581	44,702		46,281			

Table 2. Summary of coral by-catch frequencies by target fishery, gear type, and average depths fished; data from fisheries observations documented between April 2004 and January 2006.

Target species	Gear types (fixed)	Gear types (mobile)	Average depth fished (m)	Corals captured (frequency)
Skate (*Raja* spp.)	Gillnet	–	439	2
White hake (*Urophycis tenuis* Mitchill, 1814)	Gillnet	–	218	6
Redfish (*Sebastes* sp.)	–	Otter trawl	447	189
Yellowtail flounder (*Limanda ferruginea* Storer, 1839)	–	Otter trawl	165	18
Atlantic halibut (*Hippoglossus hippoglossus* Linnaeus)	Longline	–	867	56
Snow or queen crab (*Chionoecetes opilio* Fabricius, 1788)	Crab pot	–	399	128
Angler, common monkfish (*Lophius americanus* Valenciennes, 1837)	Gillnet	–	331	2
Greenland halibut (*Reinhardtius hippoglossoides* Walbaum, 1792)	–	Otter trawl	891	429
	Gillnet	–	995	140
	Longline	–	1,070	27
	–	Twin trawl	889	81
Shrimp (*Pandalus borealis* Kroyer, 1838; *Pandalus montagui* Leach, 1814)	–	Shrimp trawl	415	102
	–	Twin trawl	349	111
	–	Triple trawl	365	13
Total				1,304

Table 3. Summary of coral by-catch frequencies by species, target fishery, gear class, and gear type; data from fisheries observations documented between April 2004 and January 2006.

	Gear types per coral frequency							
	Fixed gear			Mobile gear				
Coral	Crab Pot	Gillnet	Longline	Otter Trawl	Shrimp Trawl	Twin Trawl	Triple Trawl	Total
Capnella florida	32	4	2	74	63	40	–	215
Gersemia rubiformis	72	21	1	26	16	6	–	142
Nephtheid	–	1	–	1	1	–	–	3
Anthomastus grandiflorus	–	2	8	4	1	1	–	16
Primnoa resedaeformis	–	1	–	2	14	–	–	17
Paragorgia arborea	–	2	1	10	6	–	–	19
Keratoisis ornata	–	–	21	3	–	–	–	24
Acanella arbuscula	14	44	7	100	–	72	–	237
Acanthogorgia armata	2	3	12	27	–	–	–	44
Radicipes gracilis	–	6	9	2	–	–	–	17
Paramuricea spp.	7	1	1	18	–	–	–	27
Antipatharia	–	14	1	17	–	3	–	35
Flabellum alabastrum	–	6	3	56	–	22	1	88
Desmophyllum dianthus	–	1	1	–	–	–	–	2
Vaughanella margaritata	–	3	–	–	–	–	–	3
Pennatulacea	1	41	16	296	1	48	12	415
Total	128	150	85	636	102	192	13	1,304
Gear total		363			943			

tracted), had a wide range of colour variations, and were frequently observed attached to pebbles, broken shells, and live gastropods.

Capnella florida (Fig. 1Y) was mostly found in deeper waters on the continental shelf edge and slope (n = 499). However some samples were captured in shallower waters on the shelf. Depth for this species ranged between 47–1404 m with average depths > 444 m. Individual samples were massive bodied colonies < 15 cm high, with multiple branches that terminated in clusters of non-retractable polyps. Colonies were mostly black with some variations of brown and beige. Attached substrates consisted of mostly rock and gravel, but some colonies were observed attached to live gastropods and sponges.

Anthomastus grandiflorus (Fig. 1W) was found only on the shelf edge and slope of the southern Labrador Shelf, Northeast Newfoundland Shelf, and the Grand Banks of Newfoundland (n = 65). The depth of this species ranged between 171–1404 m with average depths > 821 m. Most individual colonies, when contracted, were < 5 cm high characterized by a capitulum that had long polyp tubes and large polyps extended from the cap. Individual colonies were supported by a sterile basal stalk that was observed attached to pebble and cobble substrates. One juvenile specimen was observed attached to a *Keratoisis ornata* stem.

Seven species of gorgonian with a consolidated axis were recorded: *Acanella arbuscula*, *Acanthogorgia armata*, *Paramuricea* spp. (*Paramuricea placomus* and *Paramuricea grandis*), *P. resedaeformis*, *K. ornata*, and *Radicipes gracilis*. Most of these have large (> 30 cm) fan-like skeletons, with the exception of *A. arbuscula* and *R. gracilis*, which are usually smaller.

Acanella arbuscula (Fig. 1M) had the highest frequency of all gorgonians (n = 318) with concentrations on the shelf edge and slope of southeast Baffin Island, Hawke Chan-

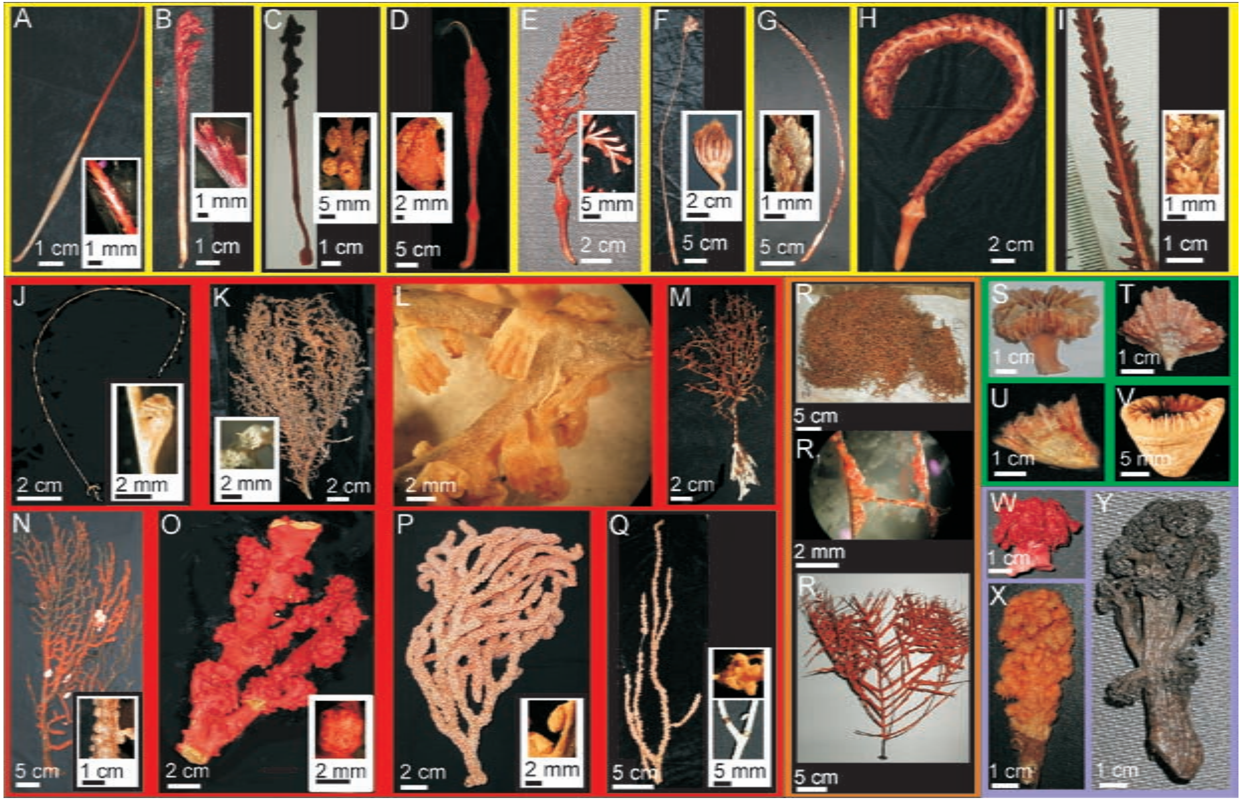

Figure. 1. Deep-sea coral specimens collected off Newfoundland, Labrador, and Baffin Island. Order Pennatulacea: (A) *Distichoptilum gracile*; (B) *Pennatula phosphora*; (C) *Kophobelemnon stelliferum*; (D) *Pennatula aculeata*; (E) *Pennatula grandis*; (F) *Umbellula lindahli*; (G) *Halipteris finmarchia*; (H) *Anthoptilum grandiflorum*; (I) *Funiculina quadrangularis*. Order Alcyonacea: (J) *Radicipes gracilis*; (K) *Acanthogorgia armata*; (M) *Acanella arbuscula*; (N) *Paramuricea* spp.(?); (P) *Primnoa resedaeformis*; (Q) *Keratoisis ornata*; (L) *Anthothela grandiflora*; (O) *Paragorgia arborea*; (W) *Anthomastus grandiflorus*; (X) *Gersemia rubiformis*; (Y) *Capnella florida*. (R) Order Antipatharia (?). Order Scleractinia: (S) *Desmophyllum dianthus*; (T) *Flabellum alabastrum*; (U) *Dasmosmilia lymani*; (V) *Vaughanella margaritata*.* (?) = species not confirmed.

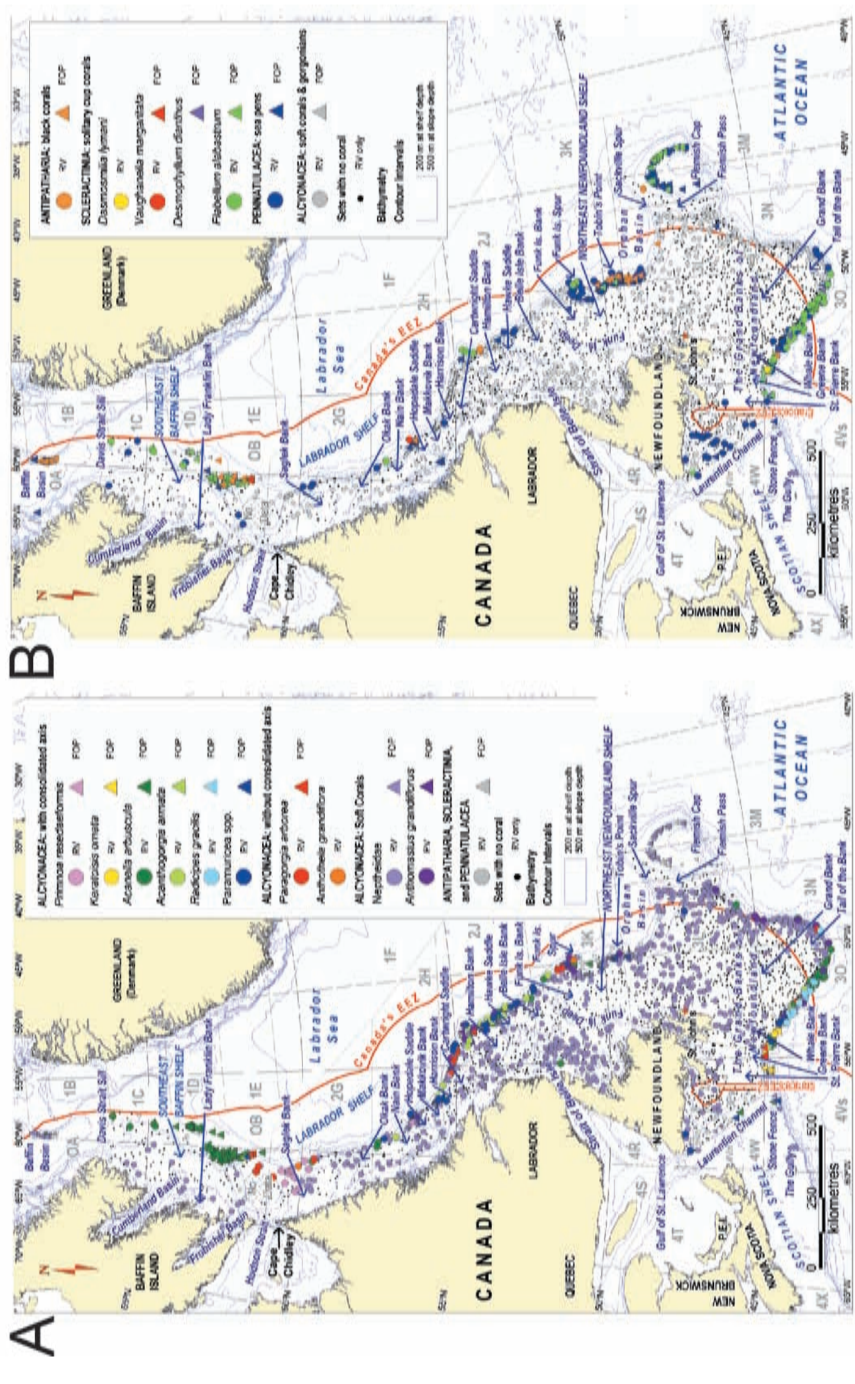

Figure 2. (A) Distribution of alcyonaceans in scientific surveys (RV) 2003–2006 and fisheries observer data (FOP) 2004–2006. (B) Distribution of Pennatulaceans, solitary scleractinians, and antipatharians in scientific surveys (RV) 2003–2006 and fisheries observer data (FOP) 2004–2006.

nel, Funk Island Spur, and southwest Grand Bank (Fig. 2A). Depth of this species ranged between 154–1433 m with average depths > 822 m. Individual colonies were usually < 15 cm high, red, bush-like, and supported by a distinctly banded stem and calcareous root-like base. Polyps were located at opposite angles on brittle segmented branches. Samples were usually damaged and captured in multiples with several tows acquiring 50–100 individual colonies per tow.

Acanthogorgia armata (Fig. 1K) had the second highest frequency of this group (n = 74) with concentrations off: southeast Baffin Island, Hawke Channel, Tobin's Point, and the southwest Grand Bank. Depth for this species ranged between 171–1415 m with average depths > 513 m. Individual colonies were < 50 cm in height, characterized by dense yellow-beige branches with long narrow polyps that have crown like tips. Many samples were covered with juvenile gooseneck barnacles (*Lepas* sp. Linnaeus) and Icelandic scallops (*Chlamys islandica* Müller, 1776). As well, two samples were attached to two separate *K. ornata* colonies.

Paramuricea samples are believed to be *P. grandis* based on spicule analysis, but *P. placomus* may also be present. When grouped, *Paraumuricea* spp. had the third highest occurrence of this group (n = 49), with most of these concentrated on the continental slope off the Labrador Shelf—Northeast Newfoundland Shelf, and the continental slope off the southwest Grand Bank. One sample was captured as far north as the Hudson Strait and a second sample was captured as far south as the Tail of the Bank. Depth for this genus ranged between 152–1415 m, with most samples recovered at average depths > 594 m. Individual colonies were flexible and fan shaped in one plane, and ranged between 20–85 cm in height. Polyps were short, round, and compressed to the branch. All specimens were black with the exception of one vivid orange sample photographed ~1 hr after capture (Fig. 1N). Samples were seldom observed with a substrate attached even though holdfasts were present. Several samples were attached to cobbles and one sample (50 cm tall fan) was firmly attached to a large subfossil *K. ornata* base. The lifespan of this *K. ornata* colony was likely to be several centuries, based on known growth rates of *Keratoisis* sp. from the family Isididae (Roark et al., 2005).

Primnoa resedaeformis (Fig. 1P), for the most part, were not widely distributed (n = 28). Most were found off Saglek Bank, with five other samples documented on the north end of Hamilton Bank on the Labrador Shelf. Depth for this species ranged between 162–1157 m with average depths > 402 m. Two samples on Saglek Bank were captured at depths of 162 m and 165 m; the remaining colonies occurred at slope depths down to 1157 m. Individual colonies were < 35 cm in height and were characterized by dense downward-directed yellow or pink polyps covering a rigid dark brown skeleton. Cross-sections of the stem revealed concentric growth rings alternating between calcite and gorgonin (Andrews et al., 2002; Sherwood et al., 2005). Four subfossil *P. resedaeformis* skeletons were submitted, but not mapped, the largest being ~ 35 cm from the base to the truncated tips of the branches.

Keratoisis ornata (Fig. 1Q) was only found on the southwest Grand Bank (n = 30) between 43°52´N–45°00´N and 52°10´W–55°35´W. Depth of this species ranged between 195–1262 m with average depths > 491 m. Individual colonies were < 50 cm with the majority of the samples submitted being either fragments of the original colony or large masses that were severely damaged in trawls. The skeletons are rigid and characterized by thick white calcified branches with proteinaceous internodes. Polyps ranged in density from thick mats to sparse polyps on a predominantly bare skeleton. One rare intact sample, captured by longline gear, had many associated species encrusting on the axis or attached among the branches. The notable species were the solitary scleractinian *D. dianthus*, gorgonian *A. armata*, and numerous juvenile Icelandic scallops and gooseneck barnacles.

Radicipes gracilis (Fig. 1J) were distributed on the southwest Grand Bank only (n = 28). Depth of this species ranged between 384–1419 m with average depths > 981 m. Individual colonies were < 80 cm in height and consisted of a single coiled or twisted iridescent axis. Polyps were sparse but evenly spaced on the stem and the entire colony was supported by a calcareous root-like holdfast.

The final group belonging to the alcyonaceans are the gorgonians that lack a consolidated axis. Two species were documented: *P. arborea* and *Anthothela grandiflora*. *Paragorgia arborea* (Fig. 1O) (n = 27) were clustered in an area adjacent to the Hudson Strait and off the northeast shelf of Hamilton Bank. The remainder were sporadically distributed off Cape Chidley, Funk Island Spur, and the Grand Bank slope. Depth of this species ranged between 370–1277 m with average depths > 481 m. Most samples were small, fragmented pieces (< 25 cm); no whole intact colonies were collected. Polyps were usually retracted inside bulbous branch tips. Samples were either red, yellow-beige or salmon colour. One particular set from the Northern Shrimp Survey captured 50 kg of *P. arborea* from an area adjacent to the Hudson Strait (61°22´N, 61°10´W). The subsample was forwarded to DFO and consisted of a large laterally compressed midsection of the main stem (25 cm in length and 11 cm in diameter) and several branch tips. *Anthothela grandiflora* (Fig. 1L) had only two small samples submitted from RV surveys; one sample from off Cape Chidley, Labrador at 528 m and a second sample from the Funk Island Spur at 918 m. Both samples were identified using polyp morphology and sclerite descriptions (cf. Verseveldt, 1940; Miner, 1950).

The order Antipatharia (Fig. $1R_{1,2}$) was represented by two species, *Stauropathes arctica*, and probably *Bathypathes* sp. (S. France, Univ. of Louisiana, pers. comm.). See Figure 2B for antipatharian distributions. The majority of the samples were from observers with only two samples from scientific surveys. Antipatharians were widely distributed on the continental slope in deep waters from Baffin Basin to southwest Grand Bank (n = 37). Three clusters emerged: southeast Baffin Basin (North of Davis Strait sill), southeast Baffin shelf (south of Davis Strait sill), and on the southwest slope of the Orphan Basin (Tobin's Point area). Depth of this species ranged between 745–1287 m with average depths > 1027 m. Two growth forms were observed among samples: *S. arctica* (Pax, 1932; Opresko, 2002) with an open-branched skeleton (Fig. $1R_2$), and a compressed "tumbleweed-like" form referred to as *Bathypathes* sp. (Fig. 1R). A 45 cm long × 30 cm wide × 15 cm high specimen of the tumbleweed form, captured at 1013 m off the northwest Flemish Cap, was the largest antipatharian recorded.

The order Scleractinia was represented by four solitary cup corals: *F. alabastrum*, *D. dianthus*, *Vaughanella margaritata*, and *Dasmosmilia lymani*. Cup corals were distributed along the continental shelf edge and slope with concentrations off the southwest Grand Bank and southeast Baffin Island. See Figure 2B for scleractinian distributions.

Flabellum alabastrum (Fig. 1T) distributions were clustered off the Southeast Baffin Shelf, the Flemish Cap, and southwest Grand Bank (n = 141). To a lesser extent, other occurrences were noted off the slope of the Northeast Newfoundland Shelf and Labrador Shelf. Depth ranged between 218–1433 m with average depths > 629 m. *Flabellum alabastrum* samples were identified by the corallum and compressed calice (cf. Cairns, 1981). *Vaughanella margaritata* samples (n = 4) were documented off the Southeast Baffin Shelf and east of the Hopedale Saddle. Depth of this species ranged between

1163–1320 m with average depths > 1199 m. Three samples with multiple specimens of living and subfossil *V. margaritata* per sample, were captured by benthic gillnets targeting Greenland halibut off the Southeast Baffin Shelf. One specimen, missing a holdfast, was captured in a RV survey east of the Hopedale Saddle (Fig. 1V).

Desmophyllum dianthus (Fig. 1S) samples were submitted only by observers (n = 2). Both samples were from the southeast Grand Bank; one sample was captured at 1052 m by benthic gillnet gear and the second sample, which was attached to a *K. ornata* colony, was captured at 713 m by longline gear. In addition one subfossil specimen, not included in the dataset, was captured by a gillnet at 1125 m off the Southeast Baffin Shelf. *Dasmosmilia lymani* (Fig. 1U) was only documented once off the southwest slope of Grand Bank (44°52´N, 54°23´W) at 457 m. All scleractinians were identified by gross morphology of the corallum, and confirmed by S. Cairns, Smithsonian Institution.

The order Pennatulacea (Fig. 1A–I) was represented by 11 types of sea pen. Nine sea pens were identified to species level, and two have yet to be determined. See Figure 2B for pennatulacean distributions. Pennatulaceans were distributed along the edge of the continental shelf east of Baffin Basin, off southeast Baffin Island, Tobin's Point, the Flemish Cap, and the southwest Grand Bank (n = 577). The greatest diversity of sea pens was found near the southwest Grand Bank. Species were found at depths between 96–1433 m. Individual colonies varied in size between 10–80 cm. Specimens were identified by peduncle, rachis, and polyp morphology (cf. Williams, 1995, 1999). *Anthoptilum grandiflorum* (Fig. 1H) and *Pennatula phosphora* (Fig. 1B) were the most abundant followed by *Halipteris finmarchia*, *Funiculina quadrangularis*, and *Pennatula grandis* (Table 1). Numerous samples of *H. finmarchia* were observed with commensal sea anemones *Stephanauge nexilis* (Verrill, 1883) firmly attached to the rachis (cf. Miner, 1950). Samples that were damaged beyond identification to genus, were grouped as "sea pen spp.", as were observer records of sea pens.

Coral species richness hotspots.—Based on maps of scientific survey data, two coral species richness hotspots were identified (Fig. 3). The first hotspot (Fig. 4A) was situated on the Labrador continental slope between Makkovik Bank (55°30´N, 57°05´W) and Belle Isle Bank (52°00´N, 51°00´W). The second hotspot (Fig. 4B) was located off southwest Grand Bank and Tail of the Bank (~42°50´–45°10´N, 49°00´–55°00´W). Both areas had higher species richness per tow than sets surrounding them and higher frequencies of scientific survey stations containing corals than surrounding areas. Southwest Grand Bank and Tail of the Bank had the greatest species richness (16 spp.), with nine alcyonaceans, five pennatulaceans, and two scleractinians recorded. Makkovik Bank-Belle Isle Bank hotspot (14 spp.) had seven alcyonaceans, four pennatulaceans, two scleractinians, and one antipatharian recorded. Species richness per tow based on scientific survey data ranged between 0 and 11 species per set with only two sets capturing nine or more species.

Discussion

Distribution maps presented contribute to the growing knowledge of deep-sea coral distribution and diversity off Newfoundland, Labrador, and southeast Baffin Island. Thirteen alcyonaceans, two antipatharians, four solitary scleractinians, and 11 pennatulaceans were documented. Corals were more widely distributed on the continental edge and slope than previously thought, but only nephtheids were found on top of the shelf.

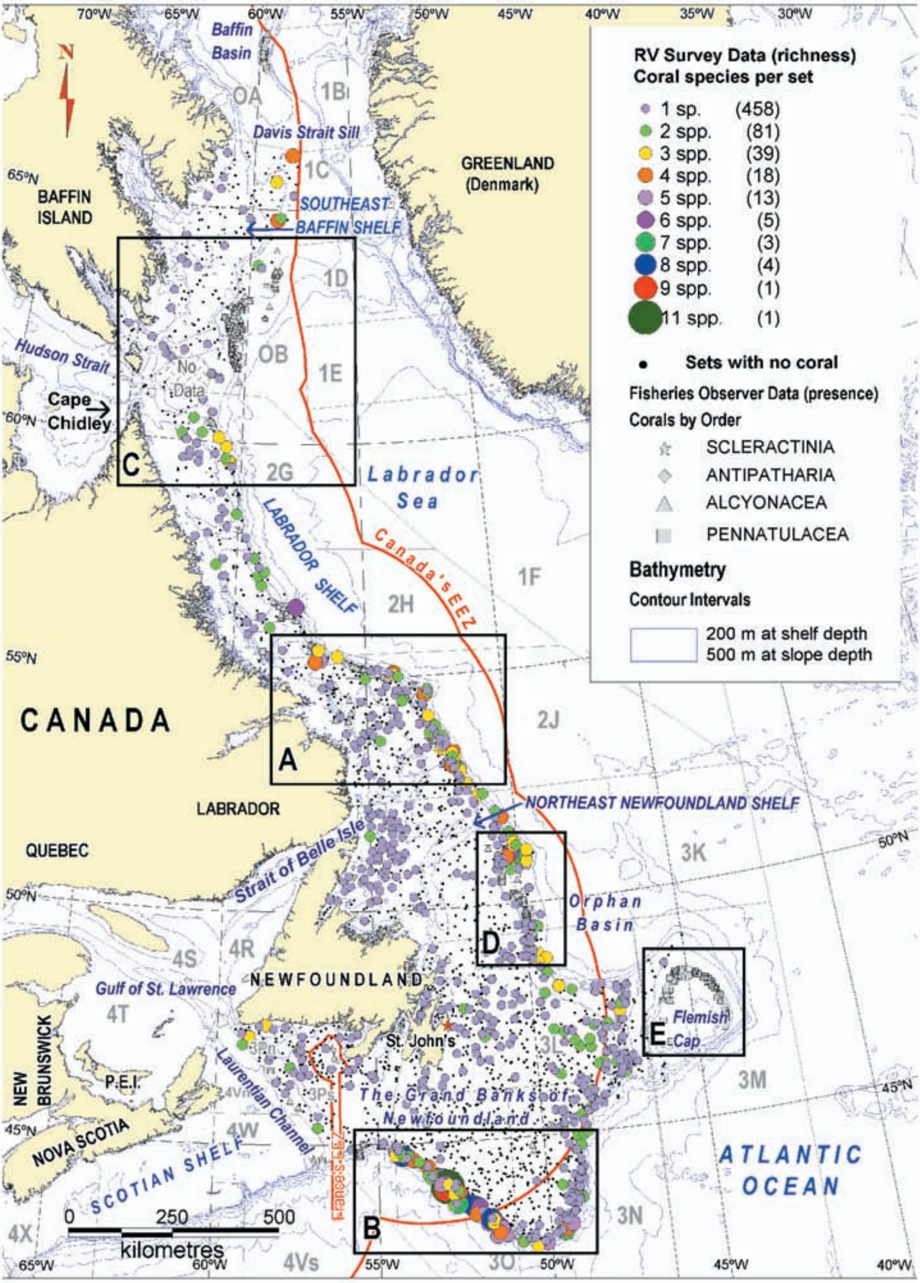

Figure 3. Coral species richness per set in scientific survey data. Most speciose areas were (A) Makkovik Bank to Belle Isle Bank, and (B) southwest Grand Bank. Distribution of coral rich areas from DFO survey data and fisheries observer data: (C) Southeast Baffin Shelf to Cape Chidley, (D) Funk Island Spur to Tobin's Point, and (E) Flemish Cap.

Only ahermatic corals were identified with no occurrence of the reef building *Lophelia pertusa* (Linnaeus, 1758), as reported at the Stone Fence, Scotian margin (Gass and Willison, 2005; Mortensen et al., 2006). The present study documented hundreds more unique records than previously known, and with much more complete and systematic data coverage than was previously available. Many of the coral-rich areas in this study were identified previously by Gass and Willison (2005). Their results partially overlapped with the findings presented in this study off Cape Chidley, Northeast Newfoundland Shelf, and the Grand Banks of Newfoundland.

Distribution of hotspots.—Coral species richness hotspots were identified in two distinct locations. The hotspot on the southwest Grand Bank and Tail of the Bank had the greatest species richness in the study with 16 coral species documented. The topography of this area is complex with steep slopes, and numerous canyons. The area is most likely influenced by warm Labrador slope water (cf. Haedrich and Gagnon, 1991). Previous reports from fisheries observers and local fishermen indicated the presence of corals in this region, but very little data from scientific surveys had been documented (Gass and Willison, 2005; Mortensen et al., 2006). The second hotspot extended along the continental shelf edge and slope of the Labrador Shelf from Makkovik Bank to Belle Isle Bank. It spanned the greatest area and included 14 coral species. Most corals were concentrated on the shelf edge and slope with some neptheid soft corals on the bank tops. *Acanella arbuscula* and soft corals were the most abundant species, as both dominated the Funk Island Spur along with several species of sea pens (i.e., *A. grandiflorum*, *P. phosphorea*, and *P. grandis*). Rare species were documented in this area, with one occurrence of *A. grandiflora* off the Funk Island Spur at 918 m and one occurrence of *V. margaritata* at 1320 m off Hopedale Saddle. Jourdan (1895) reported *V. margaritata* (= Caryophyllia) was common off the south side of the Flemish Cap at 1267 m, but only one sample was collected from the Labrador slope and several samples east of the Hudson Strait.

Topography of the southern Labrador Shelf encompasses five banks (> 200 m), three saddles (> 500 m), and two shelves. The Labrador Current flows along the edge of the Labrador shelf and branches at Hamilton Bank (Lazier and Wright, 1993). The main stream continues along the edge and slope of the Newfoundland Shelf, while the secondary branch of the Labrador Current continues inshore along the coasts of Labrador and Newfoundland (Lazier and Wright, 1993). Gass and Willison (2005) also made reference to corals on the southern Labrador slope but did not identify it as a biodiversity hotspot. They documented sporadic coral occurrences off Harrison Bank using fisheries observer reports, off Hamilton Bank using fishers' LEK, off the slope Northeast Newfoundland Shelf using DFO surveys and fishers' LEK, and off the south slope of Orphan Basin using fishers' LEK. Gass and Willison (2005) documented *P. arborea* near Tobin's Point, southwest Grand Bank, "trees" on the southern margin of the Orphan Basin, and *A. arbuscula* and "trees" on the southern Labrador slope. By contrast, *P. arborea* was relatively rare in the current study. Scarcity of *P. arborea* in the current study may reflect depletion of this large species by fisheries damage.

Other areas of interest.—When observer data were mapped in conjunction with survey data three additional areas of interest were identified: the area from southeast Baffin Shelf to Cape Chidley (Fig. 4C), Funk Island Spur to Tobin's Point (Fig. 4D), and the north side of the Flemish Cap (Fig. 4E). The coral clusters identified at Cape Chidley

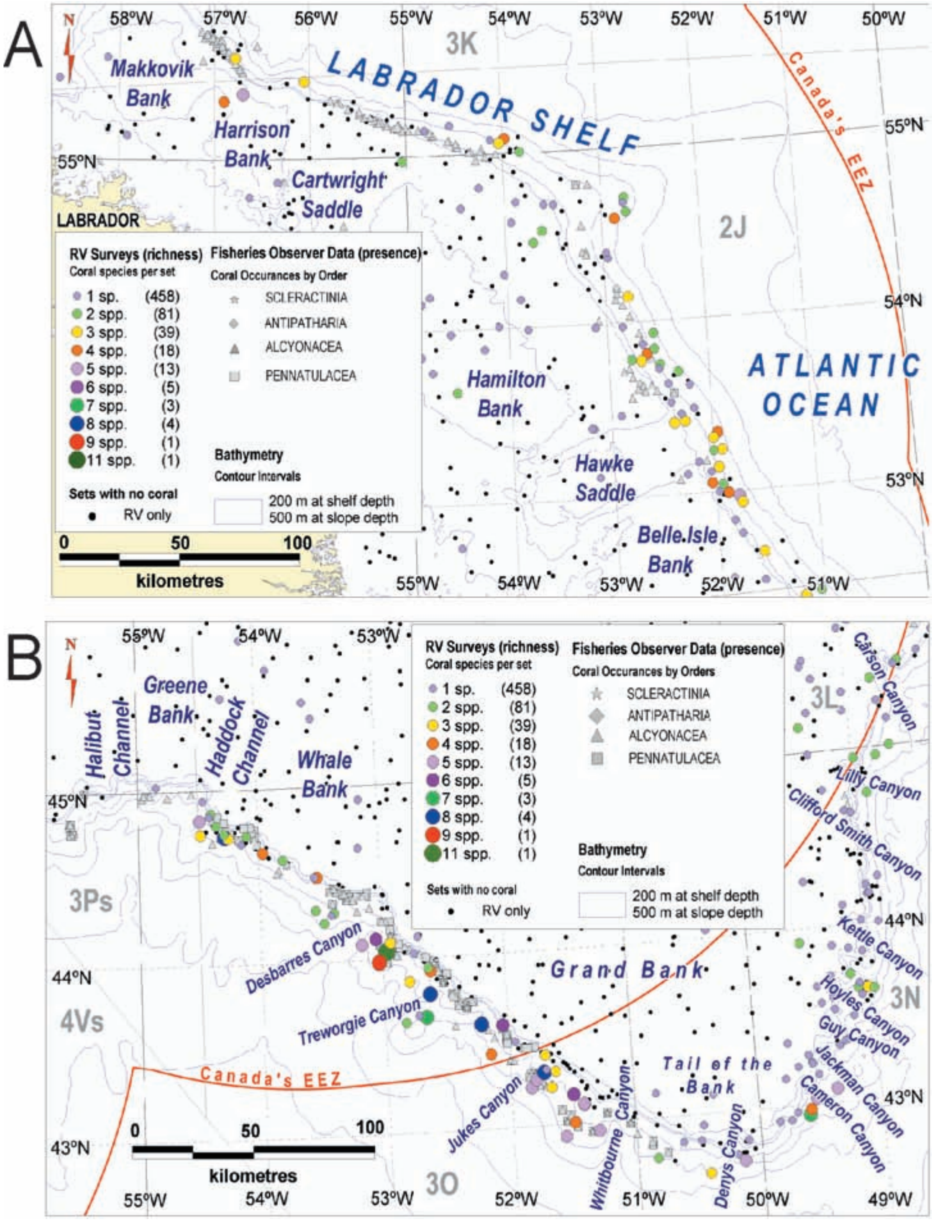

Figure 4. (A) Coral species richness per set in scientific survey data and coral occurrences by Order from fisheries observer data for Makkovik Bank-Belle Isle Bank Hotspot. (B) Coral species richness per set in scientific survey data and coral occurrences by Order from fisheries observer data for southwest Grand Bank and Tail of the Bank.

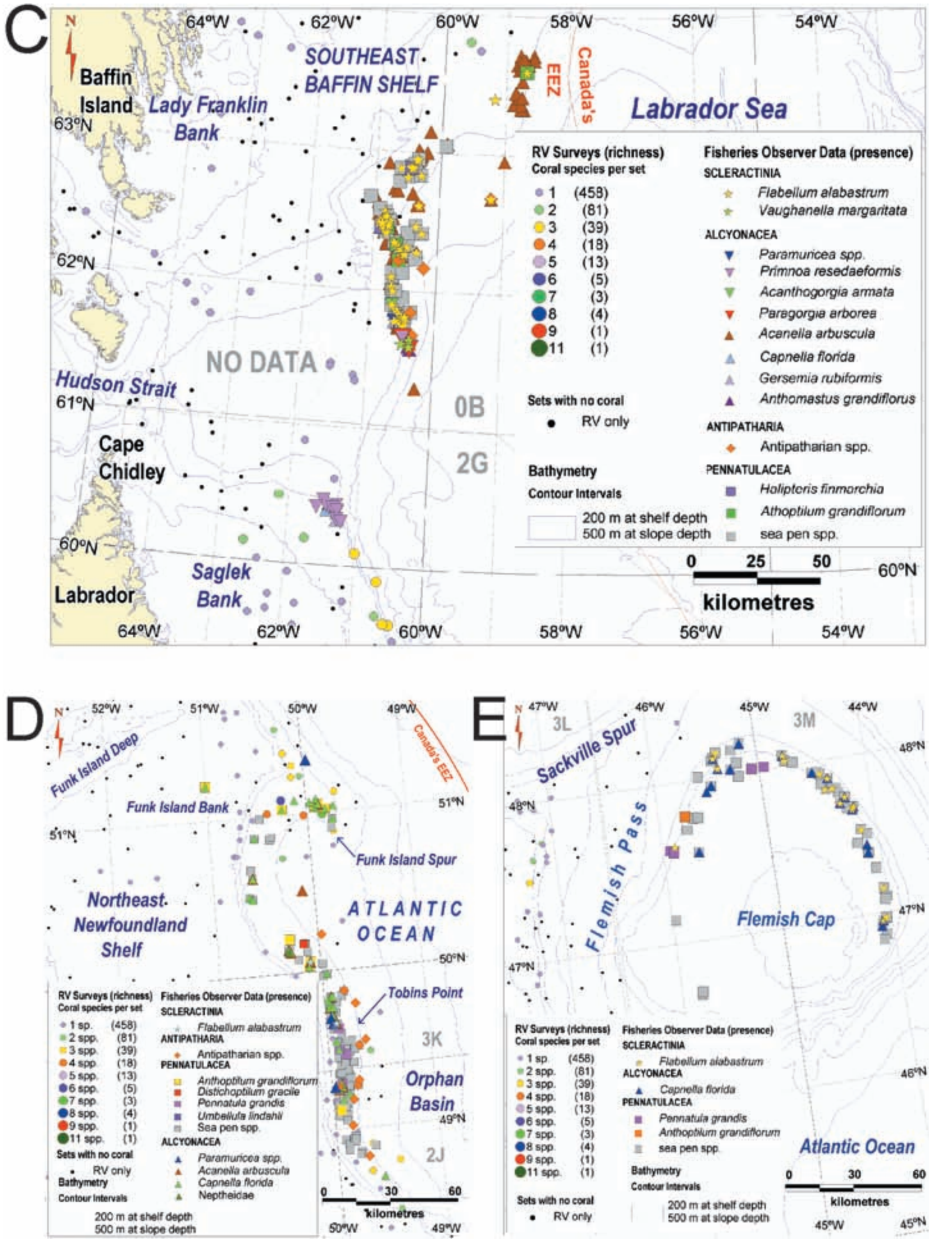

Figure 4. Continued. (C) Coral species richness per set in scientific survey data and coral occurrences by species from fisheries observer data for Southeast Baffin Shelf-Cape Chidley area. (D) Coral species richness per set in scientific survey data and coral occurrences by species from fisheries observer data for Funk Island Spur-Tobin's Point. (E) Coral species richness per set in scientific survey data and coral occurrences by species from fisheries observer data for the Flemish Cap area.

and Southeast Baffin Shelf were dominated by gorgonians, especially *Primnoa resedaeformis*, which was most abundant off Cape Chidley, based on only one year of survey data. This area was not identified as a biodiversity hotspot in the current analysis, but recent unpublished data and past reports suggest high coral abundance and intermediate coral biodiversity. High densities of *P. resedaeformis* were documented off Cape Chidley by MacIsaac et al. (2001) and Gass and Willison (2005). The area immediately east of Hudson Strait (~61°20´N, 62°30´W) was not surveyed, nor were observer data available. Nonetheless, the largest samples submitted for this study were collected from the outer edges of this area with many large gorgonians documented, primarily *P. resedaeformis* and *P. arborea* (Gass and Willison, 2005). 2006 Northern Shrimp Survey sets within this area recovered up to 500 kg of coral, mostly *P. resedaeformis* and *P. arborea* in a single tow (Wareham and Edinger, unpubl. data). The Hudson Strait region is influenced by strong currents and high nutrient flows from both the Labrador Current and Arctic waters from the Hudson Strait (Drinkwater and Harding, 2001). Observer samples and records of *A. arbuscula* were most numerous off Southeast Baffin Shelf. This area is intensively fished for Greenland halibut and northern shrimp. Coral records from surveys, observer reports, and fishers' LEK were previously documented off southeast Baffin Island (Davis Strait) and Cape Chidley (MacIsaac et al., 2001; Gass and Willison, 2005).

Tobin's Point, off the northeast Newfoundland Shelf is intensively fished for Greenland halibut, shrimp, and snow crab (*Chionecetes opilio*). The coral species reported there were dominated by *C. florida*, sea pens, and antipatharians. The Flemish Cap had mostly the neptheid *C. florida*, sea pens, the scleractinian *F. alabastrum*, and one antipatharian. Numerous juvenile *A. grandiflorus* (n = 541) were documented on the northeast side of the Flemish Cap but were not documented within the time frame of this study (Wareham and Edinger, unpubl. data). The Flemish Cap was not covered by Canadian scientific surveys, so coral distributions were derived only from observer data. The clustering of corals on the north side of the Flemish Cap may be an artifact of fishing effort, which was concentrated on the smooth north side of the cap. The south side is deeply incised by canyons, making it difficult terrain for trawling; the south side of the cap may contain suitable habitat for a variety of corals, but has had relatively little sampling effort to date. In general, the top of banks had the lowest coral diversity with only nephtheids present. Most corals are probably incapable of colonizing the top of banks due to limited hard substrates and cold temperatures (cf. Mortensen et al., 2006).

Substrates of coral biodiversity hotspots and other areas of interest.—Information on surficial geology has been sparse and limited to Soviet Fishing Investigations by Litvin and Rvachev (1963), and highly generalized maps of surficial geology of the continental margin of Eastern Canada focusing on the bank tops (Fader and Miller, 1986; Piper et al., 1988). Substrates for each hotspot and other areas of interest are discussed separately.

The Grand Banks of Newfoundland (Grand, Whale, Green, and St. Pierre Banks) are relatively shallow and are heavily influenced by wave action. Sand dominates the bank top, with gravel, shell beds, and muddy-sand patches throughout (Fader and Miller, 1986). The edge and slope are a veneer of adlophous sands and gravels. Substrates on the slope progressively change with depth from sand-mud to mud (Litvin and Rvachev, 1963; Piper et al., 1988).

The Flemish Cap and Flemish Pass are located in international waters just east of Grand Bank. Flemish Cap is a dome-shaped plateau ranging from 150 to 350 m deep.

Cap substrates are dominated by sand and shell beds, which change to muddy sand-sandy mud and boulders on the slope; mud is predominant at slope depths > 1000 m (Litvin and Rvachev, 1963). The Flemish Pass is a 1200 m deep trough that separates the Flemish Cap from the Grand Bank. Flemish Pass is strongly influenced by the Labrador Current. Substrates in the Flemish Pass consist mostly of sandy mud with some pebbles and stones (Litvin and Rvachev, 1963). The Northeast Newfoundland Shelf includes Funk Island Bank, Funk Island Spur, and Tobin's Point. Substrates abruptly change from sand on top of the Funk Island Bank at ~ 300 m, to sandy-mud on the slope at ~ 500 m, to mud off Funk Island Spur at > 1000 m (Litvin and Rvachev, 1963). The Labrador Shelf extends along the entire coastline of Labrador, with the widest section off Hamilton Bank. Transverse troughs up to 600 m deep divide the shelf into banks (Piper et al., 1988). Sand substrates dominate southern bank tops with scattered pebbles and gravel; slope composition changes rapidly with depth from muddy-sand to sandy-mud to mud. Hawke Saddle, located south of Hamilton Bank, has a mud substrate at 500 m but changes to sandy-mud on the saddle slope towards the shelf edge (Litvin and Rvachev, 1963). There is little information available on slope substrates north of Harrison Bank on the Labrador Shelf and Baffin Island Shelf.

Comparison with local ecological knowledge (LEK).—Many of the coral areas identified by fishers' LEK (Gass and Willison, 2005) were confirmed with scientific survey and observer data in the current study. Nonetheless, several important differences emerged. First, the current data suggest that there is much more continuous coral habitat along the southern Labrador slope, with a wider variety of corals than indicated from LEK. Second, the southwest Grand Bank and the Tail of the Bank hotspot, identified in the current study as an area of high species richness and coral record density, was much less prominent in LEK data or in previously available scientific survey data. These discrepancies between studies may largely be a result of more complete scientific survey sampling efforts throughout the Newfoundland and Labrador region. In the current study, the lack of large gorgonian records on the southeast Grand Bank, and the relative scarcity of *P. arborea* samples may reflect loss of corals due to trawling impacts. Evidence of deleterious effects on deep-sea corals by mobile fishing gear (e.g., trawls) has been published in detail (Watling and Norse, 1998; Auster and Langton, 1999; Fosså et al., 2002; Hall-Spencer et al., 2002; Anderson and Clark, 2003), mostly focusing on the effects of trawling on deep-sea scleractinians, with limited attention to impacts on deep-sea gorgonians (Krieger, 2001; Mortensen et al., 2005, Stone, 2006). In the current study, mobile gears captured more corals than fixed gears, and in general, covered larger areas. The duration of trawl tows ranged between 1 and 10 hrs per tow, making the precision of coral localities from observer data highly variable. Although the deep-sea coral clusters recognized by fishers have persisted despite a long history of intensive deep-water trawl fishing in the region (cf. Kulka and Pitcher, 2002), there is little information on changes in abundances of deep-sea corals through time (Gass and Willison, 2005).

Associated invertebrate diversity.—A variety of sessile invertebrates were observed growing commensally on deep-sea corals in this study. Although trawl samples tend to underestimate associated invertebrate diversity of corals (Buhl-Mortensen and Mortensen, 2005), samples from fixed gear (e.g., longline and gillnet) have contributed many intact coral assemblages, or groups of coral living together in what appears to be commensal relationships. For example, two colonies of *A. armata* were found to be attached to two separate *K. ornata* colonies, one of which also included the scleractinian *D. dianthus*. Another *K. ornata* sample had juvenile colonies of *A. grandiflorus* and *A. armata* attached. Many observations of gooseneck barnacles, Icelandic scallops, sea anemones, and echinoderms, all juveniles, were attached to *K. ornata*. Many nephtheid soft corals were observed attached to living gastropods. These observations suggest that hard substrates may be limited in some areas, and emphasize the important contribution that large corals can make towards creating and structuring deep-sea habitat, including habitat for other deep-sea corals. The nature of associations between corals and fish are difficult to determine in trawl survey data because fish and corals may have co-occurred in the same habitat without any direct biological interaction (Edinger et al., 2007).

Limitations and conservation implications.—The findings reported here complement earlier work (Gass and Willison, 2005), and provide specific information on deep-sea coral distribution and diversity in the region. However, caution must be exercised when interpreting these results for three reasons. First, the data resulted from only 3 yrs of sampling, with only 1 yr of scientific sampling in northern Labrador and the Davis Strait, and with sampling gaps in scientific data. Second, the distribution data from fisheries observers were biased by fishing effort. Finally, point maps imply a greater degree of sampling area coverage than the area actually surveyed in the present work. Coral conservation is a fairly new concept in Eastern Canada. Three areas with unique features including very high densities of corals or unique species occurrences were established on the Scotian margin to help protect corals: the Northeast Channel Coral Conservation Area (2002), the Stone Fence *Lophelia* reef fisheries closure (2004), and The Gully Marine Protected Area (2004; Breeze and Fenton, 2007). Corals in Newfoundland and Labrador waters are generally widespread along the continental edge and slope. Hence a network of representative areas would be the most appropriate conservation approach (cf. Fernandes et al., 2005).

Acknowledgments

We thank all the fisheries observers, DFO technicians, and Canadian Coast Guard personnel that helped contribute to the study. J. Firth, P. Veitch, D. Orr, and K. Gilkinson (DFO) made invaluable contributions and provided moral support. We thank the Northern Shrimp Research Foundation for coral data from the Northern Labrador and Baffin Island regions. R. Devillers (MUN) and T. Bowdring (DFO) assisted in generating maps. S. Gass provided guidance and raw data on prior records including LEK records. DFO Science division provided logistical support. P. Etnoyer, S. France, K. Gilkinson, R. Haedrich, O. Sherwood provided useful critiques of the manuscript. Study supported by the Department of Fisheries and Oceans, Oceans and Habitat Division, NSERC Discovery grant to E. E., and by Memorial University. Special thanks to our families and friends for their ongoing support, and never-ending patience.

Literature Cited

Anderson, O. F. and M. R. Clark. 2003. Analysis of by-catch in the fishery for orange roughy *Hoplostenthus atlanticus*, on the south Tasman Rise. Mar. Freshwat. Res. 54: 643–652.

Andrews, A. H., E. E. Cordes, M. M. Mahoney, K. Munk, K. H. Coale, G. M. Cailliet, and J. Heifetz. 2002. Age, growth, and radiometric age validation of a deep-sea, habitat forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. Hydrobiologia 471: 101–110.

Auster, P. J. 2005. Are deep-water corals important habitats for fishes? Pages 747–760 *in* A. Freiwald and J. M. Roberts, eds. Cold-water corals and ecosystems. Springer-Verlag, Heidelberg.

__________ and R. W. Langton. 1999. The effects of fishing on fish habitat. Am. Fish. Soc. Symp. 22: 150–187.

Bayer, F. M. 1981. Key to the genera of Octocorallia exclusive of Pennatulacea (Coelenterata: Anthozoa), with diagnoses of new taxa. Proc. Biol. Soc. Wash. 94: 902–947.

Breeze, H. and D. G. Fenton. 2007. Designing management measures to protect cold-water corals off Nova Scotia, Canada. Pages 123–133 *in* R. Y. George and S. D. Cairns, eds. Conservation and adaptive management of seamount and deep-sea coral ecosystems. Rosenstiel School of Marine and Atmospheric Science, University of Miami. Miami. 324 p.

________, D. S. Davis, M. Butler, and V. Kostlyev. 1997. Distribution and status of deep sea corals off Nova Scotia. Marine Issues Committee Special Publication1, Ecology Action Centre, Halifax.

Buhl-Mortensen, L. and P. B. Mortensen. 2005. Distribution and diversity of species associated with deep-sea gorgonian corals off Atlantic, Canada. Pages 771–805 *in* A. Freiwald and J. M. Roberts, eds. Cold-water corals and ecosystems. Springer-Verlag, Heidelberg.

Cairns, S. D. and R. E. Chapman. 2001. Biogeographic affinities of the North Atlantic deep-water Scleractinia. Pages 30–57 *in* J. H. M. Willison, J. Hall, S. E. Gass, E. L. R. Kenchington, M. Butler, and P. Doherty, eds. Proc. First Int. Symp. on Deep-Sea Corals. Ecology Action Centre, Halifax.

Collins, J. W. 1884. On the occurrence of corals on the Grand Banks. Bull. U.S. Fish. Comm. 237.

Deichmann, E. 1936. The Alcyonaria of the western part of the Atlantic Ocean. Mem. Mus. Comp. Zool. 53: 1–317 + 37 plates.

Drinkwater, K. F. and G. C. Harding. 2001. Effects of the Hudson Strait outflow on the biology of the Labrador Shelf. Can. J. Fish. Aquat. Sci. 58: 171–184.

Edinger, E. N., V. E. Wareham, and R. L. Haedrich. 2007. Patterns of groundfish diversity and abundance in relation to deep-sea coral distributions in Newfoundland and Labrador waters. Pages 101–122 *in* R. Y. George and S. D. Cairns, eds. Conservation and adaptive management of seamount and deep-sea coral ecosystems. Rosenstiel School of Marine and Atmospheric Science, University of Miami. Miami. 324 p.

Fader, G. B. and R. O. Miller. 1986. A reconnaissance study of the surficial and shallow bedrock geology of the southeastern Grand Banks of Newfoundland Geol. Surv. Can. Pap. 86-1B: 591–604.

Fernandes, L., J. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De'Ath, B. Mapstone, H. Marsh, H. H. Possingham, I. Ball, T. Ward, K. Dobbs, J. Aumend, D. Slater, and K. Stapleton. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conserv. Biol. 19: 1733–1751.

Fosså, J. H., P. B. Mortensen, and D. M. Furevik. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia 471: 1–12.

Freiwald, A. and J. M. Roberts, eds. 2005. Cold-water corals and ecosystems. Springer-Verlag, Berlin Heidelberg.

Gass, S. E. and J. H. M. Willison. 2005. An assessment of the distribution of deep-sea corals in Atlantic Canada by using both scientific and local forms of knowledge. Pages 223–245 *in* A. Freiwald and J. M. Roberts, eds. Cold-water corals and ecosystems. Springer-Verlag, Heidelberg.

GEBCO. 2003. GEBCO digital atlas: centenary edition of the IHO/IOC general bathymetry of the oceans. National Environment Research Council, Swindon, UK.

Haedrich, R. L. and J. M. Gagnon. 1991. Rock wall fauna in a deep Newfoundland fiord. Cont. Shelf. Res. 11: 1199–1207.

Hall-Spencer, J., V. Allain, and J. H. Fosså. 2002. Trawling damage to Northeast Atlantic ancient coral reefs. Proc. R. Soc. Lond., B. 269: 507–511.

Harding, G. C. 1998. Submarine canyons: deposition centers for detrital organic matter? Pages 105–107 *in* W. G. Harrison and D. G. Fenton, eds. The Gully; A scientific review of its environment and ecosystem. Dept. Fish Oceans, Can. Stock. Assess. Secr. Res. Doc. 98/83, Dartmouth. 202 p.

Hecker, B., G. Blechschmidt, and P. Gibson. 1980. Final report-Canyon assessment study in the Mid and North Atlantic areas of the U.S. outer continental shelf. US Dept. Interior, Bureau of Land Management, Washington, DC. Contract No BLM-AA551-CT8-49.

Jourdan, E. 1895. Zoanthaires provenant des campagnes du yacht l'Hirondelle (Golfe de Gascogne, Açores, Terra-Neuve). Rés. Camp. Scient. Prince de Monaco. 8: 1–36.

Krieger, K. L. 2001. Coral (*Primnoa*) impacted by fishing gear in the Gulf of Alaska. Pages 106–116 *in* J. H. M. Willison, J. Hall, S. E. Gass, E. L. R. Kenchington, M. Butler, and P. Doherty, eds. Proc. First Int. Symp. on Deep-sea Corals. Ecology Action Centre and Nova Scotia Museum, Halifax,

___________ and B. L. Wing. 2002. Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. Hydrobiologia 471: 83–90.

Koslow, J. A., G. W. Boehlert, J. D. M. Gordon, R. L. Haedrich, P. Lorance, and N. Parin. 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. ICES J. Mar. Sci. 57: 548–557.

Kulka, D. W. and J. R. Firth. 1987. Observer Program Training Manual-Newfoundland Region. Canadian Technical Report of Fisheries and Aquatic Sciences No 1355 (Revised). 197 p.

__________ and D. A. Pitcher. 2002. Spatial and temporal patterns in trawling activity in the Canadian Atlantic and Pacific. ICES CM 2001/R:02. 57 p.

Lazier, A., J. E. Smith, M. J. Risk, and H. P. Schwarcz. 1999. The skeletal structure of *Desmophyllum cristagalli*: the use of deep-water corals in sclerochronology. Lethaia 32: 119–130.

Lazier, L. R. N. and D. G. Wright. 1993. Annual velocity variations in the Labrador Current. J. Phys. Oceanogr. 23: 659–678.

Litvin, V. M. and V. D. Rvachev. 1963. The bottom topography and sediments of the Labrador and Newfoundland fishing areas. Pages 100–112 *in* Y. Y. Marti, ed. Translated from Russian. United States Department of the Interior and the National Science Foundation.

MacIsaac, K., C. Bourbonnais, E. Kenchington, D. Gordon, and S. Gass. 2001. Observations on the occurrence and habitat preference of corals in Atlantic Canada. Pages 58–75 *in* J. H. M. Willison, J. Hall, S. E. Gass, E. L. R. Kenchington, M. Butler, and P. Doherty, eds. Proc. First Int. Symp. on Deep-sea Corals. Ecology Action Centre and Nova Scotia Museum, Halifax.

McCallum, B. R. and S. J. Walsh. 1996. Groundfish survey trawls used at the Northwest Atlantic fisheries centre, 1971-present. Doc. 96/50. Serial No. N2726. 18 p.

Miner, R. W. 1950. Field book of seashore life. G. P. Putnam's Son, New York. 215 p.

Mortensen, P. B. and L. Buhl-Mortensen. 2004. Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Mar. Biol. 144: 1223–1238.

______________ and ______________. 2005a. Morphology and growth of the deep-water gorgonians *Primnoa resedaeformis* and *Paragorgia arborea*. Mar. Biol. 147: 775–788.

______________ and ______________. 2005b. Deep-water corals and their habitats in the The Gully, a submarine canyon off Atlantic Canada. Pages 247–277 *in* A. Freiwald and J. M. Roberts, eds. Cold-water corals and ecosystems. Springer-Verlag, Heidelberg.

______________, ______________, and D. C. Gordon, Jr. 2006. Distribution of deep-water corals in Atlantic Canada. Pages 1832–1848 *in* Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B. E. Casareto, K. Nadaoka, H. Yamano, and M. Tsuchiya, eds. Proc. 10th Int. Coral Reef Symp., Okinawa.

______________, ______________, D. C. Gordon, Jr., G. B. J. Fader, D. L. McKeown, and D. G. Fenton. 2005. Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. Am. Fish. Soc. Symp. 41: 369–382.

Nesis, K. I. 1963. Soviet investigations of the benthos of the Newfoundland-Labrador fishing area. Pages 214–222 *in* Y. Y. Marti, ed. Translated from Russian. United States Department of the Interior and the National Science Foundation.

Opresko, D. M. 2002. Revision of the Antipatharia (Cnidaria: Anthozoa). Part II. Schizopathidae. Zool. Med. Leiden. 76: 411–442.

Piper, D. J. W., G. D. M. Cameron, and M. A. Best (comp.) 1988: Quaternary geology of the continental margin of eastern Canada; Geological Survey of Canada, Map 1711A, scale 1:5,000,000.

Risk, M. J., J. M. Heikoop, M. G. Snow, and R. Beukens. 2002. Lifespans and growth patterns of two deep-sea corals: *Primnoa resedaeformis* and *Desmophyllum cristagalli*. Hydrobiologia 471: 125–131.

Roark, E. B., T. P. Guilderson, S. Flood-Page, R. B. Dunbar, B. L. Ingram, S. J. Fallon, and M. McCulloch. 2005. Radiocarbon-based ages and growth rates of bamboo corals from the Gulf of Alaska, Geophys. Res. Lett., 32, L04606, doi:10.1029/2004GL021919.

Sherwood, O. A., D. B. Scott, and M. J. Risk. 2006. Late Holocene radiocarbon and aspartic acid racemization dating of deep-sea octocorals. Geochimica et Cosmochimica Acta 70: 2806–2814.

Stone, R. P. 2006. Coral habitat in the Aleutian Islands of Alaska: depth distribution, fine-scale species associations, and fisheries interactions. Coral Reefs 25: 229–238.

Tendal, O. S. 1992. The North Atlantic distribution of the octocoral *Paragorgia arborea* (L., 1758) (Cnidaria, Anthozoa). Sarsia 77: 213–217.

__________. 2004. The Bathyal Greenlandic black coral refound: alive and common. Deep-sea newsletter [Serial online]; 33. 28-30. Available from: http://www.le.ac.uk/biology/gat/deepsea/DSN33-final.pdf via the Internet. Accessed 10 Sept. 2005.

Thrush, S. F. and P. K. Dayton. 2002. Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. Annu. Rev. Ecol. Syst. 2002. 33: 449–473.

Verseveldt, J. 1940. Studies on Octocorallia of the families Briareidae, Paragorgiidae and Anthothelidae. Temminckia 5: 1–142.

Watling, L. and P. J. Auster. 2005. Distribution of deep-water Alcyonacea off the Northeast Coast of the United States. Pages 279–296 *in* A. Freiwald and J. M. Roberts, eds. Cold-water corals and ecosystems. Springer-Verlag, Heidelberg.

_________ and E. A. Norse. 1998. Disturbance of the seabed by mobile fishing gear: a comparison to forest clear cutting. Conserv. Biol. 12: 1180–1197.

Williams, G. C. 1995. Living genera of sea pens (Coelenterata: Octocorallia: Pennatulacea): illustrated key and synopses. Zool. J. Linn. Soc. 113: 93–140.

____________. 1999. Index Pennatulacea: Annotated bibliography and indexes of the sea pens (Coelenterata: Octocorallia) of the world 1469–1999. Proc. Calif. Acad. Sci. 51: 19–103.

ADDRESSES: (V.E.W.) *Environmental Science Program, Memorial University, St. John's, Newfoundland and Labrador, Canada; and Fisheries and Oceans Canada, St. John's, Newfoundland and Labrador, Canada A1C 5X1.* (E.E.) *Geography Dept. and Biology Dept., Memorial University, St. John's, Newfoundland and Labrador, Canada A1B 3X9.* CORRESPONDING AUTHOR: (V.E.W.) *E-mail: <warehamv@dfo-mpo.gc.ca>.*