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Coldwater Corals off Newfoundland and Labrador:

Distribution and Fisheries Impacts

Evan Edinger, Krista Baker, Rodolphe Devillers,
Vonda Wareham

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Photo on cover © CSSF 2006. (CSSF stands for Canadian Scientific Submersible Facility). This photo was taken during the 2006 Discovery Corridor Cruise off Nova Scotia. *Primnoa resedaeformis*, *Paragorgia arborea*, and an unidentified skate are visible.

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Abstract

Corals comprise an important component of benthic biodiversity and structural habitat complexity in the deep (coldwater) marine ecosystem. Unfortunately, little is known about their distributions, life-history traits, and trends in bycatch off Newfoundland and Labrador despite decades of activities in these areas.

Coral records from the Fisheries Observer Program and scientific survey coral databases compiled by Memorial University and Fisheries and Oceans Canada were used to illustrate the distribution of coral bycatch and highlight the commercial fisheries and gear types responsible for significant disturbance to corals. These data consist of presence/absence records of coral per fishing set.

Corals appeared to be distributed along the edge of the continental slope. Gorgonian corals, which are thought to be most sensitive to disturbance because they are long-lived and have stiff skeletons, were most diverse along the southeast Labrador continental slope and the edge and slope of the southwest Grand Banks.

Areas with highest concentrations of coral bycatch in scientific surveys and commercial fisheries did not consistently coincide with areas of highest fish species richness, except near the southwest Grand Banks. Bycatch frequencies were normalized for fishing effort by calculating the percentage of fishing sets containing corals of a given functional group (e.g. large gorgonians) within 20x20 km cells. Peak regions of coral bycatch were consistent among fisheries and gear types and occurred in the Hudson Strait – Davis Strait, Funk Island Spur to Tobin's Point (southeast Labrador to the edge of the northeast Newfoundland shelf), and southwest Grand Banks. These three areas had high bycatch of all coral functional groups, including large gorgonians. Bycatch of soft corals, sea pens, and cup corals had a secondary peak on the north side of the Flemish Cap.

Overall, the Greenland halibut (*Reinhardtius hippoglossoides*) fishery had the highest number of sets containing corals, but the Atlantic halibut (*Hippoglossus hippoglossus*) fishery had the highest percentage of sets with corals per 20x20 km cell. The Atlantic cod (*Gadus morhua*) fishery and redfish (*Sebastes* spp.) gillnet fishery had no coral bycatch. Trawling (regardless of directed species) had the highest number of sets with corals. However, it also had the most observer coverage and the lowest average percentage of sets with corals per 20x20 km grid cell.

Comparison of bycatch with the scientific surveys suggests that distribution of coral bycatch in commercial fisheries was controlled primarily by coral distributions and only secondarily by fishing effort. Coral bycatch was not specific to particular gear types or directed species. Therefore, marine protected areas established for corals should be closed to all fishing, rather than closed to particular gear types or directed species. Marine protected areas for corals could be established and used to protect areas with high coral densities and/or diversities.

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List of Abbreviations

CCGS:	Canadian Coast Guard Ship
DFO:	Department of Fisheries and Oceans Canada
ESSIM:	Eastern Scotian Shelf Integrated Management
FOP:	Fisheries Observer Program
MPA:	marine protected area
SS:	scientific survey

1. Introduction

Coldwater corals occur worldwide along continental slopes, seamounts, and mid-ocean ridges, but knowledge of their distribution is strongly biased by research effort (Roberts et al. 2006). Coldwater corals include a variety of cnidarians, including both solitary and colonial scleractinian corals (stony corals) such as the reef-building *Lophelia pertusa*, skeletal and non-skeletal octocorals (gorgonians and soft corals), antipatharians (black corals), and sea pens.

Coldwater corals likely play important roles in structuring deep marine habitats. Corals are important as physical substrates, feeding sites, and shelter for invertebrates and fish, including both commercial and non-commercial species. A wide variety of fish, including both commercial and non-commercial species, were more abundant and larger on *Lophelia pertusa* reefs than in non-coral habitats (Husebø et al. 2002). Gorgonian coral gardens in Alaska contained ten megafaunal groups associated with *Primnoa* (Krieger and Wing 2002), and high densities of fish, including commercially fished species (Stone 2006). By contrast, some research from coldwater coral areas without carbonate buildups indicated that the relationship between coldwater corals and fish was merely coincidental (Tissot et al. 2006). Nevertheless, the fact that corals often co-occur with high diversities and/or densities of fish and provide habitat for a wide diversity of marine invertebrates (Jensen and Frederiksen 1992; Buhl-Mortensen and Mortensen 2005) suggests they may be useful as a flagship group for marine conservation, irrespective of whether the relationships between fish and corals are functional or coincidental (Edinger et al. 2007).

Coldwater corals are long-lived and sensitive to mechanical damage (Hall-Spencer et al. 2002; Roberts et al. 2006). These characteristics make them vulnerable to some types of fisheries (Mortensen et al. 2005; Stone 2006). Bycatch records from seamount fisheries, such as the orange roughy (*Hoplostethus atlanticus*) fishery in the southern ocean, have shown rapid depletion of coldwater coral. Decline is indicated by exponential declines in coral bycatch rates in fewer than 10 years (Anderson and Clarke 2003). Climate change and ocean acidification are additional potential threats to coldwater corals with calcium carbonate (aragonite) skeletons (Guinotte et al. 2006). Scleractinian corals use aragonite to build their skeletons, and it is projected that 70% of coral locations that were in aragonite-saturated waters during the pre-industrial times will not be by 2099 (Guinotte et al. 2006).

Marine protected areas (MPAs) in a variety of forms have been used to safeguard regions where coldwater corals are particularly abundant or diverse. In Nova Scotia waters, three closed areas were established to protect coldwater corals as part of the Maritimes Region Coral Conservation Plan (ESSIM Planning Office 2006). The Gully Marine Protected Area was gazetted as a marine protected area under the Oceans Act in 2004. The Northeast Channel Coral Conservation Area (created in 2002) and the Stone Fence *Lophelia* reef closed area (created in 2004) were both established as fisheries closures under the Fisheries Act.

As an initial step in designing a conservation plan for coldwater corals in Newfoundland and Labrador waters, the distribution of coral and fisheries impacts on corals must be examined.

Coral distributions have been mapped using fisheries bycatch as an important source of data (Breeze et al. 1997; MacIsaac et al. 2001; Gass and Willison 2005; Wareham and Edinger 2007). Coldwater corals are strictly heterotrophic, depending on particulate organic matter such as plankton for their food, and tend to be most abundant in areas of strong bottom currents. Because most colonial scleractinians and gorgonians require hard substrates upon which to grow, their distributions are strongly controlled by surficial geology (Mortensen and Buhl-Mortensen 2004).

The frequencies of coral bycatch in different fisheries and gear types have never been analyzed in Canadian waters. The current report presents preliminary maps of coral bycatch frequencies in various commercial fisheries in the Newfoundland and Labrador region, analogous to the recently released status report for coldwater corals in the United States (Morgan et al. 2006). Maps are preliminary because data are available for only two fishing years.

This report has five main objectives:

(1) To compare incidence and distribution of coldwater coral bycatch among bottom-contact fisheries off Newfoundland and Labrador using maps of bycatch in each fishery.

(2) To compare maps of coldwater coral bycatch between gear types.

(3) To compare patterns of bycatch in commercial fisheries with coral distribution maps from scientific surveys.

(4) To determine effort-normalized areas of peak coral bycatch.

(5) To compare areas of peak coral diversity and peak coral bycatch with areas of high fish diversity.

This report provides crucial mapping information for the development of a coral conservation strategy, analogous to the Maritimes Region Coral Conservation Plan (ESSIM Planning Office 2006) in Newfoundland and Labrador waters. Statistical analyses of the bycatch data, including spatial statistics, will be published separately in appropriate peer-reviewed journals.

2. Methods

2.1 Data Collection and Organization

Two datasets were obtained from the Department of Fisheries and Oceans (DFO) Canada (Newfoundland) and used for analysis: the Fisheries Observer Program (FOP) dataset and the scientific survey (SS) dataset. The SS data highlight coral distribution in DFO scientific surveys and northern shrimp surveys between 2003 and 2005 (Wareham and Edinger 2007). The FOP data include coral bycatch records in the observer program between 2004 and 2006 (Wareham and Edinger 2007). The study area and underwater features are displayed in Figure 1.

2.1.1 Fisheries Observer Program Data

The FOP database documents the occurrence of corals caught in commercial fisheries as part of the observer program, which monitored coral bycatch off Newfoundland and Labrador between 2004 and 2006. Observers were issued coral identification sheets with species descriptions, and they attended brief coral identification training sessions in March 2004 and 2005. They were asked to record corals on set/catch datasheets and collect one voucher specimen of each species encountered on a single trip. They were requested to record wet weight of corals landed, but the minimum weight value was 1 kg; this is much heavier than the expected average wet weight of corals collected. Many observers recorded coral presence, but not abundance. Accordingly, FOP coral data were limited to presence-absence within each fishing set.

The FOP database contained approximately 45,000 sets from a wide range of fisheries and gear types. Data analysis was limited to only those sets that had the potential to affect corals. Therefore, only observer records from bottom-contact fisheries in waters deeper than 125 m were considered. This depth cutoff was chosen because nearly all of the coral species found off Newfoundland occur in waters deeper than 150 m (Wareham and Edinger 2007). A final database of 31,504 fishing sets was analyzed for this report.

The directed species and associated gear types considered are listed in Table 1. Although scallop dredges are bottom gear with high potential to impact sessile benthos (Gilkinson et al. 2005), no coral bycatch records were reported from the scallop dredges in the data analyzed for this report.

Table 1. Fisheries off Newfoundland and Labrador with available observer data: directed species and gear types considered in this analysis. See Figure 1 for location of NAFO zones.

Common name	Scientific name	Gear types	NAFO zones
Atlantic cod	*Gadus morhua* (L.)	Cod trap, otter trawl, gillnet, handline	3Pn, 3Ps, Gulf
Deepwater redfish Golden redfish	*Sebastes mentella* (Travin, 1951) *Sebastes marinus* (L.)	Otter trawl, gillnet	All zones
Greenland halibut	*Reinhardtius hippoglossoides* (Walbaum, 1792)	Otter trawl, twin trawl, triple trawl, gillnet, longline	All zones, no otter trawl in 3N, 3O, 3Ps
Atlantic halibut	*Hippoglossus hippoglossus* (L.)	Longline	3M, 3N, 3Ps
Northern shrimp	*Pandalus borealis* (Kroyer, 1838), *P. montagui* (Leach, 1814)	Shrimp trawl, twin trawl, triple trawl	All zones
Snow crab/Queen crab	*Chionectes opilio* (Fabricius, 1788)	Crab pot	All zones

The positional accuracy of sets (i.e. latitude and longitude) was first checked visually on a map. Several sets were found to be on land and sets with obvious errors were removed from the analysis. This was done in collaboration with DFO in order to check the original set/catch datasheets and to ensure these errors were not created when the data were digitized. Positional accuracy was also assured by comparing reported depths with the GEBCO World Bathymetric database. These bathymetric data record the average depth on a 1 minute (lat/long) grid. Those records for which the difference exceeded 300 m were verified against the original set/catch datasheets. Erroneous position data were corrected. In other cases, the extreme difference in depth was verified by the point's position. These points were usually at coastal sites in deep fjords. An additional randomly selected 1% of sets were verified against the set/catch datasheets and checked for data entry errors

2.1.2 Scientific Survey Data

Scientific survey data were used as a measure of coral distributions not biased by fishing effort. Surveys were conducted as part of the DFO multi-species stock assessment and structured as a random-stratified sampling design. Surveys used a Campelen 1800 shrimp trawl, with 15 minute tows conducted along depth contour, for an average tow length of 1.4 km. Corals encountered were collected by DFO groundfish survey technicians aboard *CCGS Wilfred Templeman* and *CCGS Teleost* between September 2003 and January 2006. Specimens were then identified and tabulated at Memorial University of Newfoundland. A total of 2,194 sets were analyzed (Wareham and Edinger 2007).

Northwest Atlantic Location Map

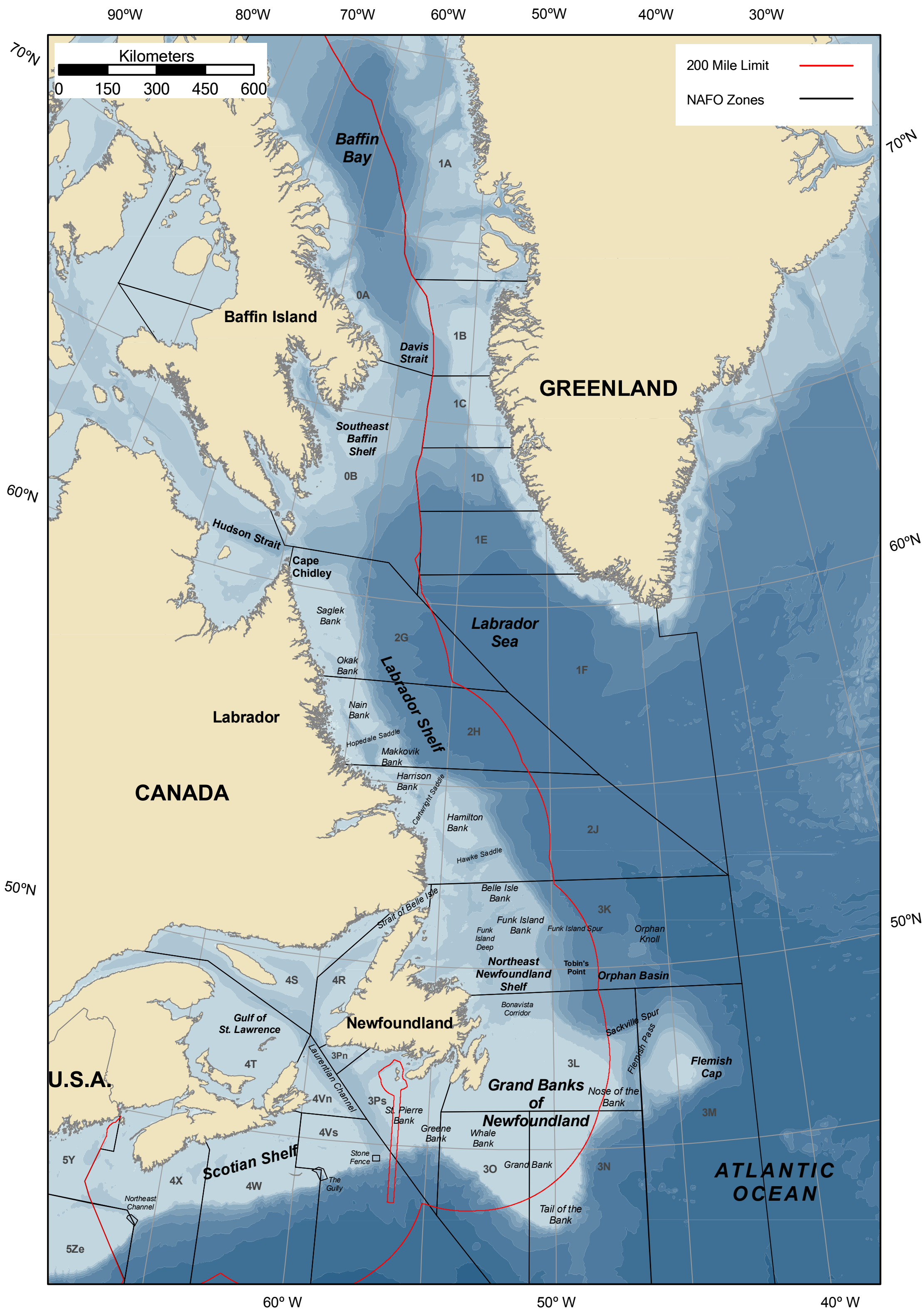

Figure 1: Location map. Important underwater features in Newfoundland and Labrador waters, including features identified by fishermen (e.g. Tobin's Point) and current coral conservation areas in the Maritimes region.

2.2 Data Analysis

Corals were divided into five functional groups based on taxonomy, growth form, and size (Edinger et al. 2007). The species belonging to each functional group are outlined in Table 2. Large gorgonians and antipatharians (group 5) live decades to hundreds of years (Mortensen and Buhl-Mortensen 2004; Sherwood et al. 2005), have rigid to semi-flexible skeletons composed of calcium carbonate and/or protein, and can reach heights greater than 1 m.

Small gorgonians (group 4) have carbonate or protein skeletons reaching heights less than 1 m. These corals frequently occur on mud bottoms, where they may provide biologically important structure in deep, soft-sediment environments. *Acanella* in particular was locally abundant in some trawls, with individual counts reaching tens to hundreds (Wareham and Edinger 2007). Recent observations in deep waters off Nova Scotia found high densities of *Acanella* at 1500 m off the Northeast Channel (Discovery Corridor Cruise, unpublished data).

Cup corals (group 3) include solitary scleractinian corals, some of which can occur free-lying on sand or mud bottoms (*Flabellum*), while others are found attached to bedrock or cobble-boulder substrates (e.g. *Desmophyllum*). *Desmophyllum* can live for hundreds of years, while *Flabellum* is thought to be shorter-lived, although this species has received very little study.

The flexible sea pens (group 2) have a foot that lies inserted into sand or mud, allowing them to retract during sediment disturbance or possibly to recover after being dislodged.

The soft corals (group 1) are non-skeletal alcyonacean corals that fully retract when disturbed. They are most commonly found attached to gravel or shell fragments on sand or mud substrates. No longevity studies have been carried out on soft corals, but the soft coral *Gersemia rubiformis* can spawn when stressed by physical disturbance (Henry et al. 2003).

Table 2. Species belonging to each coral functional group. Pictures and descriptions of the corals found off Newfoundland and Labrador can be found in Appendix 2.

Coral functional group	Definition and species included
5	**Large gorgonian or antipatharian corals:** *Primnoa resedaeformis* (Gunnerus, 1763), *Paragorgia arborea* (L.), *Keratoisis ornata* (Verrill, 1878), *Acanthogorgia armata* (Verrill, 1878), *Paramuricea* spp. (*P. placomus* (L.) or *P. grandis* (Verrill, 1884)), *Bathypathes arctica* (Lütken, 1871).
4	**Small gorgonian corals:** *Acanella arbuscula* (Johnson, 1862), *Radicipes gracilis* (Verrill, 1884), or *Anthothela grandiflora*.
3	**Cup corals:** *Flabellum alabastrum* (Moseley, 1873), *Vaughanella margaritata* (Jourdan, 1895), *Desmophyllum dianthus* (Esper, 1794), or *Desmosmilia lymani* (Pourtalès, 1871).
2	**Sea pens, various pennatulaceans:** *Distichophyllum gracile* (Verrill, 1882), *Funiculina quadrangularis* (Pallas, 1766), *Halipteris finmarchia* (Sars, 1851), *Pennatula grandis* (Ehrenberg, 1834), *Pennatula* spp., *Umbellula lindahli* (Kölliker, 1875), and five other species of sea pens as yet unidentified.
1	**Soft corals:** *Gersemia rubiformis* (Ehrenberg, 1834), *Gersemia* spp., *Duva (Capnella) florida* (Verrill, 1869), *Anthomastus grandiflorus* (Verrill, 1878).

These functional groups also roughly correspond to ranked sensitivity to trawling disturbance. Corals with carbonate skeletons are more sensitive than non-skeletal corals, because if skeletal corals are dislodged they cannot re-attach. Sensitivity to disturbance is generally correlated with longevity (Huston 1994). Large gorgonian and antipatharian corals (group 5) are the longest-lived, with the least flexible skeletons, and hence probably the set of species most sensitive to damage from fishing gear. Longevity of the small gorgonians *Acanella arbuscula*, *Radicipes gracilis*, and *Anthothela grandiflora* has not been studied, but their smaller size suggests a shorter lifespan and hence lesser sensitivity to damage. Cup corals (group 3) are dominated by *Flabellum*, which is likely able to survive disturbance from fisheries on sand and mud substrates. Although the other groups of corals are considered less sensitive to fisheries damage, they may be locally important as fish habitat, either on a functional basis, or as coincidental occurrence in areas of preferred habitat for certain fish species (Edinger et al. 2007).

Coral bycatch maps were produced with soft corals, sea pens, and cup corals (functional groups 1, 2 and 3) aggregated, and with small gorgonian, large gorgonian and antipatharian corals (groups 4 and 5) aggregated to separate the generally less sensitive non-skeletal soft corals, sea pens, and cup corals from the generally more sensitive gorgonians.

2.2.1 Coral Distribution and Species Richness Analysis

The scientific survey (SS) data were used to map species distributions in the GIS software ArcGIS 9.0 (http://www.esri.com) for each functional group of coral. Coral species richness was also mapped. To make SS and FOP coral species richness data directly comparable, all sea pen species in the SS data were aggregated in calculations of coral species richness.

2.2.2 Density Analysis

Fishing effort and coral bycatch incidence were mapped as densities in 20x20 km grids, using the Spatial Analyst extension in ArcGIS 9.0. Coral bycatch incidence per unit area increases with effort, such that areas with peak coral bycatch incidence are the areas suffering the greatest damage from fisheries.

The grid size was determined based on the distribution of points in the scientific surveys, using the smallest grid cell size possible that would allow calculations within cells while preserving the spatial variation in effort density and coral bycatch. A larger-sized cell would have reduced precision along the shelf edge and integrated depth ranges.

The FOP data were examined as a combined dataset, and then each directed species in Table 1 was analyzed separately. The fisheries were broken down further into associated gear types, and the distribution of effort for each gear type (regardless of directed species) was mapped. Trawls, gillnets, and longlines were each considered independently of directed species.

Fishing sets with corals were then mapped from FOP and SS data, separately. Because SS catches were exhaustively searched, the lack of corals at a given set was a reliable indication that corals did not occur in the sample. By contrast, FOP coral bycatch frequencies reported here are considered minimum bycatch estimates, because commercial fishing sets may have contained corals that were not recorded by observers. Missed coral records may result from variability in observer opportunity to search catches, particularly in high-volume catches, a wide range of experience and taxonomic training among observers, and disparate observer coverage among fisheries. While the observers' opportunities to record coral bycatch may have varied systematically between fisheries, variation in observer experience and taxonomic training were assumed to be randomly distributed among fisheries.

Effort density maps all separated cells with 1-3 sets per cell because these cells were removed during calculations of percentage of sets per cell containing corals (see below).

Grid extent (position and size) was kept constant, such that grid cells from the SS and the various FOP fisheries could be compared directly and used for future statistical analysis.

2.2.3 Percentage of Positive Stations

To normalize for variation in fishing effort, data were mapped as percentage of sets with positive coral records. Percentage of positive stations indicates the likelihood that a fishing set in a given location will recover a coral and is a better measure of true coral distribution than coral bycatch incidence, which is biased by fishing effort. We caution that the percentage of positive stations in a given location is prone to decrease over time as coral populations are depleted (Anderson and Clarke 2003).

Normalizing for fishing effort was done by overlaying the effort density layers with the associated coral density layers for a particular fishery and/or gear type. Percentages were also reported in 20x20 km grids. Maps were created twice: first using all available sets and then repeated using only grid cells with more than three sets. Limiting the data to grids with more than three sets helped to ensure that the maps showing percentage of positive stations were not biased by sampling density.

2.2.4 Analysis of Bias

Coral records from the SS and FOP datasets were compared directly using two types of bias analysis. The purpose of the bias analysis was to compare the efficacy of the two sampling programs in recording coral data and to assess the degree to which coral distributions from FOP data were biased by fishing effort.

The first comparison applied only to those 20x20km grid cells with more than three sets in both the SS and FOP datasets. In each of these cells, the percentage of SS sets containing corals was subtracted from the percentage of FOP sets containing corals:

$Bias1_i = [\%positive\ (FOP)_i] - [\%positive\ (SS)_i]$,
where $Bias1_i$ is the difference in percentage in cell (i)
Thus values close to zero indicate agreement between the two datasets, positive values indicate an overestimate of coral occurrences in FOP data, and negative values indicate an underestimate of coral occurrences in FOP data relative to SS data.

The second bias analysis was calculated using a presence-absence matrix, where coral data were reduced to presence or absence of corals in the two datasets, subdivided by coral functional groups:

20x20 km grid cells were grouped into four categories:
(1) Corals absent in both SS and FOP
(2) Corals present in both SS and FOP
(3) Corals present in SS but not in FOP
(4) Corals present in FOP but not in SS

2.2.5 Groundfish Species Richness

Fish species richness was mapped using the SS data from September 2003 to October 2005 (Edinger et al. 2007). Fish species identifications were performed by DFO groundfish technicians at sea.

3. Results

Two hundred and eight maps of corals were produced using data from scientific surveys and fisheries observers. Only those maps with the greatest biological or conservation significance are included in the main body of this report. Appendix 3 provides a full list of the all maps created, which are included on the accompanying CD.

3.1 Scientific Survey Data

3.1.1 Coral Density and Diversity

DFO's scientific surveys found peak concentrations of coral density in several areas of the Newfoundland and Labrador region: from Funk Island Spur to Tobin's Point, on the edge of the Grand Banks, and at the mouth of the Hawke Saddle (Figure 2).

The southwest Grand Banks and the area off Funk Island Bank to the Hopedale Saddle had relatively high coral species richness (Figure 3). Gorgonian corals, which are thought to be most sensitive to disturbance (Edinger et al. 2007), were aggregated near the Hawke Saddle and the edge of the southwest Grand Banks (Figure 4).

3.2 Fisheries Observer Data

The number of sets varied among directed fisheries and gear types (Table 3).

3.2.1 Distribution of Fishing Effort

The total bottom fishing effort in waters deeper than 125 m was distributed broadly along the edge and slope of the continental shelf (Figure 5). Peaks of fishing effort occurred on the shelf edge east of Cape Chidley, northeast of Hopedale Saddle, and southeast of Belle Isle Bank. An apparent gap in fishing effort occurred in a deep area east of the Hudson Strait. This area was not sampled by the Northern Shrimp Survey in 2005 because the industry-run survey had previously reported high frequency of damage to nets from very rough bottom with many corals in that area (David Orr, DFO, personal communication 2005).

The shrimp fishery had the greatest number of sets of all fisheries represented. Effort for shrimp and crab was fairly widespread, but there was a local peak in shrimp effort east of Cape Chidley, Labrador, in a region from which abundant *Primnoa resedaeformis* have been reported (MacIsaac et al. 2001; Gass and Willison 2005). The Greenland halibut fishery was widespread across the entire study area. Pockets of increased effort were located near the Bonavista Corridor, along the shelf edge east of Cape Chidley, and east of Baffin Island. Redfish effort was more widespread, but effort increased greatly along the southwest Grand Banks. The majority of fishing for Atlantic cod took place in NAFO Zone 3P (see Figure 1 for zones). Monkfish and Atlantic halibut effort were greatest on the southwest Grand Banks.

Trawls were by far the most common fishing gear used. The peak areas of trawl effort corresponded with the peak areas of overall fishing effort described above. Peak areas of gillnet use were found in the Bonavista Corridor and along the southwest Grand Banks. Longline gear was used throughout NAFO Zones 2 and 3.

Total Coral Density
(DFO Scientific Surveys, 2003 - 2005)

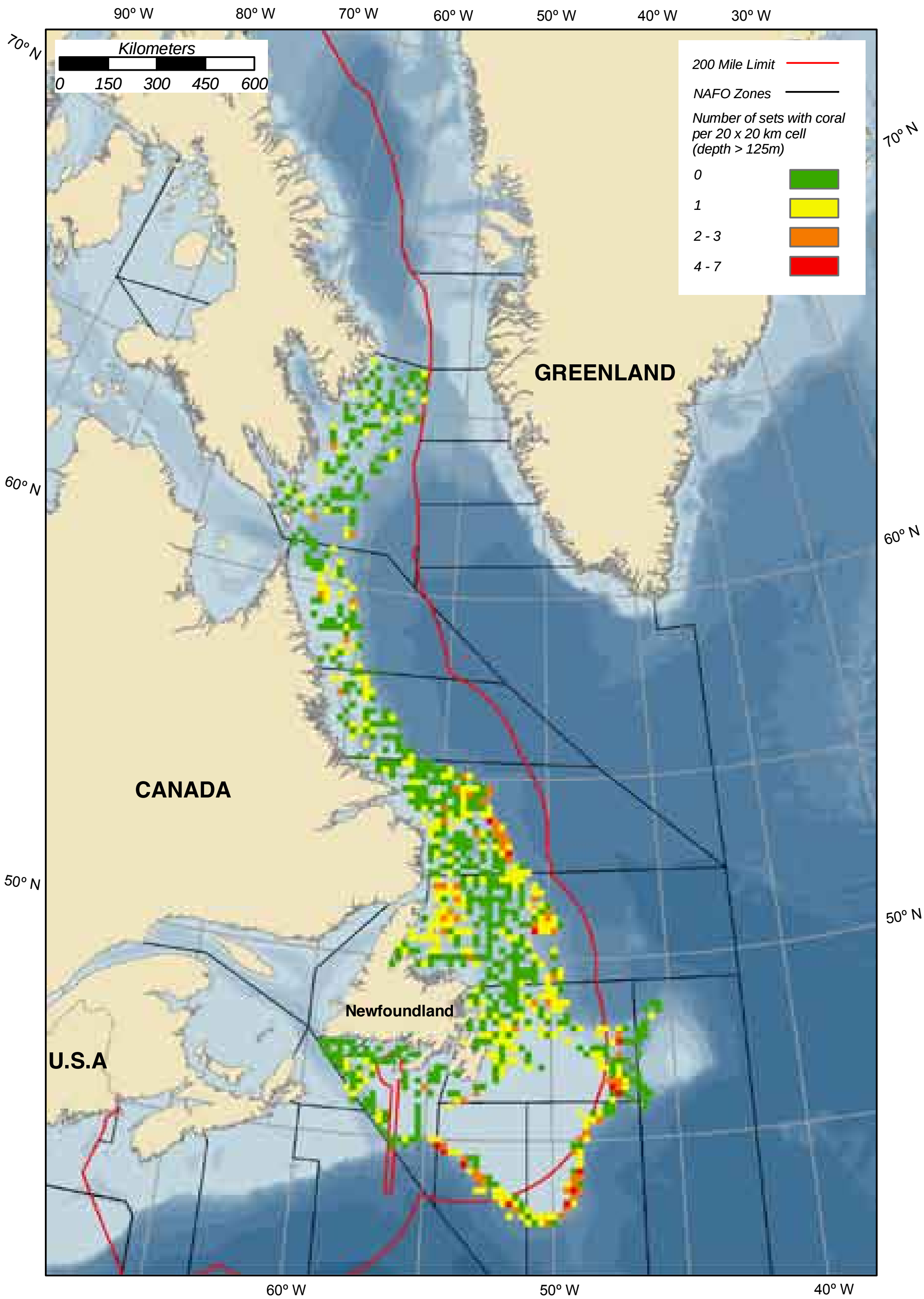

Figure 2: Total frequency of corals in scientific surveys, measured as the number of sets containing corals per 20x20 km cell.

Coral Species Richness
(DFO Scientific Surveys, 2003 - 2005)

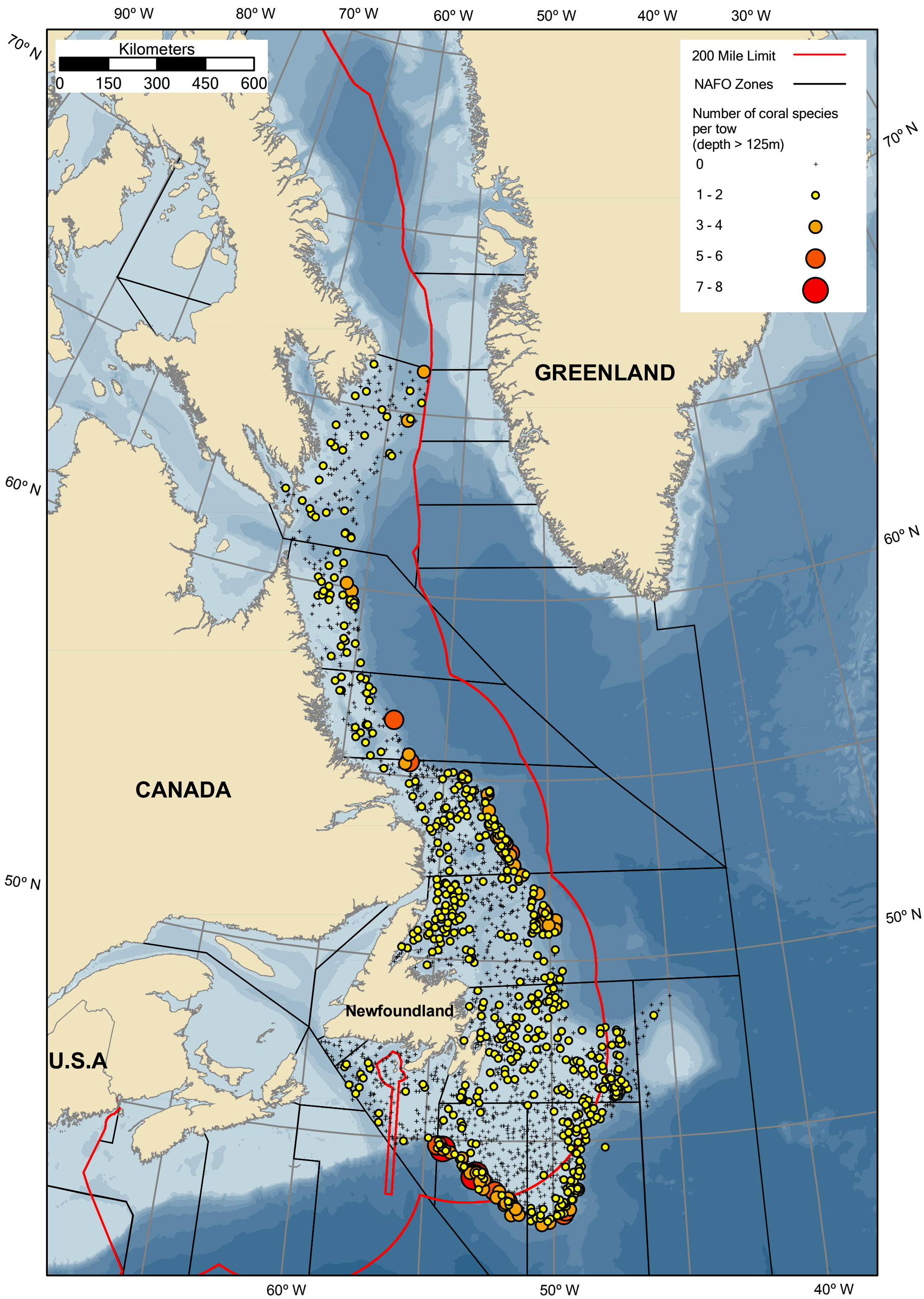

Figure 3: Species richness of deep-sea corals in scientific surveys.

Large Gorgonian Distribution
(DFO Scientific Surveys, 2003 - 2005)

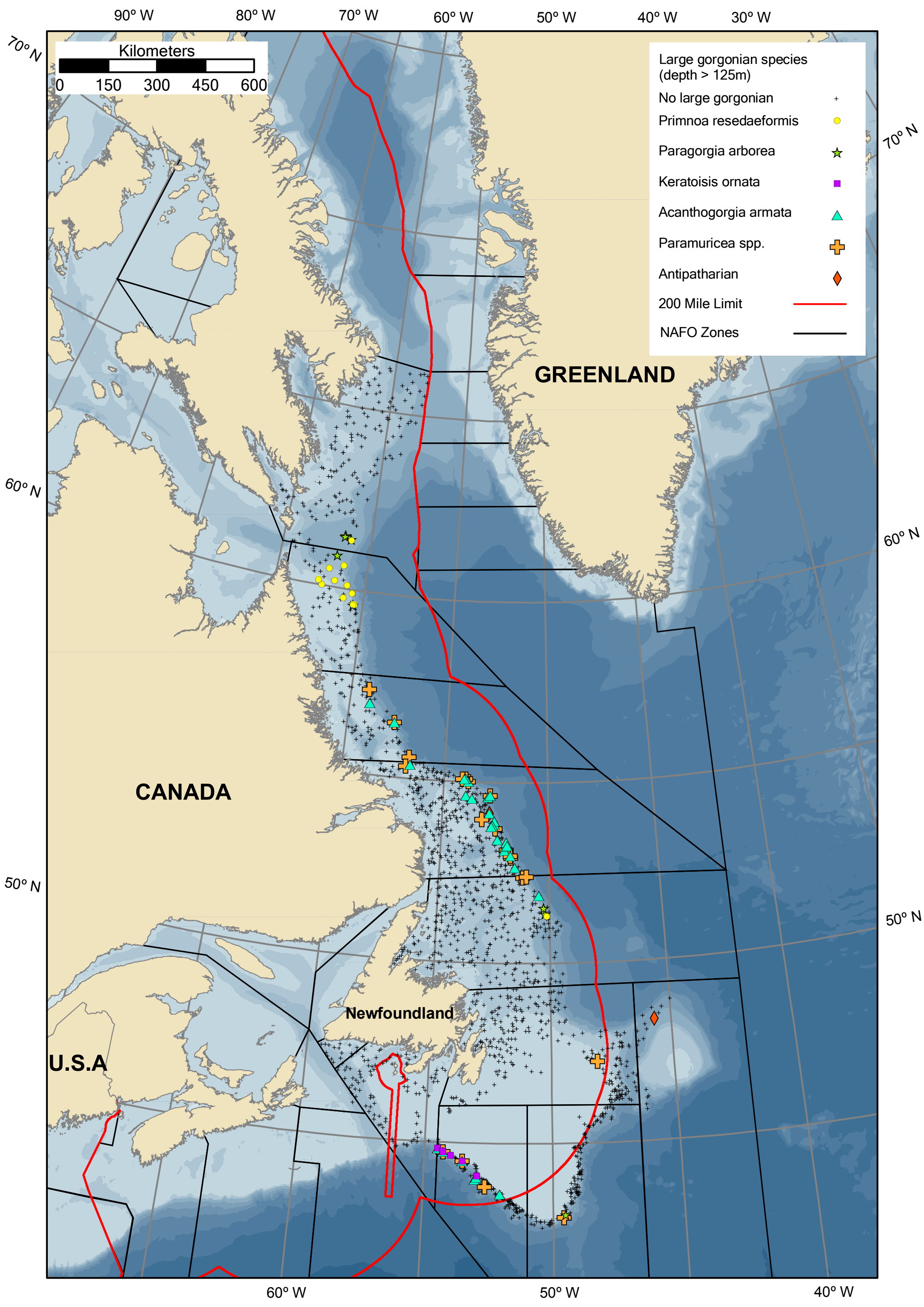

Figure 4: Distribution of large gorgonian coral species in scientific surveys.

Total Fishing Effort Density
(All Fisheries All Gear Types, 2004 - 2005)

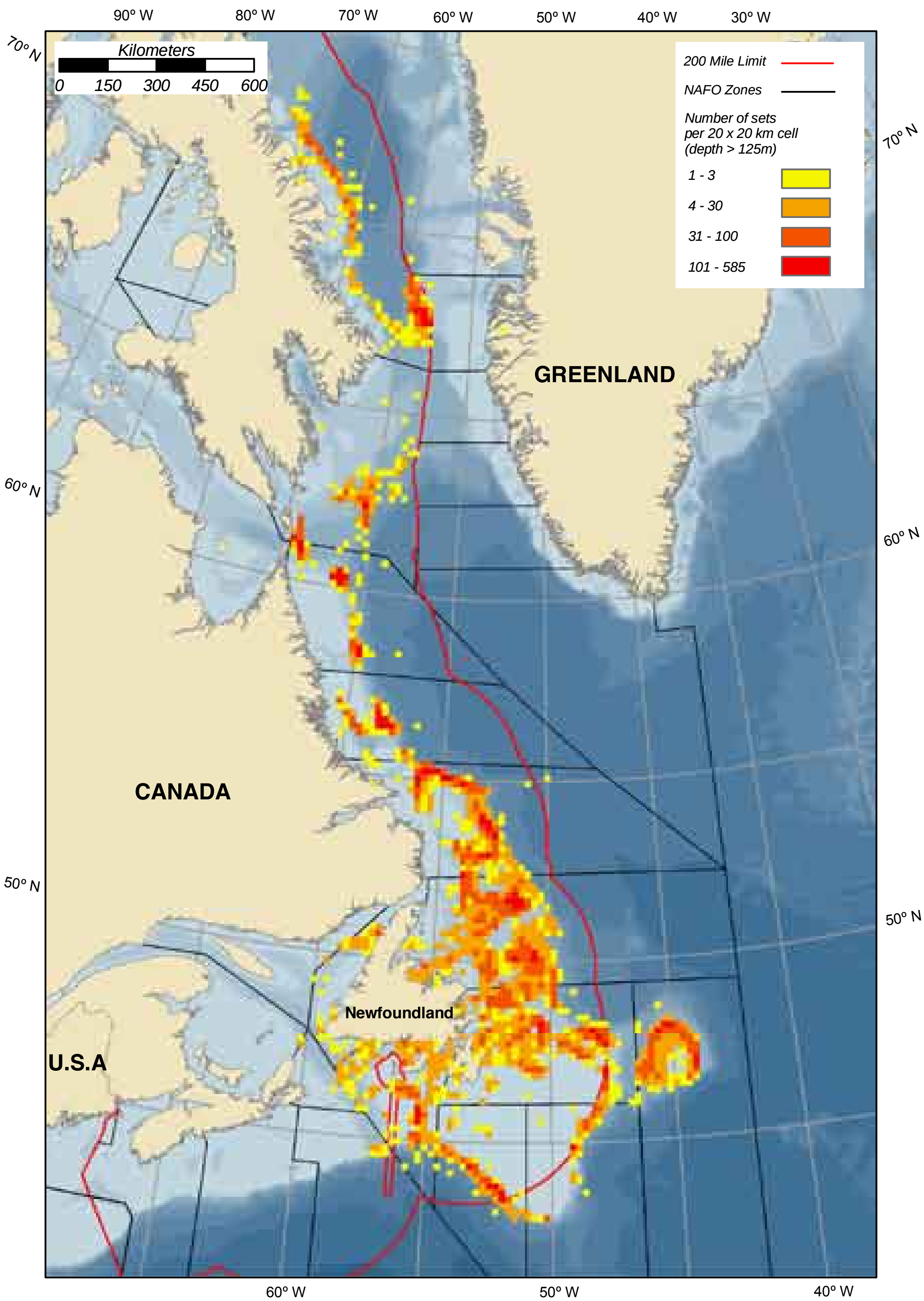

Figure 5: Distribution of total fishing effort, measured as the number of fishing sets per 20x20 km cell. See accompanying CD for distribution of fishing effort by directed species and gear type.

Table 3. Number of fishing sets from areas deeper than 125 m in databases from scientific surveys (2003-2005) and the Fisheries Observer Program (2004 and 2005), separated by dataset, directed species, and gear. See Table 4 for the percentage of sets containing corals.

		Number of sets	Number of sets with corals	Number of sets with each functional group of coral						
				1	2	3	4	5	1, 2, and 3	4 and 5
SS data		1553	516	411	85	55	91	66	483	127
FOP data										
All directed species	All gear types	31508	1130	408	555	106	336	178	866	483
Shrimp	Trawls	16438	302	193	105	23	4	41	267	45
Snow crab	Crab pots	8666	81	75	1	1	14	8	77	19
Greenland halibut	All gear types	4235	567	113	316	70	288	81	374	354
	Longline	89	10	2	5	0	5	6	5	10
	Gillnet	1464	148	28	40	10	100	17	61	115
	Trawls	2682	409	83	271	60	183	58	308	229
Redfish	Gillnet	99	0							
	Trawls	771	134	21	107	4	19	32	118	42
Monkfish	Gillnet	672	24	1	21	5	4	0	21	4
Atlantic cod	All gear types	499	0							
	Longline	23	0							
	Gillnet	216	0							
	Trawls	260	0							
Atlantic halibut	Longline	128	22	5	5	3	0	16	9	19
All directed species	Trawls	20151	845	297	483	87	206	131	693	316
All directed species	Gillnet	2451	172	29	61	15	104	17	82	119
All directed species	Longline	240	32	7	10	3	12	22	14	29

3.2.2 Coral Bycatch (Distribution and Density)

Corals were caught as bycatch along most of the shelf edge and slope off Newfoundland and Labrador (Figure 6). The highest densities of coral bycatch were located along the southeast edge of the Southeast Baffin Shelf, the edges of Hopedale Saddle, the western margin of Orphan Basin (surrounding Tobin's Point), the southwest Grand Banks, and the north side of the Flemish Cap. All these areas, except the Flemish Cap, also experienced high densities of large gorgonian bycatch (Figure 7). Although the north side of the Flemish Cap was an important area for soft corals, sea pens, and cup corals, very few gorgonians were caught there.

The highest number of sets with coral per 20x20 km cell varied between groups of corals: soft corals = 30, sea pens = 39, cup corals = 10, small gorgonian corals = 28, and large gorgonian corals = 12.

In specific directed fisheries, the highest number of sets with corals per 20x20 km grid cell ranged from 7 (monkfish) to 42 (Greenland halibut). The Greenland halibut fishery caught the highest densities of coral in the Davis Strait region (on the southeast edge of the Southeast Baffin Shelf), the mouth of Hawke Saddle, Tobin's Point to the mouth of Bonavista Corridor, and along the southwest Grand Banks. The redfish and monkfish fisheries caught the highest densities of coral along the southwest Grand Banks. The Atlantic halibut fishery caught the majority of corals near Greene Bank (in the southwest Grand Banks), while peak coral catch for the crab fishery was near Makkovik Bank, Labrador. The shrimp fishery caught high densities of coral on the north side of the Flemish Cap, in scattered locations from Hopedale Saddle to Hawke Saddle, and near Cape Chidley, Labrador. This location had a particularly high number of large gorgonian records.

High densities of coral bycatch by trawls were in the same locations as overall high densities of coral bycatch (described above). Gillnets and longlines caught high densities of corals along the southwest Grand Banks. Gillnets retrieved corals near Funk Island Spur, along the Southeast Baffin Shelf, and in NAFO Zone 0A.

Total Coral Bycatch
(All Fisheries, All Gear Types, 2004 - 2005)

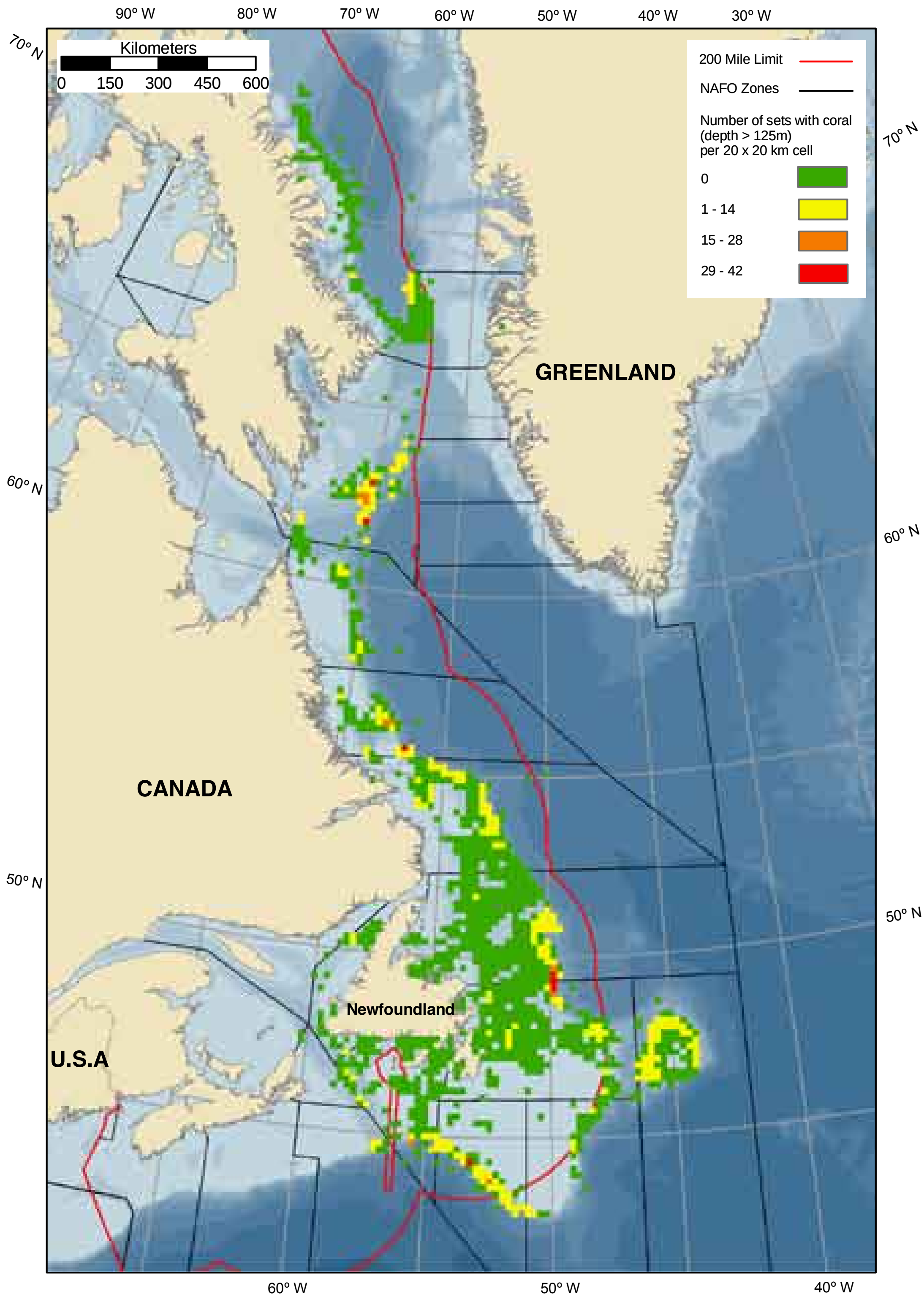

Figure 6: Frequency of coral bycatch, measured as the number of sets containing corals per 20x20 km cell. All types of corals, all directed species, and all gear types combined. See accompanying CD for distribution of coral bycatch frequency by coral functional group, directed species, and gear type.

Large Gorgonian Bycatch
(All Fisheries All Gear Types, 2004 - 2005)

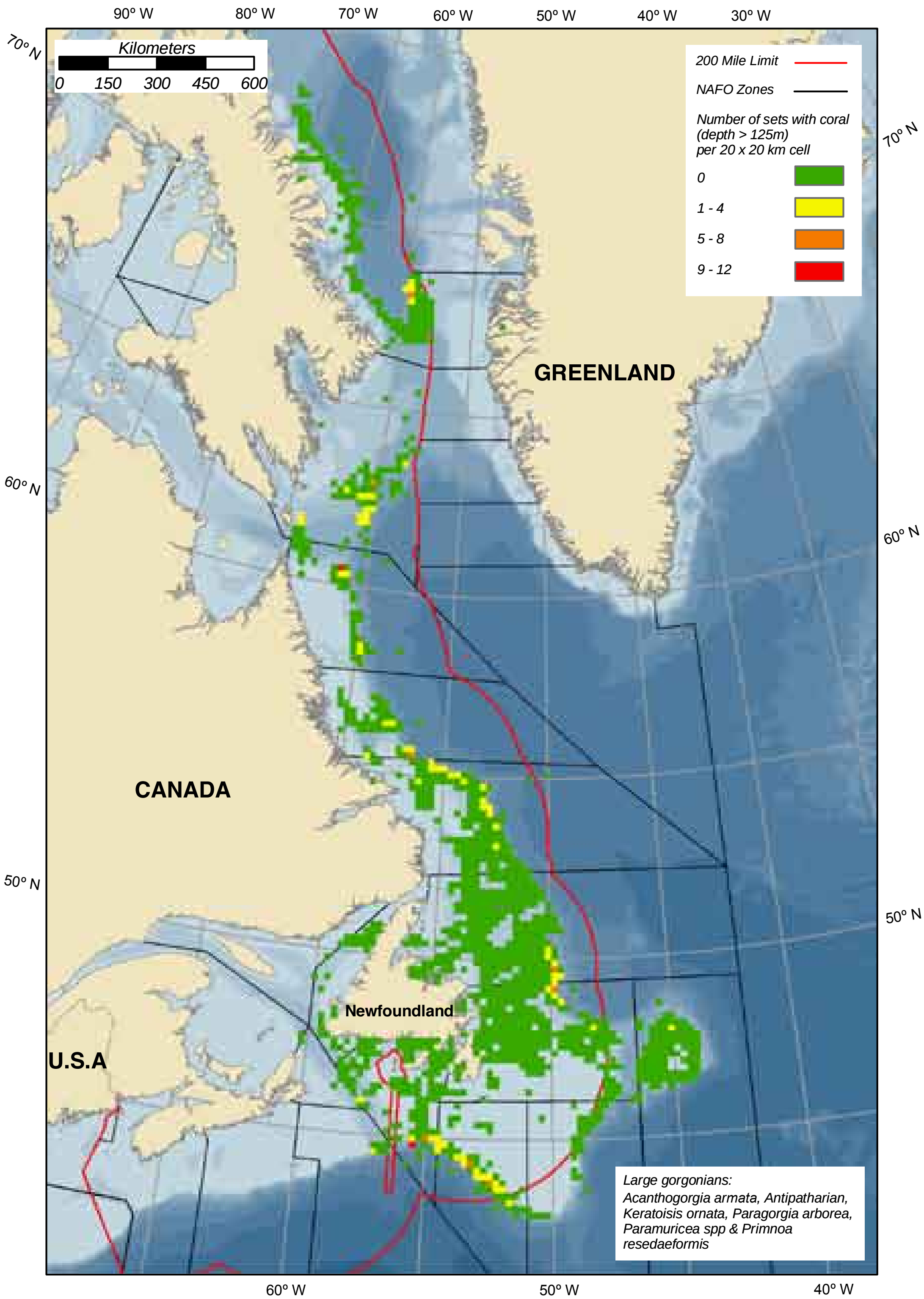

Figure 7: Frequency of large gorgonian coral bycatch, all fisheries, all gear types. See accompanying CD for distribution of large gorgonian coral bycatch frequency by directed species and gear type.

3.2.3 Percentage of Positive Sets

The largest percentage of sets with corals, regardless of fishery, occurred along the southeast edge of the Southeast Baffin Shelf, off Makkovik Bank, near Funk Island Spur, and off the southwest Grand Banks (Figures 8 and 9). A secondary peak in percentage of sets with corals occurred on the Flemish Cap, dominated almost exclusively by soft corals, cup corals, and sea pens. Peaks in the percentage of sets with gorgonian corals occurred on the Southeast Baffin Shelf, Funk Island Spur, and southwest Grand Banks (Figures 10 and 11).

Although the Atlantic halibut fishery had a high percentage of sets with coral bycatch (Table 4), this fishery had very few areas with a high percentage of coral bycatch, all off the southwest Grand Banks. This reflects the spatially limited effort in this fishery. The restricted distribution of areas with high coral bycatch in this fishery was particularly evident after any cells with fewer than three sets were removed.

Most redfish fishery sets along the southwest Grand Banks had coral bycatch. When only gorgonian coral bycatch was examined, the redfish fishery in the southwest Grand Banks still recorded a high percentage of positive sets. The percentage of sets with corals (all corals, and gorgonian corals) in the Greenland halibut fishery peaked in Davis Strait (on the southeast edge of the Southeast Baffin Shelf) and between Funk Island Spur and Tobin's Point, with a secondary peak off the southwest Grand Banks. The monkfish fishery had a relatively low percentage of sets with corals; areas of coral bycatch in this fishery were all found off the southwest Grand Banks, where nearly all of the effort in this fishery occurred.

By contrast, the shrimp fishery had no areas with a high percentage of coral bycatch, but sets containing corals occurred on the Flemish Cap and scattered along the shelf edge. Corals recovered by the shrimp fishery were mostly soft corals, sea pens, and cup corals, except near Cape Chidley, Labrador. The crab fishery also showed very few areas with a high percentage of sets with corals, but one peak area occurred off Makkovik Bank.

When analyzed by gear type, rather than directed species, the percentage of positive sets peaked along the southeast edge of Southeast Baffin Shelf for both gillnets and trawls. In addition, gillnets had a high percentage of positive sets near Funk Island Spur, while trawls had a peak off the southwest Grand Banks and west of Orphan Basin (Tobin's Point). The percentage of sets with coral peaked in the longline fishery near Greene Bank, on the southwest Grand Banks. Although trawling activity was widespread, the overall percentage of positive sets was low compared to other gear.

Percentage of Sets Containing Coral
(All Fisheries, All Gear Types, 2004 - 2005)

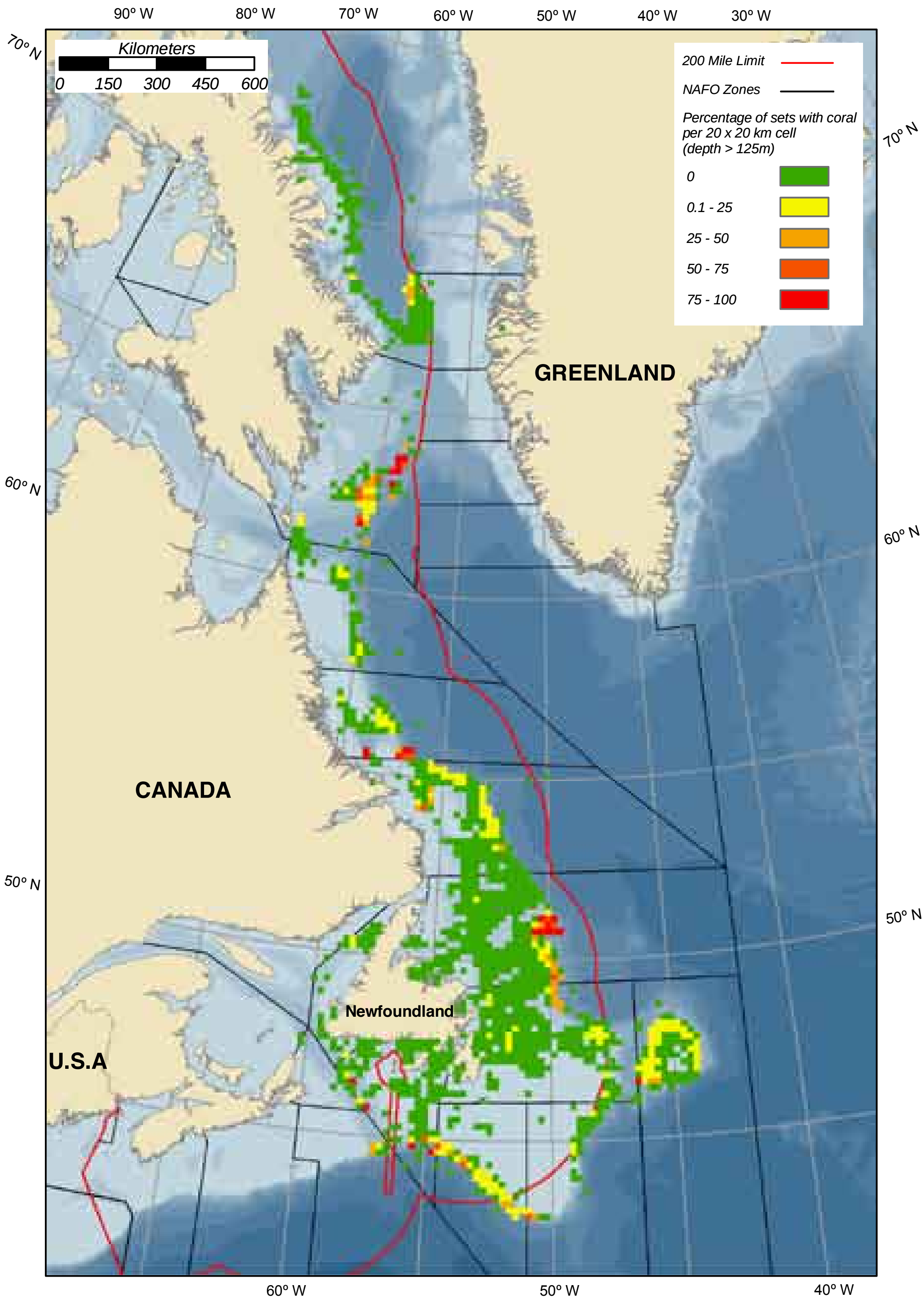

Figure 8: Percentage of fishing sets containing corals per 20x20 km cell, all fisheries, all gear types, all cells. See accompanying CD for distribution of coral bycatch percentage by directed species and gear type.

Percentage of Sets Containing Coral
(All Fisheries, All Gear Types, 2004 - 2005)

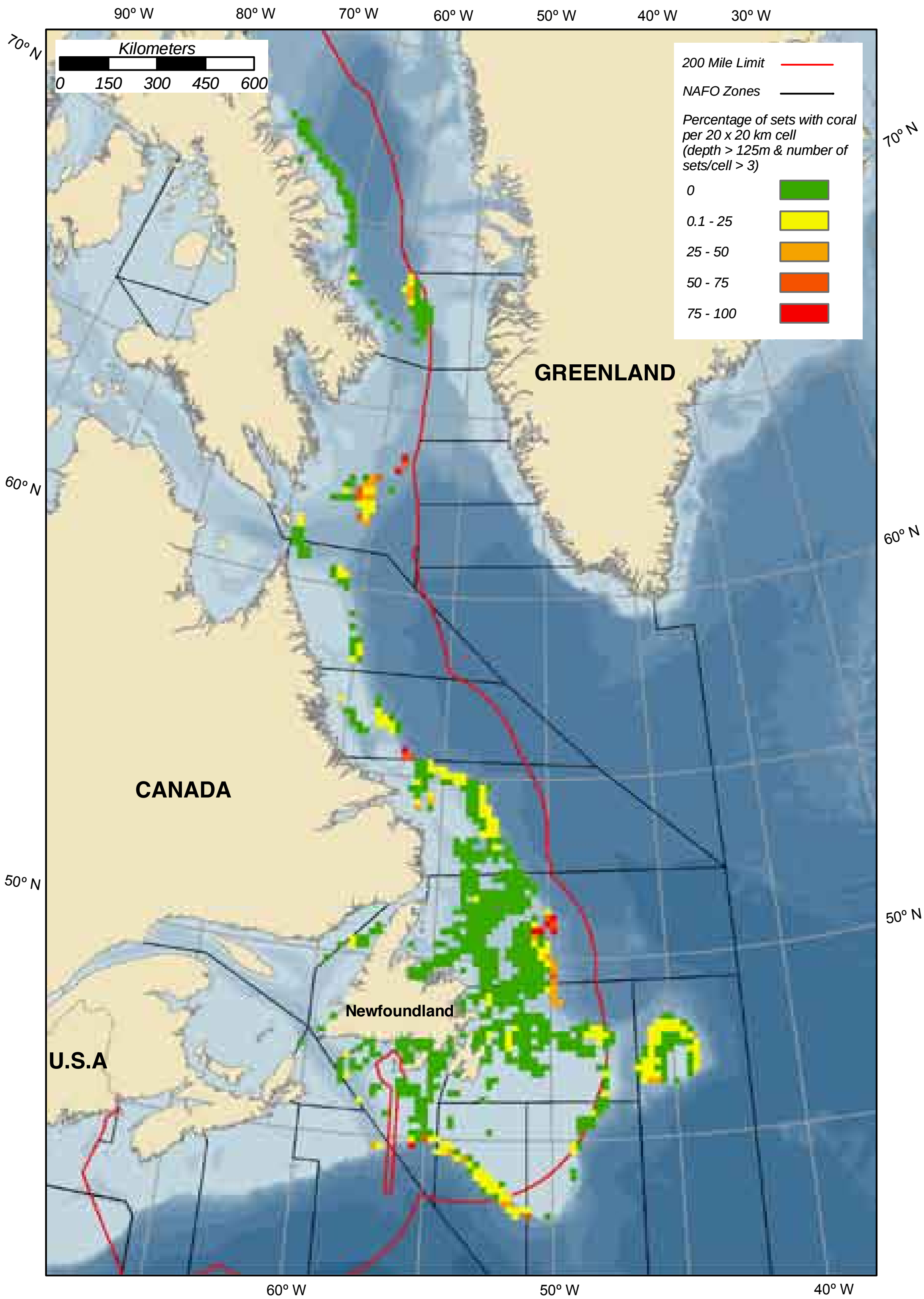

Figure 9: Percentage of sets containing corals per 20x20 km cell, all fisheries, all gear types, including only those cells with > 3 sets/cell. See accompanying CD for distribution of coral bycatch percentage by directed species and gear type.

Percentage of Sets Containing Large or Small Gorgonians
(All Fisheries, All Gear Types, 2004 - 2005)

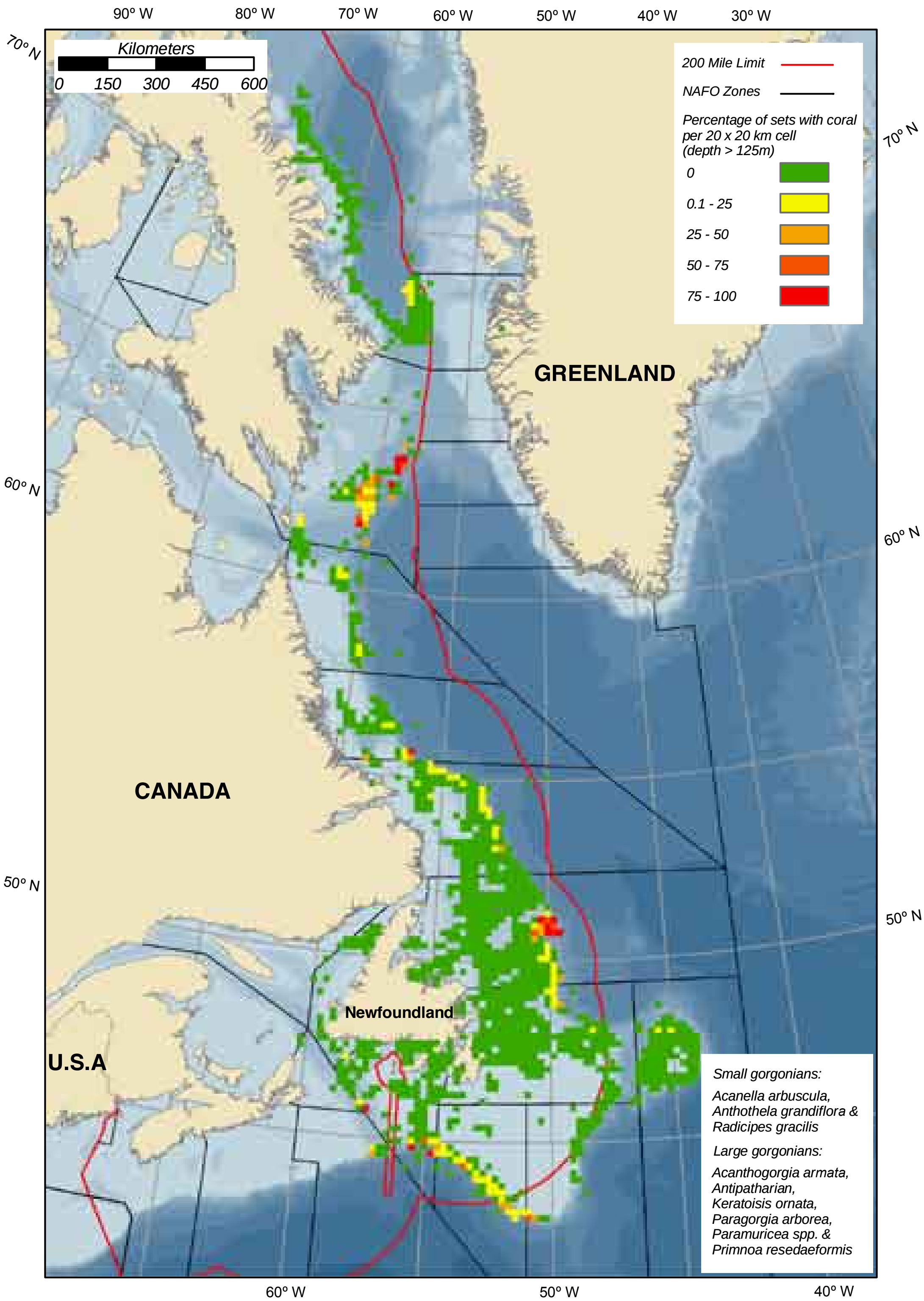

Figure 10: Percentage of fishing sets containing gorgonian corals per 20x20 km cell, all fisheries, all gear types, all cells. See accompanying CD for distribution of coral bycatch percentage by directed species and gear type.

Percentage of Sets Containing Large or Small Gorgonians
(All Fisheries, All Gear Types, 2004 - 2005)

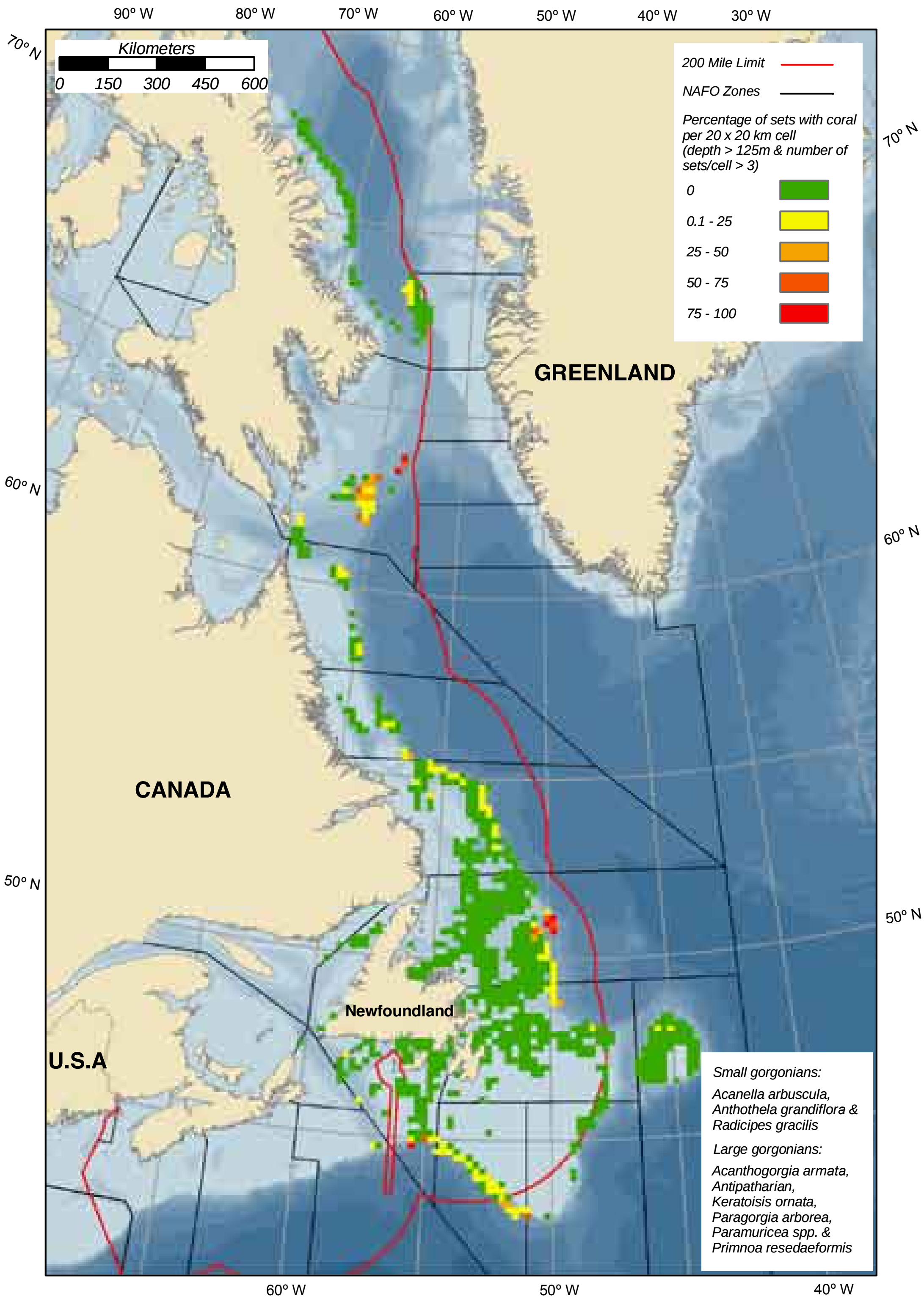

Figure 11: Percentage of fishing sets containing gorgonian corals per 20x20 km cell, all fisheries, all gear types, including only those cells with > 3 sets/cell. See accompanying CD for distribution of coral bycatch percentage by directed species and gear type.

Table 4. Average percentage of fishing sets containing corals per 20x20 km grid cell in 2004 and 2005, based on the Fisheries Observer Program database.

Directed species	Gear	Average percentage (# of cells) All data	Cells with > 3 sets
All directed species	All gear types	18.2 (148)	18.4 (142)
Atlantic halibut	Longline	49.6 (6)	38.1 (3)
Greenland halibut	All gear types	30.8 (57)	30.8 (57)
	Longline	30.8 (7)	16.5 (5)
	Gillnet	38.4 (21)	38.4 (21)
	Trawls	32.0 (40)	30.2 (37)
Redfish	Trawls	30.2 (20)	26.5 (19)
Crab	Crab pots	27.2 (18)	22.3 (16)
Monkfish	Gillnet	23.4 (8)	12.5 (7)
Shrimp	Trawls	7.5 (71)	6.2 (69)
All directed species	Longline	35.4 (10)	24.3 (7)
All directed species	Gillnet	30.7 (28)	32.6 (26)
All directed species	Trawls	17.0 (120)	16.1 (114)

3.3 Analysis of Bias

The two datasets yielded largely similar occurrences of coral (Figure 12). The majority of discrepancies were a result of corals being recorded in the SS dataset but not the FOP dataset. Nevertheless, the area from Hopedale Saddle to Cartwright Saddle had a number of sites where corals were recorded in the FOP dataset but not the SS. When cells containing more than three scientific survey sets and more than three fisheries observer sets were compared, the percentage of sets containing corals was almost always higher in the scientific surveys than in the fisheries observer data.

3.4 Groundfish Species Richness

Areas of peak fish diversity in the 2003-2005 survey data did not generally overlap with areas of peak coral diversity or areas of peak coral bycatch (Figure 13). The southwest Grand Bank region contained several sets with fish species richness well above the average. Nonetheless, average fish species richness within the southwest Grand Bank area was consistent with average fish diversity elsewhere in the Newfoundland and Labrador region. These data are consistent with the weak correlation between fish species richness and coral species richness previously reported from analysis of the scientific survey data (Edinger et al. 2007).

Comparison of Commercial Fisheries (FOP) with Surveys (SS) for Total Coral Bycatch

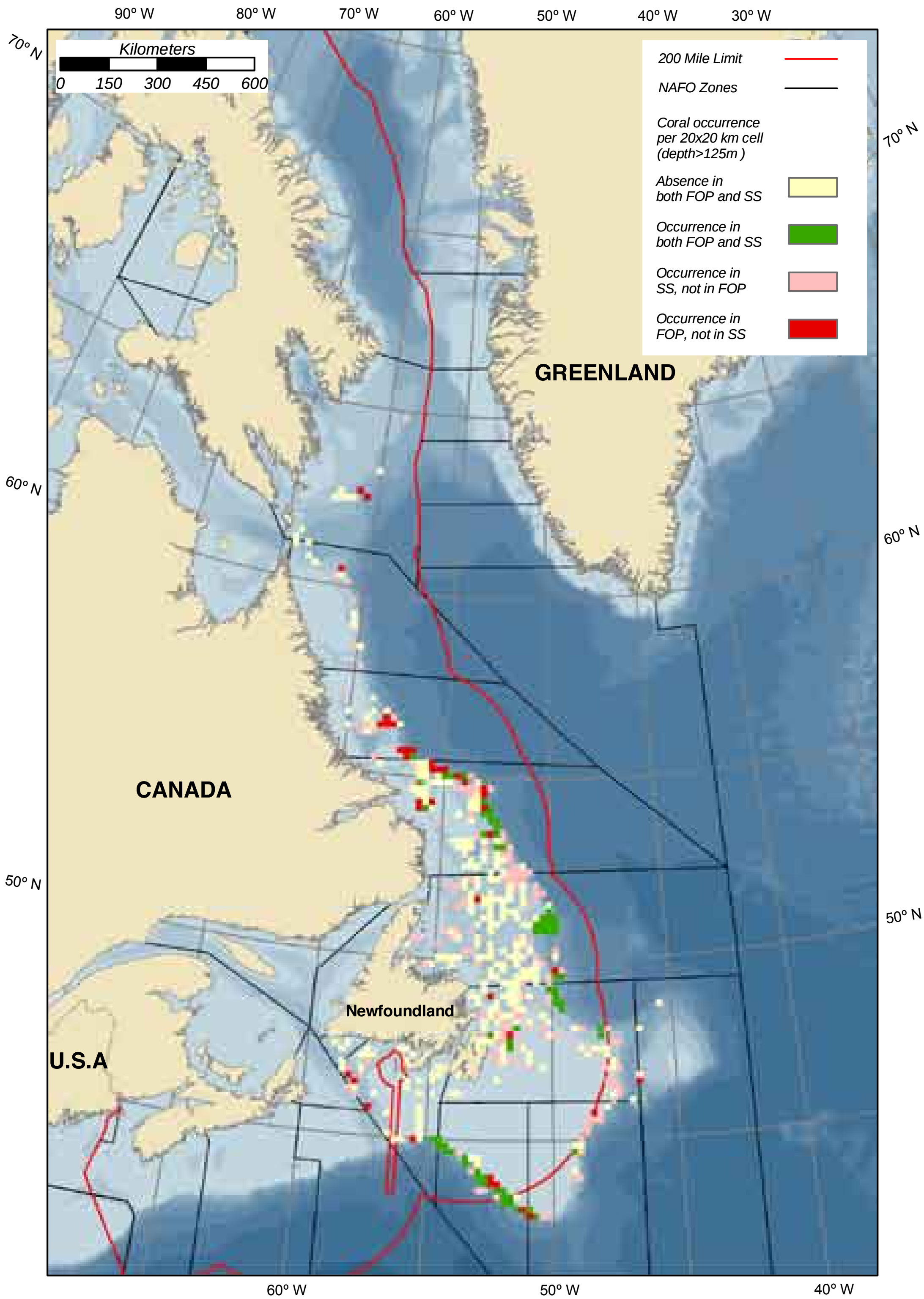

Figure 12: Comparison of coral distributions from scientific survey (SS) and Fisheries Observer Program (FOP) data, including only cells sampled by both programs.

Fish Species Richness
(DFO Scientific Surveys, 2003 - 2005)

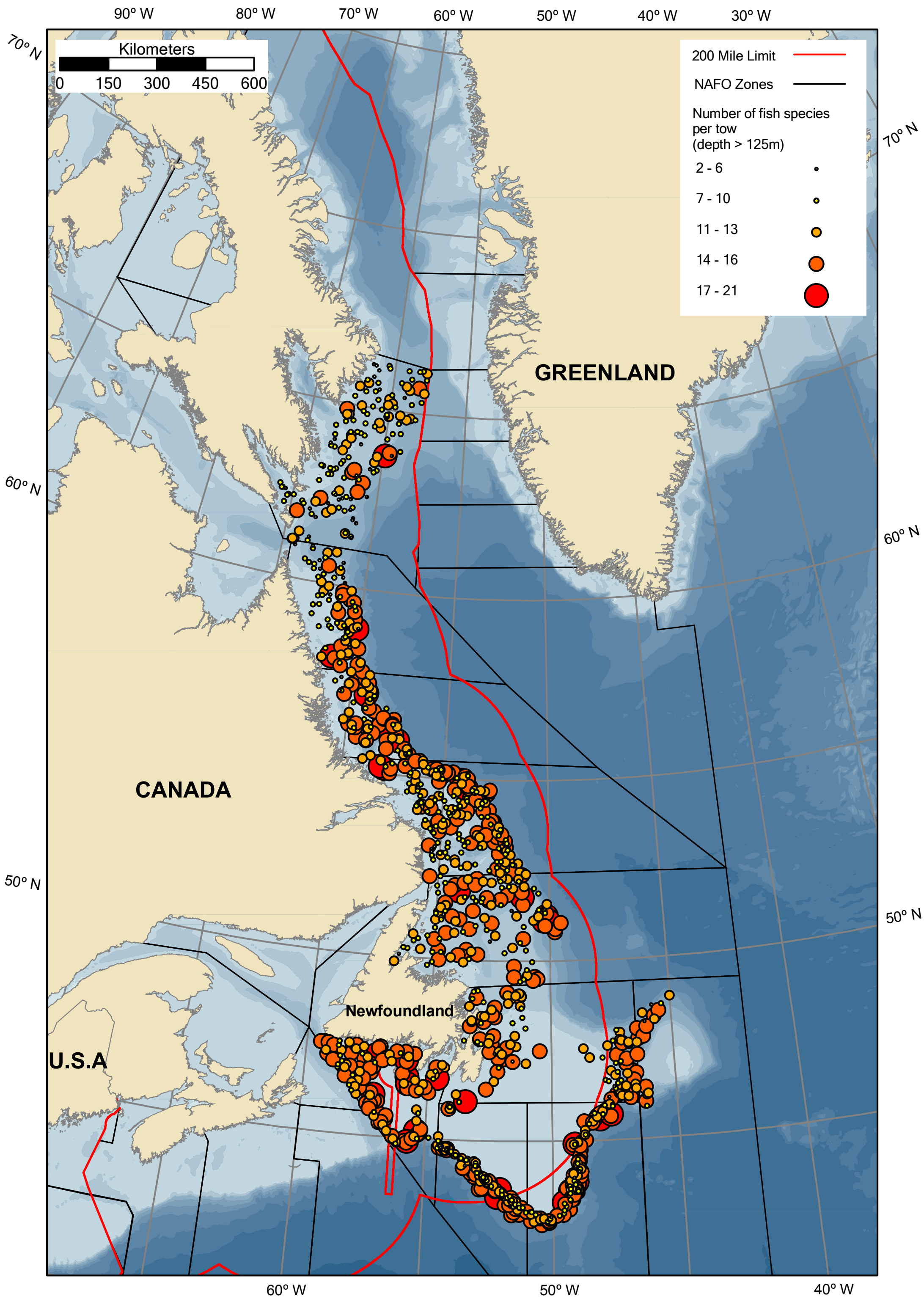

Figure 13: Groundfish species richness in scientific surveys (SS).

4. Discussion

4.1 Coral Distribution

Corals were distributed fairly regularly along the shelf edge in most of the study area. The scientific survey (SS) data recorded high densities of coral along almost the entire edge of the Grand Banks. The distribution of corals along southeast Labrador and the Funk Island Spur – Tobin's Point regions may be continuous. Densities from trawl data cannot be directly compared with organism density per square metre, because there are no data on how likely corals are to be caught in trawls, and the spatial distribution of corals within a 1.4 km long trawl is unknown, but likely to be highly clustered.

Based on observer data, soft corals, cup corals, and sea pens were regularly caught along the north side of the Flemish Cap. Canadian scientific surveys do not cover most of the Flemish Cap, and the European Union fisheries surveys on the Flemish Cap do not record coral bycatch. The NAFO Scientific Council has recommended that European Union fisheries surveys include coral bycatch in the future, using the coral identification keys and collection protocols currently used in Newfoundland and Labrador (Edinger and Wareham 2006).

The scientific surveys provide poor information on coral distributions in NAFO Zone 0A (Davis Strait and northeast Baffin Island). DFO–Arctic Region has conducted some coral collections as part of multispecies stock assessment surveys, but at a lower frequency than surveys in the Newfoundland region. The ridge separating the Davis Strait from Baffin Bay is considered a possible barrier to coral dispersal due to associated changes in temperature (Mortensen et al. 2006).

4.2 Coral Bycatch

Fisheries observers and fishermen have reported a high incidence of coral bycatch in the shrimp fishery east of Cape Chidley and in the Cape Chidley to Resolution Island area, including very large individuals of *Paragorgia arborea* (MacIsaac et al. 2001; Gass and Willison 2005; Reuben Beazley, Seawatch, personal communication 2005). This high gorgonian bycatch in this area was reflected in the current data, but may represent a depleted population compared to the unfished area immediately east of Hudson Strait. Survey trawls conducted in this unfished area by the Northern Shrimp Survey in 2006 recorded weights of up to 500 kg of *Primnoa resedaeformis* and *Paragorgia arborea* per 15 minute tow, a biomass of coral up to six times greater than recorded in any other survey station in the Newfoundland and Labrador region (Edinger et al. 2007).

Furthermore, shrimp trawling in coral-rich areas is likely to damage far more corals than are recovered by the trawl. Most corals will be broken off but pass between the footgear and the base of the net, hence remaining broken on the seafloor. Adoption of the Nordmore Grate bycatch reduction device may have further reduced recorded coral bycatch in shrimp trawls (Edinger and Wareham 2006).

Most of the trends in total fishing effort and thus in total bycatch are a result of the large influence of trawls on the dataset; trawls were much more common than other fishing gear types, and trawl activity was much more dense than other types of fishing. Coral bycatch in gillnets and longlines was locally intense but spatially restricted.

While all gear types caught corals, the percentage of sets containing corals was a somewhat deceptive measure of the aggregate damage to corals by each fishery. Longline gear had a higher percentage of sets containing corals than did trawls, probably because longline gear was often deployed deeper than trawls and was precisely targeted to rough-bottom ("un-trawlable") areas that are good habitat for corals and may be sheltered from other fishing effort due to their rough bathymetry. Nonetheless, most coral records came from trawls, because most fishing effort was conducted with trawls.

4.3 Bias Analysis

There were many scattered areas where the FOP data did not record coral bycatch but the SS data indicated coral presence. The fisheries were likely catching corals, but they were not being recorded. This point reinforces the ideas that records of zero coral bycatch in the FOP dataset may not correspond with the absence of corals and that the FOP is considered a minimal assessment of coral distribution.

4.4 Coral Conservation

Marine conservation measures in relation to fisheries include three major categories: gear regulations, temporal limits on fishing effort, and spatial limits on fishing. In the current study, coral bycatch frequencies were largely a function of fishing effort and the natural controls on coral distribution; they were not specific to a certain gear type or directed species. Therefore, gear-specific regulations or seasonal limits on fishing are unlikely to be effective for coral conservation.

Designating specific areas closed to fishing and other detrimental activities may be the most appropriate management tool available for coral conservation. Nevertheless, tools such as marine protected areas (MPAs) must be used in combination with other management techniques to reduce threats such as acidification, pollution, and destruction of corals outside the boundaries of protected areas.

Before potential locations for MPAs can be identified with any degree of success, the goals of the proposed MPA system must be clearly defined (Roberts et al. 2003). We recommend a representative areas approach (e.g. Sala et al. 2002; Fernandes et al. 2005) designed to conserve areas where corals are particularly abundant and/or diverse, as opposed to the ad-hoc approach that has been applied in other parts of the world. Within a representative areas system, a major question remains whether the MPA system should attempt to protect coral-rich areas regardless of fishing pressure (i.e. an area where the threats to corals from fishing are strong, Sala et al. 2002) or protect unfished areas where the closure would have little economic impact on the fishing industry (Fernandes et al. 2005), or some combination.

The unfished deep area immediately east of Hudson Strait would benefit from protection (Figure 14). This area is not an area of peak coral bycatch, because fishing effort in the area is low. Given the low frequency of fishing effort in this area due to net damage, and given the high abundance of large gorgonians recorded from the margins of this area, the Hudson Strait region appears to be a high benefit, low cost candidate area for protection. This area should be surveyed with cameras to document the occurrence, diversity, and density of coral prior to possible closure.

The southwest Grand Banks exhibited peak areas of coral abundance and diversity, fish species richness, and fishing effort. Funk Island Spur had a high percentage of sets with corals, particularly gorgonian corals. The southeast portion of the Southeast Baffin Shelf also consistently recorded coral bycatch (all corals in general and gorgonian corals in particular). Protective measures should be established in the southwest Grand Banks, Funk Island Spur – Tobin's Point, and Cape Chidley – Southeast Baffin Shelf areas (Figure 14).

Because all gear types caused coral bycatch in areas of peak coral abundance, protected areas should be closed to all fishing, rather than partial closures regulated by gear types.

The current report identifies high-priority regions for coral conservation using a representative areas approach. Further research is required to define the location, extent, and management regimes of protected areas within the three high-priority regions identified in this report. Research needs include direct observation of high-diversity coral areas using a drop camera and/or remote operated vehicle, as well as more detailed knowledge of coral reproduction, recruitment, growth rates, longevity, and relative sensitivity of coral species to fisheries impacts. Nonetheless, the requirement for further research should not impede current interim coral conservation measures.

Coral Conservation Priority Areas in Newfoundland and Labrador Waters

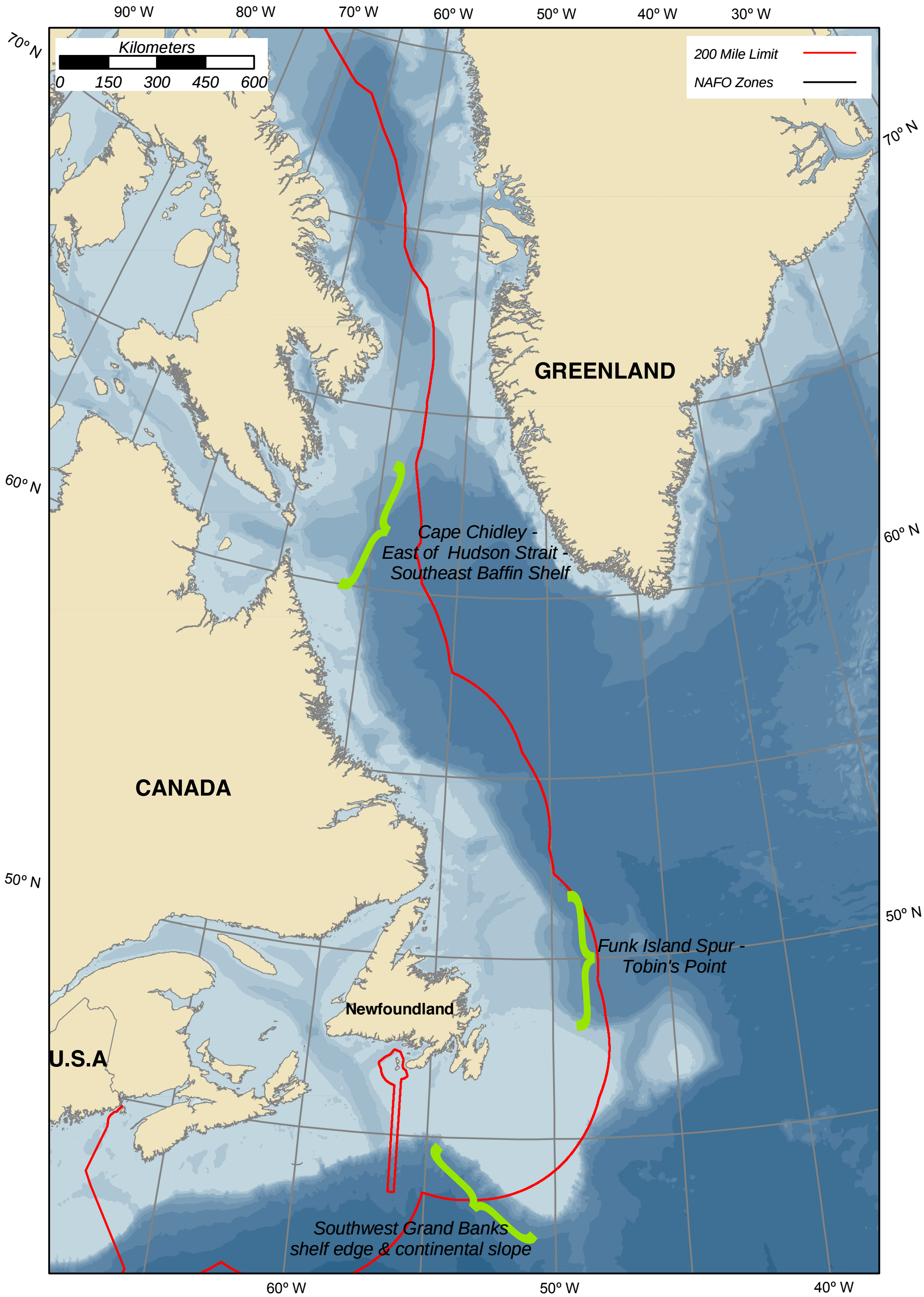

Figure 14: Priority areas for coral conservation in Newfoundland and Labrador waters.

5. Conclusions

The broad distribution of corals apparent from scientific surveys suggest that a representative areas approach is appropriate for coral conservation in the Newfoundland and Labrador region (Wareham and Edinger 2007), as opposed to the unique features approach to coral conservation adopted in the Eastern Scotian Shelf Integrated Management (ESSIM) region off the southern coast of Nova Scotia (ESSIM 2006).

Peak areas of coral bycatch in commercial fisheries occur in each of the broad coral hotspots defined from scientific surveys. Candidate sites for protection should be explored in areas currently experiencing peak bycatch frequencies and peak bycatch normalized to fishing effort. Closed areas, should they be established, should be large enough to protect a range of depths and coral habitats.

Five main conclusions can be drawn from this research:

1) All bottom fishing gear produced coral bycatch.

2) In most cases, peaks of coral bycatch were recorded in areas known from scientific surveys to have a particularly high coral abundance.

3) Peak areas of effort-normalized coral bycatch occurred near Funk Island Spur, the southwest Grand Banks, and the southeast portion of the Southeast Baffin Shelf. These were peak areas for corals as a collective group and for gorgonian corals in particular. These peak areas were consistent among directed species and gear types.

4) Areas of fish species richness did not correspond with areas of coral species richness, except along the southwest Grand Banks.

5) Area closures, in conjunction with other management options, should be established to successfully protect corals off Newfoundland and Labrador. These closed areas should be closed to all gear types.

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Appendix I: Glossary

Alcyonacean corals: Soft corals without skeletons.

Antipatharians: A distinct order of coral, often referred to as "black corals" because of their dark proteinaceous skeletons.

Aragonite: Form of calcium carbonate used by scleractinian corals to build their skeletons.

Bottom trawl: Mobile fishing gear that enables fishermen to catch fish near or on the bottom of the ocean using a net that is dragged along the seafloor.

Bycatch: Organisms caught unintentionally by fishing gear.

Continental shelf: The portion of the continent which extends below the ocean surface.

Gillnet: Fixed fishing gear that allows fish to swim partway through the net until they can swim neither forwards nor backwards to escape. The gillnets referred to in this report are exclusively bottom-set gillnets; pelagic gillnets are set near the surface.

Gorgonian corals: Octocorals with a semi-flexible skeleton composed of protein, calcite, or mixed protein and calcite. Gorgonians are also known as fan corals.

Groundfish: Fishes that live in, on, or near the bottom of the ocean.

Heterotrophic: An organism that derives its nutrition by capturing other food sources.

Longline: Fishing gear that includes many baited hooks hanging from a single line. Longline gear in this report refers exclusively to bottom-set longline; pelagic longlines are used in other fisheries and can cause extensive seabird bycatch.

Mid-ocean ridge: An underwater mountain range.

Nordmore grate: A device that reduces the amount of finfish bycatch in shrimp trawls by diverting fish through an escape hatch, while allowing shrimp to pass through the bars of the grate.

Scleractinian corals: Stony or hard corals.

Sea pens: Colony-forming soft corals belonging to the order *Pennatulacea*. Sea pens normally have a long stem (rachis) with polyps extending from both sides in a style reminiscent of feathers.

Seamounts: A mountain in the ocean that does not reach above the water's surface. Usually volcanic in origin.

Shelf edge: The perimeter of the continental shelf, where the continental slope begins at a depth of approximately 200 m. This is sometimes referred to as the shelf break. The shelf edge typically has higher productivity than waters on the shelf. Much of the offshore fishing activity in Newfoundland and Labrador has concentrated along the shelf edge since the 1970s.

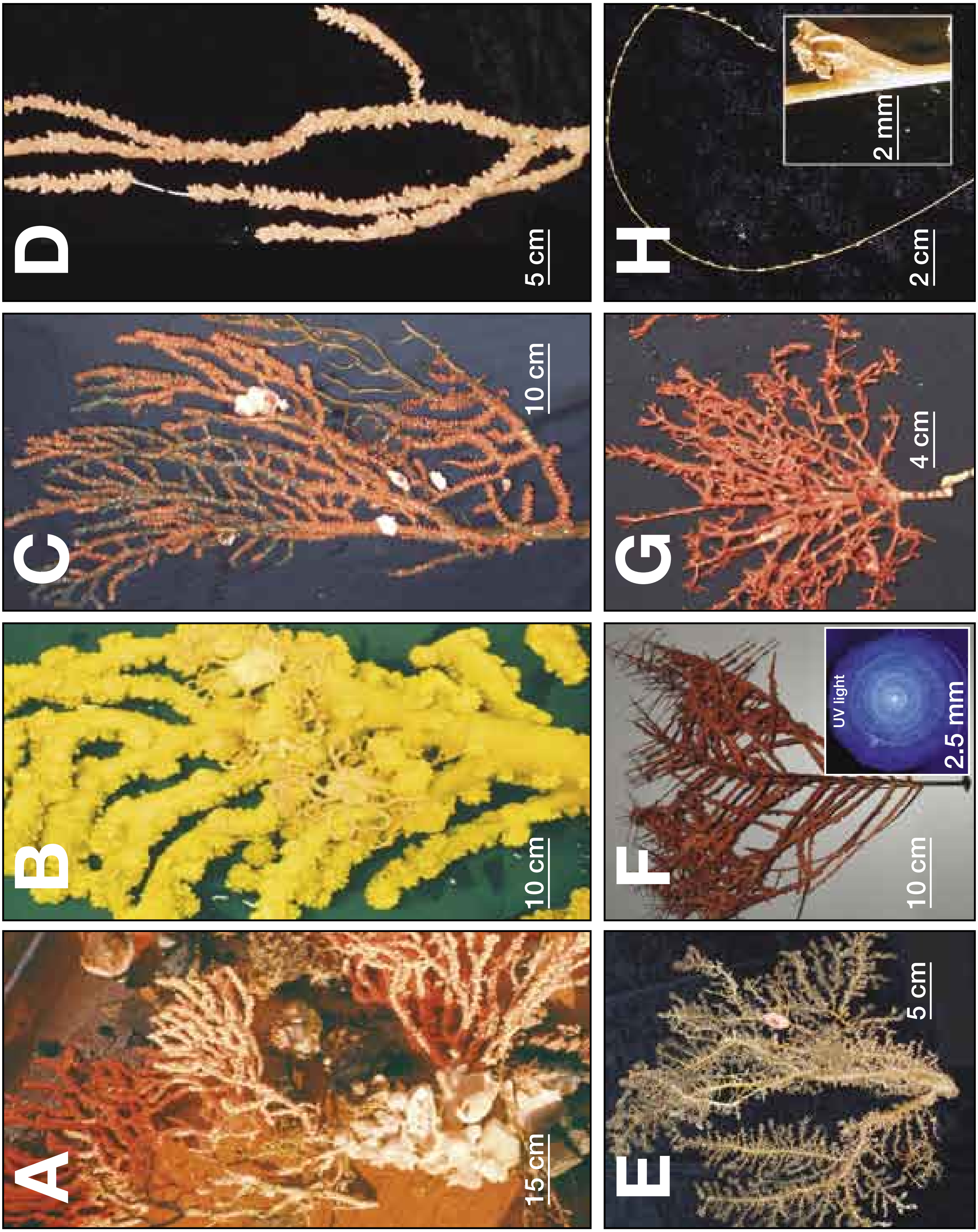
Appendix II: A Guide to Corals Found Off Newfoundland and Labrador

Plate 1. Gorgonian and antipatharian corals.

Large gorgonians (A-E). A. *Primnoa resedaeformis*. *Primnoa* tissue in this sample is red, while the skeleton is black. The encrusting sponge, bryozoans, and hydrozoans on dead portions of skeleton illustrate high invertebrate biodiversity associated with deep-sea corals. Photo: E. Edinger. **B.** *Paragorgia arborea*. *Paragorgia* has two main colour morphs, yellow and red, which are not genetically distinct. Photo: E. Edinger. Notice the encrusting basket stars, *Gorgonocephalus* sp. **C.** *Paramuricea* sp. (probably *P. grandis*). *Paramuricea* is typically red or yellow while alive but typically turns black when dead. This specimen was photographed immediately on recovery from a trawl tow. Note the encrusting anemones. The proteinaceous skeleton has growth rings, but longevity of this species has not been studied. Photo: V.E. Wareham. **D.** *Keratoisis ornata*. *Keratoisis* has a jointed calcium carbonate skeleton joined by proteinaceous nodes ("joints"). It is frequently covered in juvenile Icelandic scallops when recovered. Photo: V.E. Wareham. **E.** *Acanthogorgia armata*. *Acanthogorgia* has a proteinaceous skeleton and is the smallest of the "large gorgonian" group. Photo: V.E. Wareham.

Antipatharians (F). *Bathypathes arctica (Stauropathes arctica)*. At least one species of antipatharian (black coral) is represented in Newfoundland and Labrador waters, but the systematics of this group in deep water is poorly understood. Colonies up to 1 m tall come in at least two growth forms. The chitin and protein skeletons are black; the tissue is orange but does not preserve well. The inset photo shows a cross-section of skeleton photographed under ultraviolet light, showing very fine growth bands. Antipatharians are very slow growing. Main photo: V.E. Wareham; inset: O.A. Sherwood.

Small gorgonians (G-H). G. *Acanella arbuscula*. This small gorgonian can reach up to 50 cm high and has a jointed carbonate skeleton similar in structure to that of *Keratoisis*. It commonly occurs in large numbers as "fields", particularly in deep water. Photo: V.E. Wareham. **H.** *Radicipes gracilis*. This small gorgonian occurs as a thin rachis with polyps arranged along one side. The carbonate and protein skeleton is very slender and quite fragile. No longevity studies have been completed on either of these species. Photo: V.E. Wareham.



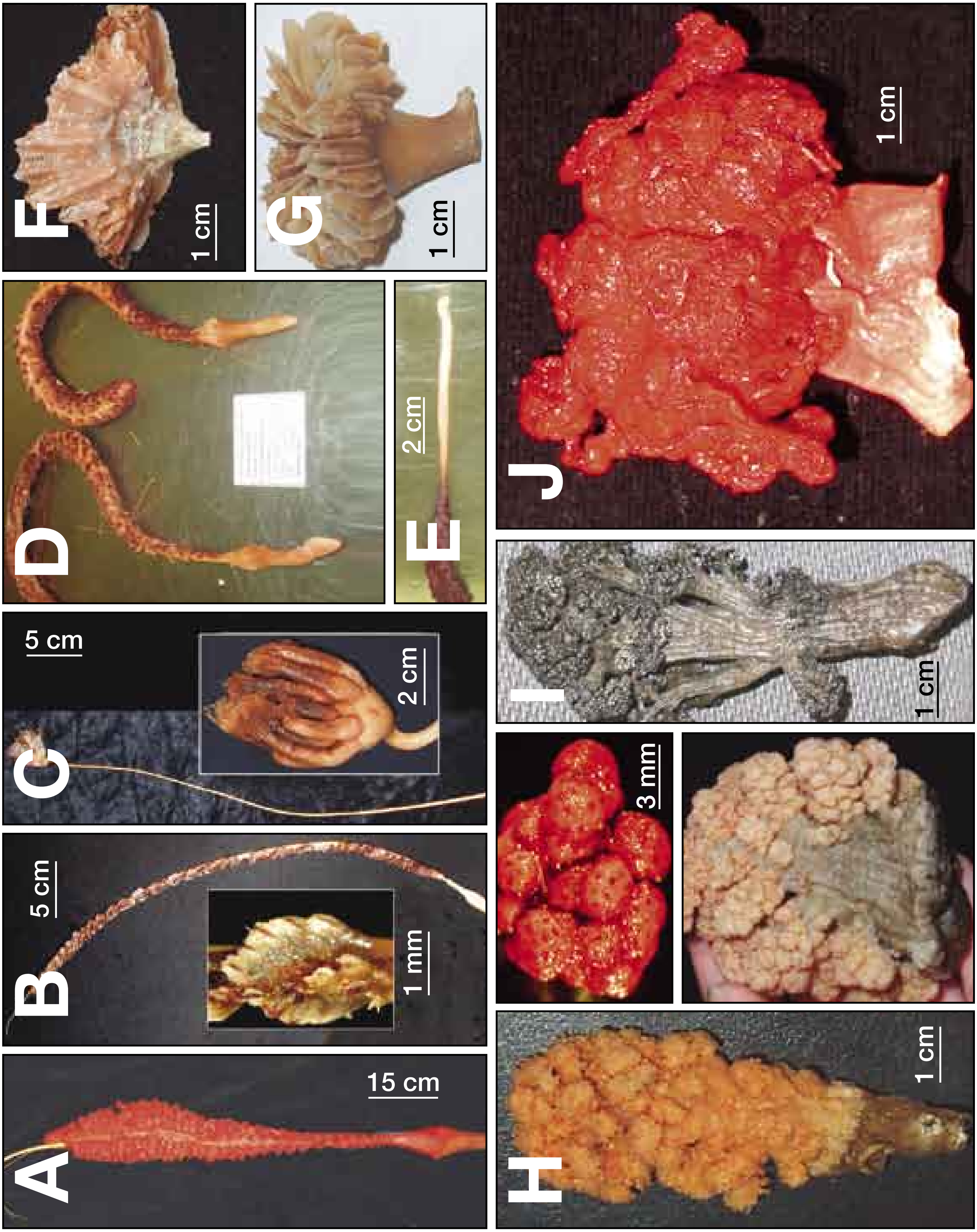
A
15 cm
B
10 cm
C
10 cm
D
5 cm
E
5 cm
F
10 cm
UV light
2.5 mm
G
4 cm
H
2 cm
2 mm

Plate 2. Sea pens, cup corals, and soft corals.

Sea pens (A-E) are pennatulaceans, a group of cnidarians most common in soft bottom environments in deep water. All sea pens have a flexible proteinaceous skeleton and polyps arranged along the rachis, but branching patterns vary widely. At least 11 species of sea pens occur in Newfoundland and Labrador waters, of which only half have been positively identified. **A.** *Pennatula* sp. **B.** *Halipteris finmarchica*. **C.** *Umbellula lindahli*. **D.** *Anthoptilum grandiflorum*. **E.** Unknown sea pen 2. All photos by V.E. Wareham.

Cup corals (F-G) are solitary scleractinian corals. **F.** *Flabellum alabastrum* is the most common cup coral in slope depth waters. *Flabellum* reclines on gravel or sand sediments and does not require hard substrates. **G.** *Desmophyllum dianthus* is relatively rare and usually occurs attached to hard substrates, including other corals. All photos by V.E. Wareham.

Soft corals (H-J). Although soft corals are quite small when retracted or compressed, when expanded on the sea floor they can reach up to 25 cm above the sediment. **H.** *Gersemia* spp. (mostly *G. rubiformis*). This Neptheid soft coral is the only species that is common in shelf-depth waters. It is usually red to pale brown in colour, although occasionally darker, and sometimes difficult to distinguish from its relative *Capnella florida* (I). **I.** *Capnella florida* resembles *Gersemia*, but is usually darker and has smaller polyps. **J.** *Anthomastus grandiflorus* is a large soft coral, distantly related to the Nephtheids. Its long tubular polyps can allow the colony to expand to widths of more than 25 cm on the sea floor. All photos by V.E. Wareham.


A
15 cm
B
5 cm
1 mm
C
5 cm
2 cm
D
E
2 cm
F
1 cm
G
1 cm
H
1 cm
3 mm
I
1 cm
J
1 cm

Appendix III: Maps Created for Analysis and Available on CD

File names are listed in parentheses.

Location map *(Location_map)*
Coral conservation areas shown with brackets *(Areas_brackets)*
Coral conservation areas shown with arrows *(Areas_arrows)*

Scientific Survey Data:

Density of effort (per 20x20 km):
Total survey effort *(Total_Effort_Den)*

Distribution:
Soft coral distribution (by species) *(Soft_Coral_SS)*
Sea pen distribution (by species) *(Sea_Pen_SS)*
Cup coral distribution (by species) *(Cup_Coral_SS)*
Small gorgonian coral distribution (by species) *(Small_Gorg_SS)*
Large gorgonian coral distribution (by species) *(Large_Gorg_SS)*

Diversity:
Species richness – graduated symbols *(Species_Richness_Grad)*
Species richness – coloured symbols *(Species_Richness_P)*

Density (per 20x20 km):
Total coral density *(Total_Coral_Density)*
Group 1, 2, and 3 density *(G123_Density)*
Group 4 & 5 density *(G4_G5_Density)*

Percentage of positive stations (per 20x20 km):
All coral *(All_Coral_Prc)*
All coral (reduced data) *(All_Coral_Prc3)*
Groups 1, 2, & 3 *(G123_Prc)*
Groups 1, 2, & 3 (reduced data) *(G123_Prc3)*
Groups 4 & 5 *(G4G5_Prc)*
Groups 4 & 5 (reduced data) *(G4G5_Prc3)*

Groundfish diversity:
Fish species richness – graduated symbols *(Fish_Richness_Grad)*
Fish species richness – coloured symbols *(Fish_Richness_P)*

Observer Data:

Distribution of fishing effort:

Close-up of southwest Grand Banks broken down by gear types *(SW_Gear_Types)*
Close-up of Northeast Newfoundland Shelf broken down by gear types *(NE_Gear_Types)*
Close-up of north of Cape Chidley broken down by gear types *(North_Gear_Types)*

Density of fishing effort (per 20x20 km):

Total fishing effort *(Ttl_TEff)*
Cod (All gear types) *(Cod_All_TEff)*
Cod (Longline) *(Cod_LL_TEff)*
Cod (Gillnet) *(Cod_Gill_TEff)*
Cod (Otter trawl) *(Cod_OttTrawl_TEff)*
Greenland halibut (All gear types) *(Ghal_All_TEff)*
Greenland halibut (Gillnet) *(Ghal_Gill_TEff)*
Greenland halibut (Longline) *(Ghal_LL_TEff)*
Greenland halibut (Otter trawl & twin trawl) *(Ghal_OT_TEff)*
Redfish (Gillnet) *(Red_Gill_TEff)*
Redfish (Otter trawl) *(Red_OttTrawl_TEff)*
Atlantic halibut (Longline) *(Ahal_LL_TEff)*
Crab (Crab pots) *(Crab_Crab_TEff)*
Monkfish (Gillnet) *(Monk_Gill_TEff)*
Shrimp (All gear types) *(Shrimp_All_TEff)*
All trawls *(All_Trawl_TEff)*
All gillnets *(All_Gill_TEff)*
All longlines *(All_LL_TEff)*

Distribution of coral bycatch:

Close-up of southwest Grand Banks *(SW_Coral_Dist)*
Close-up of northeast Newfoundland Shelf *(NE_Coral_Dist)*
Close-up of north of Cape Chidley *(North_Coral_Dist)*

Density of coral bycatch (per 20x20km):

All corals:

All coral bycatch *(TtlEff_All_Coral)*
Greenland halibut (All gear types) *(Ghal_All_Coral)*
Greenland halibut (Gillnet) *(Ghal_Gill_Coral)*
Greenland halibut (Longline) *(Ghal_LL_Coral)*
Greenland halibut (Otter trawl & twin trawl) *(Ghal_OT_Coral)*
Redfish (Otter trawl) *(Red_Otter_Coral)*
Atlantic halibut (Longline) *(Ahal_LL_Coral)*
Crab (Crab pots) *(Crab_Crab_Coral)*
Monkfish (Gillnet) *(Monk_Gill_Coral)*
Shrimp (All gear types) *(Shrimp_All_Coral)*
All trawls *(All_Trawl_Coral)*
All gillnets *(All_Gill_Coral)*
All longlines *(All_LL_Coral)*

Group 1 coral (Soft coral):

All group 1 coral bycatch *(G1_TtlEff_All)*
Greenland halibut (All gear types) *(G1_Ghal_All)*
Greenland halibut (Gillnet) *(G1_Ghal_Gill)*
Greenland halibut (Longline) *(G1_Ghal_LL)*
Greenland halibut (Otter trawl & twin trawl) *(G1_Ghal_OT)*
Redfish (Otter trawl) *(G1_Red_Otter)*
Atlantic halibut (Longline) *(G1_Ahal_LL)*
Crab (Crab pots) *(G1_Crab_Crab)*
Monkfish (Gillnet) *(G1_Monk_Gill)*
Shrimp (All gear types) *(G1_Shrimp_All)*
All trawls *(G1_All_Trawl)*
All gillnets *(G1_All_Gill)*
All longlines *(G1_All_LL)*

Group 2 coral (Sea pens):

All group 2 coral bycatch *(G2_TtlEff_All)*
Greenland halibut (All gear types) *(G2_Ghal_All)*
Greenland halibut (Gillnet) *(G2_Ghal_Gill)*
Greenland halibut (Longline) *(G2_Ghal_LL)*
Greenland halibut (Otter trawl & twin trawl) *(G2_Ghal_OT)*
Redfish (Otter trawl) *(G2_Red_Otter)*
Atlantic halibut (Longline) *(G2_Ahal_LL)*
Crab (Crab pots) *(G2_Crab_Crab)*
Monkfish (Gillnet) *(G2_Monk_Gill)*
Shrimp (All gear types) *(G2_Shrimp_All)*
All trawls *(G2_All_Trawl)*
All gillnets *(G2_All_Gill)*
All longlines *(G2_All_LL)*

Group 3 coral (Cup coral):

All group 3 coral bycatch *(G3_TtlEff_All)*
Greenland halibut (All gear types) *(G3_Ghal_All)*
Greenland halibut (Gillnet) *(G3_Ghal_Gill)*
Greenland halibut (Otter trawl & twin trawl) *(G3_Ghal_OT)*
Redfish (Otter trawl) *(G3_Red_Otter)*
Atlantic halibut (Longline) *(G3_Ahal_LL)*
Crab (Crab pots) *(G3_Crab_Crab)*
Monkfish (Gillnet) *(G3_Monk_Gill)*
Shrimp (All gear types) *(G3_Shrimp_All)*
All trawls *(G3_All_Trawl)*
All gillnets *(G3_All_Gill)*
All longlines *(G3_All_LL)*

Group 4 coral (Small gorgonian coral):

All group 4 coral bycatch *(G4_TtlEff_All)*
Greenland halibut (All gear types) *(G4_Ghal_All)*
Greenland halibut (Gillnet) *(G4_Ghal_Gill)*
Greenland halibut (Longline) *(G4_Ghal_LL)*
Greenland halibut (Otter trawl & twin trawl) *(G4_Ghal_OT)*
Redfish (Otter trawl) *(G4_Red_Otter)*
Atlantic halibut (Longline) *(G4_Ahal_LL)*
Crab (Crab pots) *(G4_Crab_Crab)*

Monkfish (Gillnet) *(G4_Monk_Gill)*
Shrimp (All gear types) *(G4_Shrimp_All)*
All trawls *(G4_All_Trawl)*
All gillnets *(G4_All_Gill)*
All longlines *(G4_All_LL)*

Group 5 coral (Large gorgonian coral):
All group 5 coral bycatch *(G5_TtlEff_All)*
Greenland halibut (All gear types) *(G5_Ghal_All)*
Greenland halibut (Gillnet) *(G5_Ghal_Gill)*
Greenland halibut (Longline) *(G5_Ghal_LL)*
Greenland halibut (Otter trawl & twin trawl) *(G5_Ghal_OT)*
Redfish (Otter trawl) *(G5_Red_Otter)*
Atlantic halibut (Longline) *(G5_Ahal_LL)*
Crab (Crab pots) *(G5_Crab_Crab)*
Shrimp (All gear types) *(G5_Shrimp_All)*
All trawls *(G5_All_Trawl)*
All gillnets *(G5_All_Gill)*
All longlines *(G5_All_LL)*

Percentage of positive stations (per 20x20 km):
*Each map in this section is available twice: One is all data and the other has any cells with less than 3 sets removed (reduced-3)

All corals:
All coral *(TtlEff_All_All)*
Greenland halibut (All gear types) *(Ghal_All_All)*
Greenland halibut (Gillnet) *(Ghal_Gill_All)*
Greenland halibut (Longline) *(Ghal_LL_All)*
Greenland halibut (Otter trawl & twin trawl) *(Ghal_OT_All)*
Redfish (Otter trawl) *(Red_Otter_All)*
Atlantic halibut (Longline) *(Ahal_LL_All)*
Crab (Crab pots) *(Crab_Crab_All)*
Monkfish (Gillnet) *(Monk_Gill_All)*
Shrimp (All gear types) *(Shrimp_All_All)*
All trawls *(All_Trawl_All)*
All gillnets *(All_Gill_All)*
All longlines *(All_LL_All)*

Coral groups 1,2, and 3:

All corals in groups 1, 2, and 3 *(Ttl_Eff_123P)*
Greenland halibut (All gear types) *(Ghal_All_123P)*
Greenland halibut (Gillnet) *(Ghal_Gill_123P)*
Greenland halibut (Longline) *(Ghal_LL_123P)*
Greenland halibut (Otter trawl & twin trawl) *(Ghal_OT_123P)*
Redfish (Otter trawl) *(Red_Otter_123P)*
Atlantic halibut (Longline) *(Ahal_LL_123P)*
Crab (Crab pots) *(Crab_Crab_123P)*
Monkfish (Gillnet) *(Monk_Gill_123P)*
Shrimp (All gear types) *(Shrimp_All_123P)*
All trawls *(All_Trawl_123P)*
All gillnets *(All_Gill_123P)*
All longlines *(All_LL_123P)*

Coral groups 4 and 5:

All corals in groups 4 and 5 *(G4G5_All_Coral)*
Greenland halibut (All gear types) *(G4G5_Ghal_All)*
Greenland halibut (Gillnet) *(G4G5_Ghal_Gill)*
Greenland halibut (Longline) *(G4G5_Ghal_LL)*
Greenland halibut (Otter trawl & twin trawl) *(G4G5_Ghal_OT)*
Redfish (Otter trawl) *(G4G5_Red_Otter)*
Atlantic halibut (Longline) *(G4G5_Ahal_LL)*
Crab (Crab pots) *(G4G5_Crab_Crab)*
Monkfish (Gillnet) *(G4G5_Monk_Gill)*
Shrimp (All gear types) *(G4G5_Shrimp_All)*
All trawls *(G4G5_All_Trawl)*
All gillnets *(G4G5_All_Gill)*
All longlines *(G4G4_All_LL)*

Analysis of bias:

Comparison of all corals in FOP and SS data (percentages) (CoralBias_All_3)
Comparison of all corals in FOP and SS data (presence/absence) (CoralBias_All_)
Comparison of Group 4 and 5 corals in FOP and SS data (percentages) (CoralBias_G4G5_3)
Comparison of Group 4 and 5 corals in FOP and SS data (presence/absence) (CoralBias_G4G5_)
Comparison of Group 1, 2, and 3 corals in FOP and SS data (percentages) (CoralBias_G123_3)
Comparison of Group 1, 2, and 3 corals in FOP and SS data (presence/absence) (CoralBias_G123_)