OCCURRENCE, SENSITIVITY TO FISHING, AND ECOLOGICAL FUNCTION OF CORALS, SPONGES, AND HYDROTHERMAL VENTS IN CANADIAN WATERS

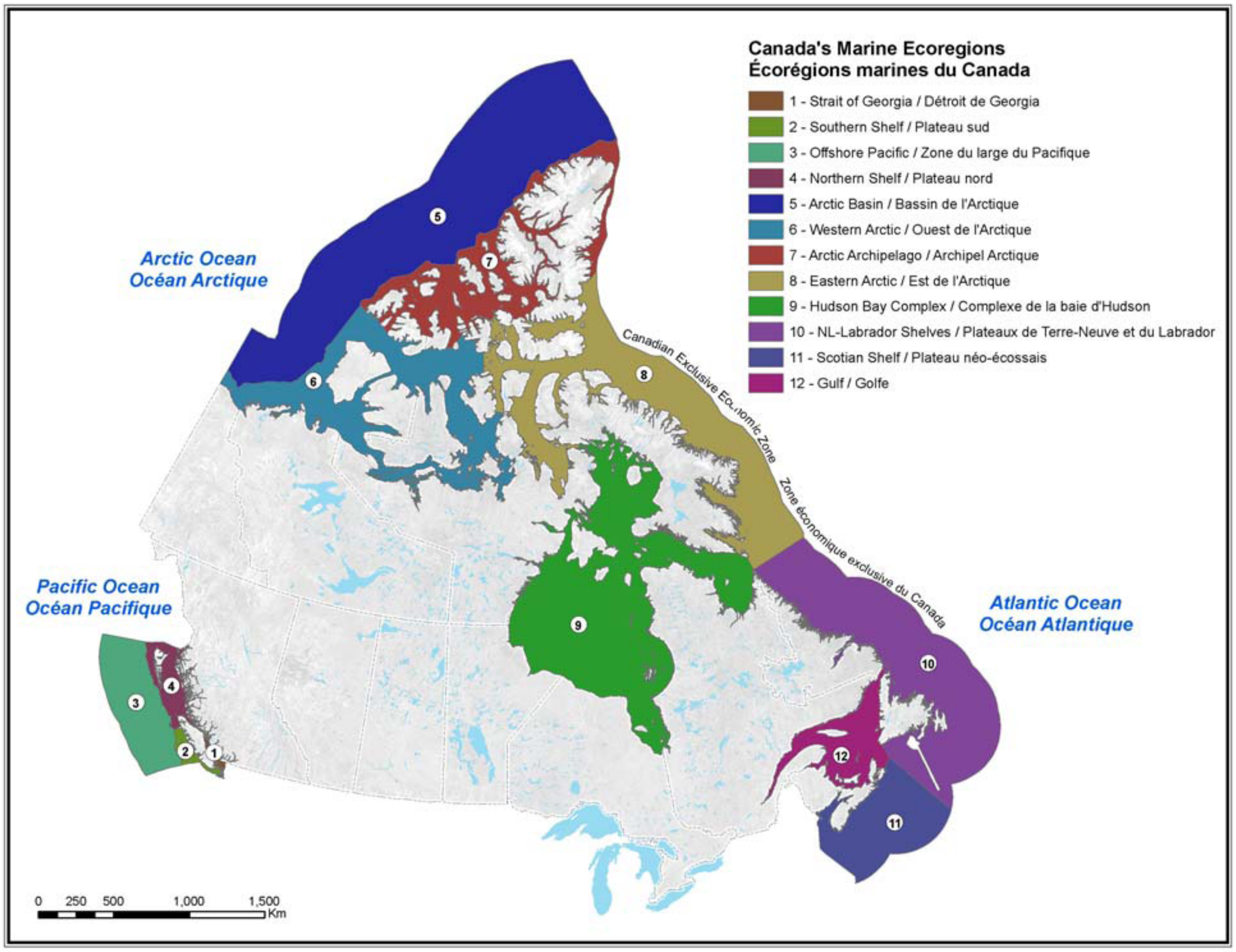

Figure 1. The biogeographic units (DFO, 2009) that were considered when determining the occurrence of corals, sponges, and hydrothermal vents in Canadian waters.

Context

Canada is committed domestically and internationally to conserve, manage, and exploit fish stocks in a sustainable manner, as well as to manage the impacts of fishing on sensitive benthic areas and vulnerable marine ecosystems. In support of these commitments and initiatives, and in response to requests for advice from various sectors within DFO, a national science advisory process was held (March 9-12, 2010; Ottawa) to review the available information, and provide science advice, concerning the occurrence, sensitivity to fishing, and ecological function of corals, sponges, and hydrothermal vents in the Canadian Exclusive Economic Zone (EEZ).

SUMMARY

- A national science advisory process was held to review the available information and provide science advice, concerning the occurrence, sensitivity to fishing, and ecological function of corals, sponges, and hydrothermal vents in the Canadian Exclusive Economic Zone (EEZ).
- There are a variety of methodologies and sampling techniques available that can be used to determine the occurrence of corals, sponges, and hydrothermal vents. In the Canadian EEZ, hydrothermal vents are found exclusively in the Pacific; however corals and sponges are known to occur throughout Canadian waters.
- Hydrothermal vents are an ecologically important deep-ocean energy source that support communities of specialised bacteria which provide a trophic basis for communities of higher organisms (e.g. mussels, worms, snails, crabs, anemones, fish, octopus, etc.), many of which are endemic to these benthic features.
- Corals and sponges form complex, three-dimensional biogenic structures that directly and indirectly influence the occurrence and abundance of many fish and invertebrate species.
- Corals, sponges, and hydrothermal vents are sensitive and susceptible to anthropogenic activities, including direct (e.g. removal or damage) and indirect (e.g. smothering by sedimentation) fishing impacts.
- Ecological goals to consider when managing benthic attributes were discussed; however as consensus could not be reached, science advice is not provided on this topic.
- A suite of ecological indicators were reviewed (i.e. uniqueness, rarity, species density, species richness, species distribution, and species diversity) and their strengths and weaknesses discussed. Three methodologies (i.e. cumulative distribution, area of aggregation, and species distribution models) were considered appropriate predictors of several ecological indicators.
- Elements to consider when developing an encounter protocol were briefly discussed and will be revisited in detail at a future science-advisory process.

BACKGROUND

Canada is committed domestically and internationally to conserve, manage, and exploit fish stocks in a sustainable manner, as well as to manage the impacts of fishing on sensitive benthic areas and vulnerable marine ecosystems.

As a result of ongoing requests from environmental groups and some States for a moratorium on high seas bottom trawling, the United Nations General Assembly (UNGA) took up the issue in its annual negotiations of the *Sustainable Fisheries Resolution*, which resulted in a series of agreed commitments related to improving fisheries governance in areas beyond national jurisdiction, rather than prohibiting certain fishing gears. States are expected to directly, or through regional fisheries management organisations and arrangements (RFMO/A), apply the precautionary and ecosystem approaches to sustainably manage fish stocks and identify and protect vulnerable marine ecosystems (VME) from significant adverse impacts in areas beyond national jurisdiction. Features that may indicate the presence of a VME include seamounts, hydrothermal vents, corals, and sponges, among others.

At the request of the Committee on Fisheries (COFI) of the Food and Agriculture Organisation (FAO) of the United Nations, the *International Guidelines for the Management of Deep-sea Fisheries in the High Seas* were developed to assist States and RFMO/A to sustainably manage deep-sea fisheries consistent with the precautionary approach and to guide the implementation of the relevant elements of the 2006 UNGA *Sustainable Fisheries Resolution 61/105*.

The ecosystem considerations included in *UNGA Resolution 61/105* and Canada's domestic practices are generally in alignment. Domestically, Canada is implementing the *Sustainable Fisheries Framework* (SFF) which aims to ensure fisheries are environmentally sustainable while supporting economic prosperity. A key component of the SFF is the *Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas*. This *Policy* will aid in the management of fisheries to mitigate impacts of fishing on sensitive benthic areas and avoid impacts of fishing that are likely to cause serious or irreversible harm to sensitive marine habitats, communities, and species.

In addition to the SFF and its related *Policies*, there are a number of regional coral and sponge conservation strategies/plans, potential *Oceans Act* Marine Protected Areas (MPA) regulations, and plans for bioregional networks of MPA in various stages of development or implementation. These initiatives outline conservation, management, and research objectives that provide the framework for managing fishing and non-fishing impacts on corals and sponges in Canadian waters.

In support of the aforementioned commitments and initiatives, and in response to requests for advice from various sectors within DFO, a national science advisory process was held (March 9-12, 2010; Ottawa) to review the available information, and provide science advice, concerning the occurrence, sensitivity, and ecological role and function of corals, sponges, and hydrothermal vents in Canadian waters.

ANALYSIS AND SCIENCE ADVICE

The basis for the science advice provided in this report was drawn from available relevant peer-reviewed publications, as well as domestic and international experiences. Please note that Figures 2 to 42 can be found in Appendix 1.

<u>Terminology</u>

In this report, *benthic attributes* refers to corals, sponges, and/or hydrothermal vents located within the Canadian Exclusive Economic Zone (EEZ). There are a wide variety of benthic attributes that are not included in this science advice. In no way does failure to include them imply that they do not serve any ecological functions, nor does it imply that they are not susceptible to fishing or other anthropogenic activities within the Canadian EEZ. The benthic attributes referred to in this report were specifically selected for consideration as the request of the Oceans and Fisheries and Aquaculture Management sectors of DFO singled them out for priority consideration.

Throughout this report, the term *species* may be used to refer to a specific species or taxonomic group(s).

Corals refers to any of the numerous, sessile marine polyps of the Class Anthozoa that secrete calcareous skeletons and attach themselves to bottom substrates. *Sponges* include any of the sessile marine invertebrates in the Phylum Porifera that attach themselves to bottom substrates and characteristically have a porous skeleton composed of siliceous or calcareous spicules. *Hydrothermal vents* are fissures on the seafloor from which hot, mineral-rich water flows.

Discussion regarding the *impacts* of any human activity, including fishing, on an ecosystem cannot avoid addressing the impact relative to a particular benchmark state. In this report, *impacts* are discussed relative to the current state of corals, sponges, and/or hydrothermal vents. The benchmarks do not necessarily take account of the possible impacts of past fishing or other activities on corals, sponges, and hydrothermal vents. It should be noted that once ecological and operational objectives have been specified for an area, the context for evaluating *impacts* of fishing gears or other human activities will be relative to the state of the ecosystem that is consistent with the defined objectives. However, *impacts* were not considered in this report in the context of specific ecological and/or operational objectives.

Perturbation is to be interpreted as the degree to which a current fishery results in changes to a population, and/or community of corals, sponges, and/or hydrothermal vents from its state prior to current fishing events.

For corals and sponges, *ecological function* is achieved when a species, population, and/or a community of species is of the sufficient size, distribution, and composition to allow it to exercise its role in the ecosystem. For hydrothermal vents, *ecological function* is achieved when any given vent is in a state sufficient to allow it to perform its role in the ecosystem.

In this report, *susceptibility* is to be interpreted as the vulnerability of corals, sponges, and hydrothermal vents to impacts resulting from fishing activities. The likelihood of an impact occurring and the sensitivity of the benthic attribute in question should be considered when determining its susceptibility to fishing activities.

Sensitivity is considered the capacity of corals, sponges, or hydrothermal vents to respond to impacts resulting from fishing activities and is dependent on the physical and/or life history characteristics that affect their capacity to respond.

When *recovery* is mentioned in this report, it refers to the return of the benthic attribute to the state from which the current fishery impacted it. It is not intended to refer to the return of the benthic attribute to a pristine state (i.e. prior to any fishing or other human activities).

In determining the *recovery potential* of a benthic attribute, a variety of factors should be taken into consideration (e.g. population size, range and spatial distribution, recruitment and growth productivity, age composition, the minimum number of individuals required to maintain the population, threats, habitat, etc.). However, these factors may vary among the benthic attributes included for consideration in this science advisory report.

Species diversity considers species richness and abundance within a community of organisms. *Species richness* is defined as the number of species present in a community or ecosystem and can be determined at the order, family, genus, or species level.

Ecological Function of Benthic Attributes in Canadian Waters

The Ecological Function of Hydrothermal Vents

Hydrothermal vents are unique geological structures situated at a range of depths from shallow to abyssal. The energy source that sustains these deep-ocean ecosystems is not sunlight, but the energy resulting from chemosynthesis. The water and sediment around hydrothermal vents provides habitat for many species, including some that are endemic to these benthic features. In addition, they play a key role in the oceanic carbon-nitrogen cycle.

Bacteria associated with hydrothermal vents use hydrogen sulphide as their sole energy source and form the basis of associated food chains. Through symbiotic relationships, these bacteria are critical to ecological functions that support a variety of macrofauna (e.g. mussels, worms) which in turn support a number of other organisms (e.g. crabs, anemones, fish, octopus, snails, limpets, etc.).

The Ecological Function of Corals

There is a growing body of information that demonstrates that corals may form some of the most complex habitats in the ocean. Corals create biogenic habitat (i.e. via their body size and shape) and form complex, three-dimensional structures with spaces and gaps which are important for other marine life. They provide shelter for numerous species and also influence, both directly and indirectly, the local occurrence or abundance of fish and invertebrate species. Species diversity is considered to be higher in areas containing corals compared to structurally-complex abiotic habitats (e.g. boulder erratics) or habitats that do not contain these organisms.

Coldwater corals can form important structural habitats that contribute to vertical relief and increase the availability of microhabitats. Increasing complexity alters local flow patterns and provides feeding opportunities for aggregating species, nutrient regeneration, hiding places from predators, shelter from high flow regimes and local currents, a nursery area for juveniles, fish spawning aggregation sites, and attachment substrate for fish and invertebrate egg cases and also sedentary invertebrates. As such, they provide habitats at key life stages of many marine species as well as a food source for other invertebrates.

Where there is very little abiotic structure in the habitat, biogenic structures are often patchy but may provide the only habitats in these regions for unique assemblages of organisms. In determining the significance of the ecological function of the biogenic structures, consideration must be given to the relative abundance of the biogenic structure-derived habitat in relation to the available abiotic habitat.

The Ecological Function of Sponges

Sponges provide significant deep-sea habitat, enhance species richness and diversity, and exert clear ecological effects on other local fauna. Sponge grounds and reefs support increased biodiversity compared to structurally-complex abiotic habitats or habitats that do not contain these organisms.

Morphological forms such as thick encrustations, mounds, and branched, barrel- or fan-like shapes influence near-bottom currents and sedimentation patterns. They provide substrate for other species and offer shelter for associated fauna through the provision of holes, crevices, and spaces. Siliceous hexactinellid sponges can form reefs as their glass spicules fuse together such that when the sponge dies the skeleton remains. This skeleton provides settlement surfaces for other sponges, which in turn form a network that is subsequently filled with sediment.

Although some of the siliceous spicules of non-reef-forming species dissolve quickly, there is some accumulation of shed spicules forming a thick sediment-stabilizing mat, which constitutes a special bottom type supporting a rich diversity of species. Organisms commonly associated with sponges and sponge grounds include species of marine worms and bryozoans, as well as higher fauna. Live glass sponge reefs have been show to provide nursery habitat for juvenile rockfish and high-complexity reefs are associated with higher species richness and abundance.

Sensitivity of Benthic Attributes to Fishing Impacts and their Potential for Recovery

The Sensitivity of Hydrothermal Vents to Fishing and their Potential for Recovery

Hydrothermal vents and their associated ecosystems are extremely fragile and sensitive to anthropogenic activities. Owing to the depth in which they are located within Canadian waters (~ 2200 m), current fishing gear technologies and methods are not likely to pose a threat to hydrothermal vents. At the present time, the primary threat to hydrothermal vents is research and sample collection for scientific purposes as well as exploratory industry studies. As these activities can be quite selective, they have the potential to overexploit specific organisms and resources, if not managed appropriately. In addition, without adequate management, other activities (e.g. mining, biotechnology, biomedical, hydroelectric, etc.) that may, in the future, aim to exploit resources associated with hydrothermal vents, could pose a threat to these unique ecosystems.

The Sensitivity of Corals and Sponges to Fishing and their Potential for Recovery

Sensitivity of Corals and Sponges to Fishing Impacts

Corals and sponges are particularly sensitive to fishing impacts through both direct (e.g. removal and/or damage) and indirect impacts (e.g. smothering by sedimentation). However, some species of corals and sponges are more susceptible and/or sensitive to fishing impacts than others. In evaluating a species' degree of sensitivity and susceptibility to fishing activities (either commercial or for research purposes), the following factors should be considered: its range and spatial distribution, its morphology and skeletal composition (i.e. rigid vs. flexible), its means of attachment to the substrate, its life history characteristics, and its habitat preferences.

Both mobile and fixed fishing gears that are likely to contact the bottom during normal fishing operations, can impact coral and sponge species, populations, and communities. Bottom-trawling and dredging have been acknowledged to have the greatest anthropogenic impact to benthic environments. The effects of fishing gear on the current state of the ecosystem of concern are not uniform and depend on, among other factors, the type of gear used, the specific features of the seafloor habitats (including the natural disturbance regime), the species present, the methods and timing of deployment of the gear, the frequency with which a site is impacted by specific gears, and the history of human activities, especially past fishing, in the area of concern.

A review of empirical studies on the impacts of fishing on temperate deepwater marine ecosystems was undertaken which included studies that measured the impacts of fishing disturbances against temporal and/or spatial references (e.g. sites with little or no previous fishing activity). Most of these studies focused on trawling impacts and results indicate that corals and sponges generally exhibit greater declines in relative abundance than other invertebrate and fish taxa following fishing disturbance. Studies reviewed reported that within the path of a single trawl, 1-8% of corals and 20-70% of sponges were removed, and damage (e.g. crushed, broken or missing branches, tipped over, or severed from holdfast) occurred at varying extent to the corals and sponges that remained (ranging from 23-100% for corals and 14-67% for sponges), depending on their growth form and size.

Although a suite of fishing gear types can impact corals and sponges, fishing does not currently occur in all areas in which these organisms exist. Lack of fishing effort in these areas may be the result of a combination of factors such as: i) closures (either directed or voluntary), ii) the absence of fish and invertebrate species that are currently targeted, iii) difficult bottom types, iv) the ability of current technologies to access these areas, and/or v) these areas have not been included in the historical fishing footprint.

Potential for Recovery of Corals and Sponges from Fishing Impacts

Current literature indicates that some species of deep sea corals and sponges, including many found in Canadian waters, that have been impacted through fishing activities may take from decades to centuries to recover (in terms of abundance, recruitment, or re-growth), if they do so at all. If the impact completely removes the biogenic structures that were present prior to perturbation, and/or if the distance between colonies is great enough that gametes from other sources cannot re-colonise the impacted area, the site may never recover.

Once impacted by fishing, coral and sponge species vary in their potential for recovery. To evaluate recovery for any given species of coral or sponge, the following biological characteristics must be considered: i) recruitment potential (e.g. larval competency, ii) distance from other potential sources of colonizers), iii) age at first maturity, iv) reproduction strategies, v) maximum age, and vi) growth rates. In addition, recovery potential is based on the frequency, extent, and spatial scale of the impact.

Ecological Goals to Consider when Managing Fishing Impacts on Corals, Sponges, and Hydrothermal Vents

Science advice is not provided on this topic as no consensus could be reached among participants owing to time constraints and as the focus of the material presented was not considered specifically related.

Occurrence of Benthic Attributes in Canadian Waters

A variety of different methodologies were utilised in order to map the occurrence of corals, sponges, and hydrothermal vents in Canadian waters and in particular, determine where aggregations are located. Figures demonstrating the occurrence of the benthic attributes are provided below, along with a brief explanation of the methods used to produce them; further details can be found in the associated CSAS Research Documents.

<u>Occurrence of hydrothermal vents in Canadian waters</u>

Most of the known hydrothermal vent sites in the world are found in international waters and have been discovered in the last 25 years. The only three known sites of hydrothermal vents in Canadian waters are located along the Juan de Fuca/Explorer ridge located 256 km southwest of Vancouver Island (Clayoquot Sound) and centered at 47°57'N and 129°06'W (Figure 2). There are currently no known hydrothermal vents in Canadian Arctic or Atlantic waters.

Occurrence of corals and sponges in the Canadian Pacific

Based on scientific surveys, commercial observer records, primary literature, and museums

A database of 5,553 coral records and 10,689 sponge records was compiled using data from primary literature, museums, online databases, DFO survey data, and commercial observer records. Records contained differing levels of taxonomic resolution and not all records were confirmed by an expert. The coral records are comprised of 97 species from 25 families and five orders, while the sponge records represent over a hundred species from 55 families and 22 orders. Although comprehensive, these records do not provide a complete description of the distribution of coral and sponges in Canadian Pacific waters and it is expected that additional areas containing these organisms exist. The known distribution of corals and sponges in Canadian Pacific waters are presented in Figures 3 and 4.

The Canadian Pacific is home to globally unique hexactinellid sponge reefs. The locations of all known hexactinellid sponges in Canadian waters are presented in Figure 5; a small sponge reef located in the Portland Canal could not be included. Antipatharia (black corals) are also considered globally rare; the known locations of this taxon in the Canadian Pacific are presented in Figure 6.

Based on predictive modelling

Species distribution models use algorithms to relate occurrence data to environmental and habitat variables. Such models can be used to predict suitable habitat where target species or other taxonomic groups are likely to be found, but have not been physically sampled.

It was agreed that in the absence of complete information on the distribution of taxa, species distribution models can help both science and management better address conservation and planning needs.

Using Maxent software (Version 3.2.19; http://www.cs.princeton.edu/~schapire/maxent/), a model was constructed to predict the potential distribution of four orders of coral: Alcyonacea, Antipatharia, Pennatulacea, and Scleractinia (Figures 7 to 10).

Occurrence of corals and sponges in the Eastern Arctic, Hudson Bay Complex, and Canadian Atlantic using scientific and industry survey data

Data were the collated results of research vessel multi-species surveys conducted by five DFO Regions and the Northern Shrimp Research Foundation (NSRF) industry survey and augmented by fisheries observer data where they provided information that extended the distribution of corals and sponges. Surveys conducted were all stratified-random in design giving good spatial coverage of samples across all biogeographic units to a maximum depth of 1500 m. There were 4,501 records of coral from the research vessel surveys and 1,042 records from fisheries observers in the Eastern Arctic. These recorded 29 coral species (39 taxa in total) from five Orders. Similar datasets produced 4,702 records of sponge (Porifera) from the research vessel surveys with 59 fisheries observer records providing additional information on the range of the Russian Hat sponge (*Vazella pourtalesi*) on the Scotian Shelf.

Analysis was based on five Canadian biogeographic units (Figure 1). The known presence and absence of corals and sponges are presented as follows:

- Eastern Arctic (Figures 11 and 12);
- Hudson Bay Complex (Figures 13 and 14);
- Newfoundland-Labrador Shelves (Figures 15 and 16),
- Gulf of St. Lawrence (Figures 17 and 18); and
- Scotian Shelf (Figures 19 and 20).

Species of special interest are also presented for several of the biogeographic units:

- *Antipatharia* (black corals) in the Newfoundland and Labrador Shelves (Figure 21);
- *Pennatulacea* (sea pens) in the Laurentian Channel (Figure 22); and
- *Lophelia pertusa* and *Vazella poutalesi* (Russian Hat sponge) in the Scotia Shelf (Figures 23 and 24, respectively).

Key data gaps include the deepwater (>1500 m) on the Scotian Shelf and Newfoundland-Labrador Shelves where large parts of the Canadian EEZ have not been surveyed. In addition, large areas of the Hudson Bay Complex and the Eastern Arctic have also not been surveyed, regardless of depth. In other areas, rough bottom is eliminated from the survey strata for a variety of reasons (e.g. potential damage or loss of gear, sampling design, etc.) although these areas may be good habitat for some corals and sponges.

On the Scotian Slope, where a number of remote-operated vehicle (ROV) surveys were conducted in deepwater outside the study area, the number of coral species was greatly increased and areas of high biomass and diversity identified. ROV surveys are particularly useful in expanding the sampling area, not only on the Scotian Slope but in most areas, and as a result may allow the discovery and identification of many more species that cannot be determined using traditional trawl-sampling methods alone.

<u>Case studies indicating the occurrence of corals and sponges in the Hatton Basin and the Gulf of Saint Lawrence</u>

Hatton Basin using research and commercial survey data

Hatton Basin is an area of the Labrador Shelf 7300 km^2 that straddles NAFO Divisions 2G-0B and has an average depth of approximately 600 m. Data from the NSRF survey (2005-2009) and the DFO multi-species survey (1996-1999) were used to map the distribution of corals (Figure 25) and sponges in NAFO Divisions 2G-0B (Figure 26). These surveys used a stratified-random sampling design at depths less than 750 m and 1500 m respectively. In addition, the NSRF data were used to map species richness in Divisions 2G-0B and are represented as the number of species per set. Both of the surveys are considered very robust, however they are biased towards bottom substrates in which trawling can occur and target different depth strata.

Northern Gulf of St. Lawrence using the Local Ecological Knowledge (LEK) of local fish harvesters

Local Ecological Knowledge (LEK) can be useful to aid in determining the occurrence of corals and sponges, particularly when combined with predictive modelling or survey methodologies.

Twenty-eight interviews were conducted with Northern Gulf fish harvesters in November and December 2009 in three communities on the west coast of Newfoundland (Port-Au-Choix, Norris Point and Port-Aux-Basques). Fish harvesters were asked to draw polygons on nautical charts representing their fishing areas and also areas where they remember seeing coral. During interviews, fish harvesters were shown pictures and specimens of different species of coral to confirm identification. The majority (85%) of fish harvesters interviewed were familiar with Nephtheid soft corals and 57% were familiar with sea pens. Fish harvesters reported these species to be widespread in the Northern Gulf of St. Lawrence which correlates with what has been reported from DFO groundfish research surveys. In addition, Scleractinian cup corals and large gorgonians (*Acanthogorgia armata*, *Keratoisis ornata* and *Primnoa resedaeformis*) were also reported during interviews (Figures 27 to 30).

Uncertainties with Data and Methodologies used to Determine Coral and Sponge Distributions

The methodologies employed to determine coral and sponge distribution share uncertainties among them which includes but is not limited to, taxonomic and/or mapping errors and a bias in the data that is associated with the sampling design and/or tools. These uncertainties are discussed in detail below for predictive models, research and commercial survey data, commercial fisheries observer data, and Local Ecological Knowledge.

Predictive Modeling

The main uncertainties can be attributed to: i) the algorithm used to determine the relationship between coral locations and the background data, ii) modeled environmental data, and iii) the coral records used (i.e. taxonomic and spatial uncertainties). Uncertainty associated with the coral records was addressed in two ways. First, taxonomic uncertainty was minimized by limiting records used to those that were obtained through research surveys, other scientific studies, and as bycatch in commercial fisheries that were identified by experts. Records were also grouped to Order, further reducing the likelihood of a misclassification. Spatial uncertainty was addressed by only including records with sufficient spatial resolution that allowed assignment to the correct 500 m by 500 m grid cell. Uncertainty in the modeled environmental variables was reduced by using data from a well-validated tidal circulation model for the eastern North Pacific. Predictive model results were not sensitive to modeled environmental data, however there is always uncertainty associated with model results. Nonetheless, the algorithms used by Maxent (the distribution modeling tool used) have been proven to provide reasonable predictions of species distributions in other studies.

Research and Commercial Survey Data

There are a number of uncertainties in research vessel bycatch data. Taxonomic accuracy is not critical here, since the analyses are based on species groups. In the studies considered in this advice, four different trawls were used for sample collection. The configurations of the trawls vary significantly and it is assumed that they have different “catchability” of coral and sponge. These differences can affect the volume collected making direct comparisons across gear types problematic. However, for this advice data were analysed separately by gear type and therefore any differences that may exist between gear types does not affect the conclusions presented.

Fisheries Observer Data

Fisheries observers collect data on coral and sponge bycatch in some fisheries and in most cases specimens are retained for taxonomic verification. Sometimes the commercial fisheries operate in areas not covered by the research vessel trawl surveys, and on the Scotian Shelf and in the Eastern Arctic these data have extended the known distribution of corals and sponges. Uncertainties associated with this type of data for the presence/absence of corals and sponges are related to absence records which may not necessarily indicate no corals or sponges in the catch for a variety of reasons.

Local Ecological Knowledge (LEK)

Fish harvesters have been proven to be a valuable source of information regarding the distribution of deep-sea corals owing to their repeated interactions with the marine environment. However, there are limitations to this type of data as fish harvesters are not likely to have training in coral taxonomy. Another limitation is the geographical accuracy with which the locations of specific species or groups are reported. Often fish harvesters can confirm capture of a specific organism in a general area, but may be unsure of the exact location on a map. Therefore, maps created from interviews represent only the general area in which these groups or species were found and not precise locations.

Overview of Selected Ecological Indicators

The ecological indicators included in this report represent those presented and discussed at this particular science advisory process. However, other ecological indicators exist, all with their own strengths and weaknesses, that were not examined (e.g. species associations, size composition of the community, cumulative frequency distribution, evenness, trophic interaction strengths, biological trait analysis, productivity, naturalness, connectivity, endemism).

All ecological indicators are subject to the limitations of the available data and sampling design and tools. For example, trawl surveys may not adequately sample sponge and coral species, the ability of the gear to capture and retain corals and sponges is unknown, and ROV can only sample small areas at a time.

Uniqueness and Rarity

This ecological property is particularly useful as species or communities considered unique or rare are usually easily recognised. Qualitative methods can be used to identify unique/rare areas and quantitative methods are not required. Complications may arise when determining “uniqueness” using an external framework (e.g. IUCN Red List, General Status, etc.), or when confirmation of presence/absence may be biased by the selectivity of the sampling gear used.

Species Density

Species density as an ecological indicator identifies aggregations of species which may be related to habitat quality and community structure. This indicator is a commonly used metric, comparable across ecosystems, quantitative, and repeatable. The determination of species density utilises estimates of numerical abundances at the level of the individual per unit area. However, it is dependent on issues related to sampling selectivity – among different species and between gear types.

Species Richness

Species richness is a quantitative and repeatable measure that is an indicator of community structure. Species richness is a well used index that can be compared across ecosystems. Although it can be calculated without relative biomass estimates, it is limited by taxonomic resolution and is highly sensitive to sampling effort as well as the selectivity of the sampling device.

Species Diversity

Species diversity is a commonly used indicator of community structure that is comparable across ecosystems. Species diversity considers species richness along with relative abundance, but cannot be estimated without biomass or abundance estimates. This is a repeatable and quantitative indicator, but is sensitive to the different catchabilities of different components of marine systems.

Species Biomass

Species biomass can be determined using existing data and is an indicator of structure and productivity which is quantitative and repeatable. Changes in biomass are detectable depending on the frequency of data collection, and similar to other indicators, biomass is subject to sampling gear selectivity.

Species Range

It is possible to predict the range of a species or define its distribution using existing information. Changes in distribution are detectable depending on the frequency of data collection. Although a repeatable and quantitative indicator, the determination of species range is directly related to the coverage of the sampling method. This indicator is fairly insensitive and is slow to respond after perturbation; often by the time significant changes are documented, usually any other ecological consequences have already occurred.

Selected Ecological Indicators and their Predictors

Uniqueness and Rarity

Certain areas can be identified without the use of a predictor as they are considered unique and/or rare in the Canadian EEZ. Examples of unique and/or rare benthic attributes in Canadian waters are:

- the Endeavour Hydrothermal Ventfields (Figure 2);
- the hexactinellid (glass sponge) reefs (Figure 5);
- Antipatharians (black corals) (Figures 6 and 21);
- Aggregations of sea pens in the Laurentian channel (Figure 22);
- *Lophelia pertusa* reefs (Figure 23); and
- *Vazella pourtalesi* (Russian Hat) sponges (Figure 24).

Cumulative Distribution: A Predictor of Species Biomass

Cumulative distribution can identify relative abundance, density, and (when records are plotted on a map) can also provide information on habitat area. However this method is of limited use for species that do not aggregate or form patches. Although cumulative distribution is an abundance measure, there is rarely any biological basis for selecting any particular threshold (e.g. 90%, 97.5%, or where the greatest percent change is demonstrated). There is no geographical element to cumulative distribution and results may fluctuate in response to changes in sample size.

In terms of ecological function, areas of high biomass density are of ecological significance, thus the use of a biomass-based threshold in this case is defensible. The threshold value of 97.5% for sea pens, and small gorgonians and 90% for large gorgonian corals of catch densities as determined from trawl survey data is consistent with the advice provided to and acted upon in the Northwest Atlantic Fisheries Organisation (NAFO). However, the 97.5% threshold was based on the pattern of aggregation of the corals, and not on any ecological justification that this threshold was more *ecologically* “significant” than other percentages. The position of large catches of sea pens and small and large gorgonians using the cumulative catch distribution are shown in Figures 31 to 34.

Area of Aggregation: A Predictor of Species Distribution, Range, and Biomass.

In general for aggregating species, larger aggregations are likely more important to ecosystem function than small aggregations.

The area of aggregation predictor identifies where concentrations of aggregating species are located in the broader landscape; abrupt changes in habitat area when the locations of successively smaller survey catches are included indicate changes in distribution from aggregations to dispersed individuals. The area of aggregation method cannot be applied to non-aggregating species. Large aggregations identified by this method are generally more vulnerable to fishing impacts than small aggregations owing to their size.

The ecological rationale and threshold for this predictor are defensible when addressing the issue of patch size and indicators of species biomass and diversity. The selected threshold is the point of maximum change in the relative area occupied by successive catch weights. This value indicates the transition from areas of high density/biomass to areas of lower density/biomass. Therefore, a threshold identified via this method can be justified using the rationale that areas above the transition point are of particularly high ecological importance.

This predictor has been applied in the Canadian context and some of the areas have been confirmed using video and/or multi-beam technology. The positions of catches of sea pens, small and large gorgonians, and sponges using the area of aggregation predictor are shown in Figures 35 to 42.

Species Distribution Models: A Predictor of Species Range and Habitat Suitability

Habitat suitability can be interpreted as the probability that a species could be established and thrive in a particular area, if propagules were available and anthropogenic mortality sources managed. Species distribution models can aid in mapping the potential distribution of a particular species, including areas where there are very little presence data available (i.e. for rare and enigmatic species). Distribution maps of multiple species can be used to identify areas of high species diversity, and the extent of known or potential threats can be inferred using maps indicating their location (i.e. the “footprint” of the threat).

Species distribution models are based in ecological theory (i.e. niche theory) and empirical data. These models can be used to define the probable extent of habitat available for a particular species. They are useful in identifying potential habitats and can aid in identifying information gaps, priority areas for conservation, and areas requiring future research. However, detailed environmental data are required to parameterise models and predictions require validation.

Model results predicting habitat suitability are generally provided on a continuous gradient from completely unsuitable habitat to ideal habitat. These maps can be divided into areas of predicted presence and predicted absence based on the selection of a threshold. The size of the area of predicted presence will be sensitive to the threshold selected. Ideally this threshold should be determined using an independent dataset rather than arbitrary criteria. Such maps of the "suitability" of a coral or sponge species or community can be combined with maps of the distribution of threats (e.g. the spatial footprint of a fishery) to provide information about the potential threats to the species or community.

Species distribution models were used to determine the occurrence of corals and sponges in Canadian Pacific waters (Figures 7 to 10), however the selection of conservation limits/thresholds was not applied.

Considerations for a Science-Based Encounter Protocol

Overview of Elements to Consider when Developing a Science-Based Encounter Protocol

A science basis is needed to determine significant or key locations ("hot-spots") of corals and sponges. These are often binary thresholds derived from research vessel catch data. However, the catchability of corals and sponges in commercial and research trawl sets are unlikely to be the same. Consequently, thresholds based on research vessel data are not likely to reflect those that would be appropriate for commercial fisheries, but unfortunately there are minimal data available from commercial vessels. There is considerable additional uncertainty introduced by estimating catches based on survey tows to derive encounter thresholds that will be applied to commercial-length tows; therefore this is not a recommended approach if alternative sources of thresholds for commercial catches are available.

Encounter thresholds imply that some action is required once a specified level has been exceeded. If such options are to be considered, science-based issues that are likely to be important include:

a) The distance required for the vessel to move from the encounter location;
b) Real-time catch reporting;
c) The scale of fishing activity that produced the potential encounter;
d) At-sea species identification and quantification;
e) The impact of measuring encounters using bycatch separators;
f) The establishment and use of a database of encounters;
g) Consideration of the cumulative effect of encounters by different vessels or fleets over time;
h) Acknowledgement that the impact of the fishing activity is likely to be substantially greater than that reflected by the catch that is caught and brought on board;
i) Potential species (or group) specific thresholds for some fisheries or areas, particularly for unique/rare species;
j) The application of encounter protocols in both fished and un-fished areas;
k) How the presence of closed areas may affect encounter protocols; and
l) Evaluating the effectiveness of encounter protocols in affording protection to benthic attributes at risk from serious or irreversible harm due to fishing activities.

Case-Study: Preliminary Development of a Science-based Encounter Protocol

The model allows estimation of total sponge catches expected by a fleet fishing with the average tow length and effort distribution of the NAFO Greenland halibut fishery, and allows evaluation of the implications of different encounter thresholds on the total catch of corals and sponges. It was considered that this model could be a useful tool to evaluate the relative effectiveness, conservation benefits (e.g. reduction of impacts), and operational costs to industry associated with different distributions of closures and standards for encounter protocols.

The model used fishing effort to represent fishing behaviour, but further information on commercial fishing practices could also be incorporated into the model. For example, if the fleet is known to fish in a certain way relative to depth or slope, the model can be adapted to account for those practices. Equally, if there is a maximum catch that could be expected due to physical characteristics of the gear or to decision-making at sea, then rules could be included to align the theoretical maximum catch closer to the realized maximum catch. To allow comparison of theoretical and actual catches, model results should be compared with catch data from commercial fleets, where available.

This model would provide most accurate results if data were available on:

1) Sponge catch data from research vessel surveys;
2) Species composition of these sponge data, including spatial distribution;
3) Accurate bottom bathymetry, particularly in high slope areas or on rough bottoms;
4) Accurate information on fishing behaviour (e.g., effort, tow direction, maximum catch);
5) Accurate estimate of trawl line dimensions (width and length); and
6) Estimates of indirect effects of the fishing operation (gear retention relative to density on bottom, indirect damage).

However, illustrations of the method were available using only requirements 1, 4 and 5, which are the basic data inputs. Further research using this simulation model should focus on improving the quality and quantity of the required data.

CONCLUSIONS

Hydrothermal vents are an ecologically important deep-ocean energy source that sustains unique ecosystems. Hydrothermal vents support communities of specialised bacteria that provide a trophic basis for unique communities of higher organisms (e.g. mussels, worms, snails, crabs, anemones, fish, octopus, etc.). In the Canadian EEZ, hydrothermal vents are found exclusively in Canadian Pacific waters. Although hydrothermal vents are extremely sensitive and fragile, owing to their deepwater location, current fishing technologies mean that fisheries pose little threat to those within Canadian waters.

Corals and sponges form complex, three-dimensional biogenic structures that provide habitat for many species and influence the occurrence and/or abundance of associated fish and invertebrate species and serve several functions in marine ecosystems. Corals and sponges are sensitive to anthropogenic activities and are susceptible to both direct (e.g. removal or damage) and indirect (e.g. smothering by sedimentation) fishing impacts. Corals and sponges are known to occur throughout the Canadian EEZ.

A suite of ecological indicators were reviewed (i.e. uniqueness, rarity, species density, species richness, species distribution, and species diversity) and their strengths and weaknesses were discussed. Three methodologies (i.e. cumulative distribution, area of aggregation, and species distribution models) were considered appropriate predictors of several ecological indicators.

Elements to consider when developing an encounter protocol were discussed and will be revisited in detail at a future science-advisory process. In addition, a case-study was presented that used a GIS-based model to assess encounter-related management decisions pertaining to sponge bycatch that would be a useful method to consider in future applications.

OTHER CONSIDERATIONS FOR FUTURE RESEARCH AND INITIATIVES

- The density of corals and sponges on the seafloor is not always known. *In situ* research is required and non-invasive sampling is more desirable for investigating corals, sponges, and hydrothermal vents. Surveys with visual sampling tools (e.g. tow cameras, ROV, submersibles, etc.) are particularly useful in expanding the sampling area and as a result may allow the discovery and identification of many more species that cannot be determined using traditional trawl-sampling methods alone.

- Methodologies to select appropriate thresholds to delineate ecologically significant aggregations require further evaluation and additional work to evaluate the role of all aggregations within different types of ecosystems (e.g. open plain vs. rugged areas) is recommended.

- There is a need to refine and further validate predictive modeling for both commercial fishing encounters and for estimating the presence of coral and sponge habitat.

- An additional science-advisory process will be necessary should development of a science-based encounter protocol for corals and sponges within Canadian waters be requested.

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APPENDIX 1: FIGURES 2 to 38.

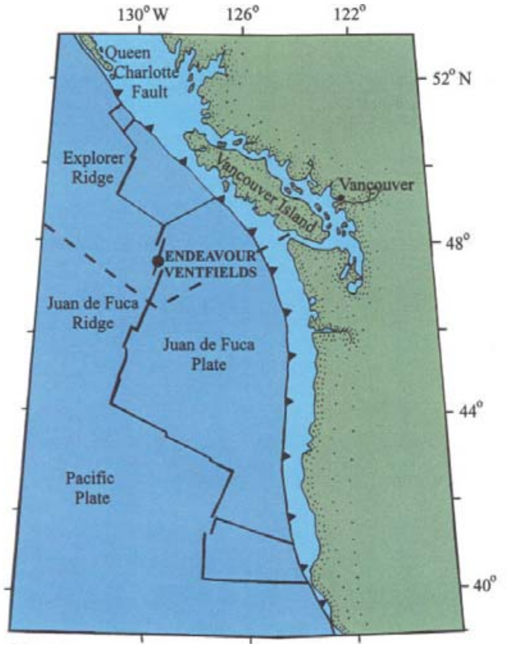

Figure 2. Location of the Endeavour Hydrothermal Ventfields on the Juan de Fuca Ridge in the Canadian Pacific. The dashed line represents the Canadian jurisdictional boundary.

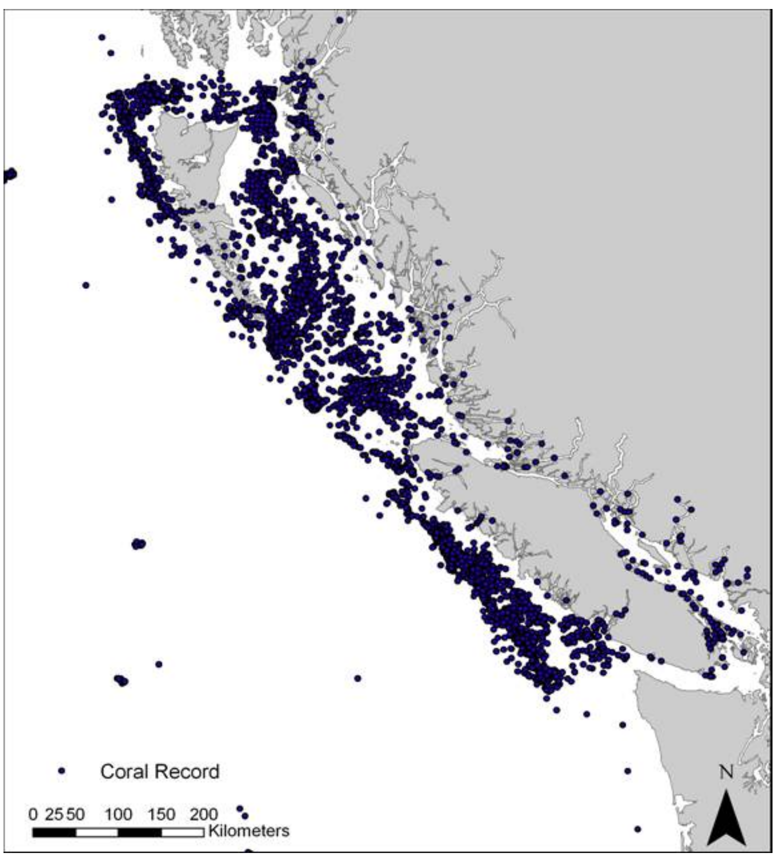

Figure 3. Known distribution of corals (n = 5553) in the Canadian Pacific. Records were obtained using data from primary literature, museums, online databases, DFO survey data and commercial observer records.

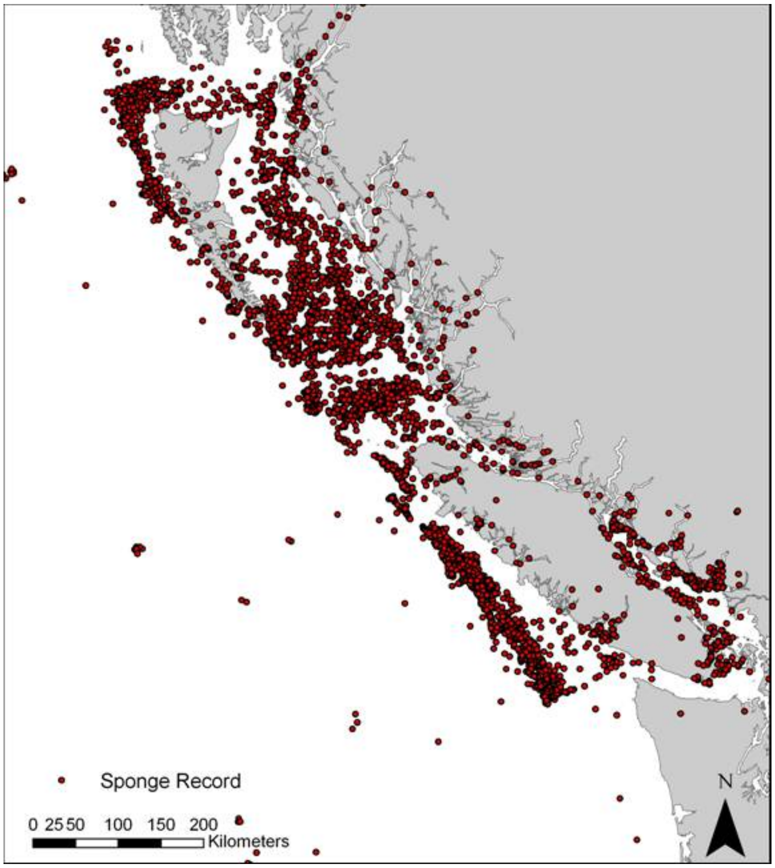

Figure 4. Known distribution of sponges (n = 10689) in the Canadian Pacific. Records were obtained using data from primary literature, museums, online databases, DFO survey data and commercial observer records.

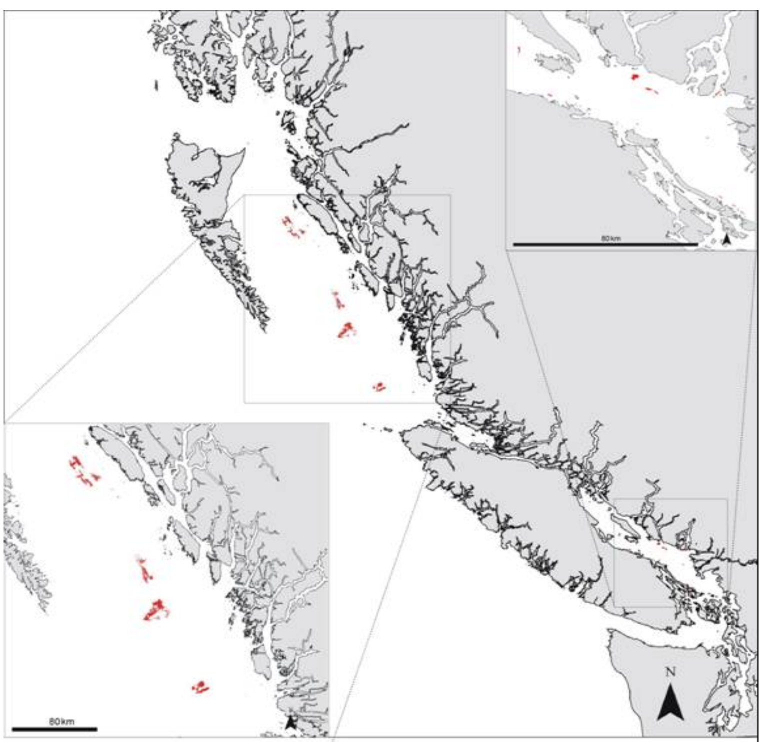

Figure 5. Known locations of hexactinellid (glass sponge) reefs in the Canadian Pacific.

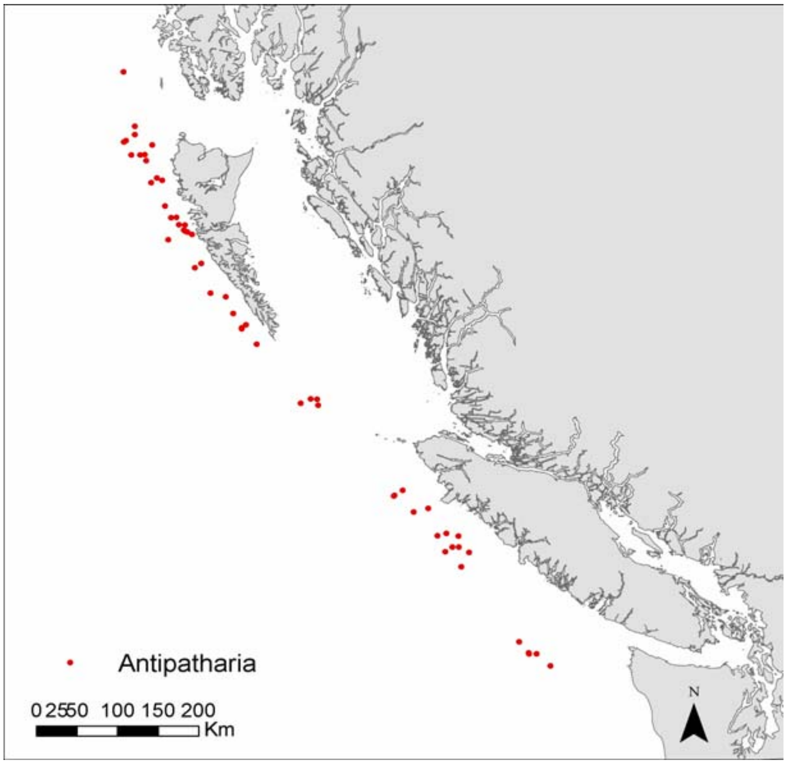

Figure 6. Known locations of Antipatharia (black coral) in the Canadian Pacific.

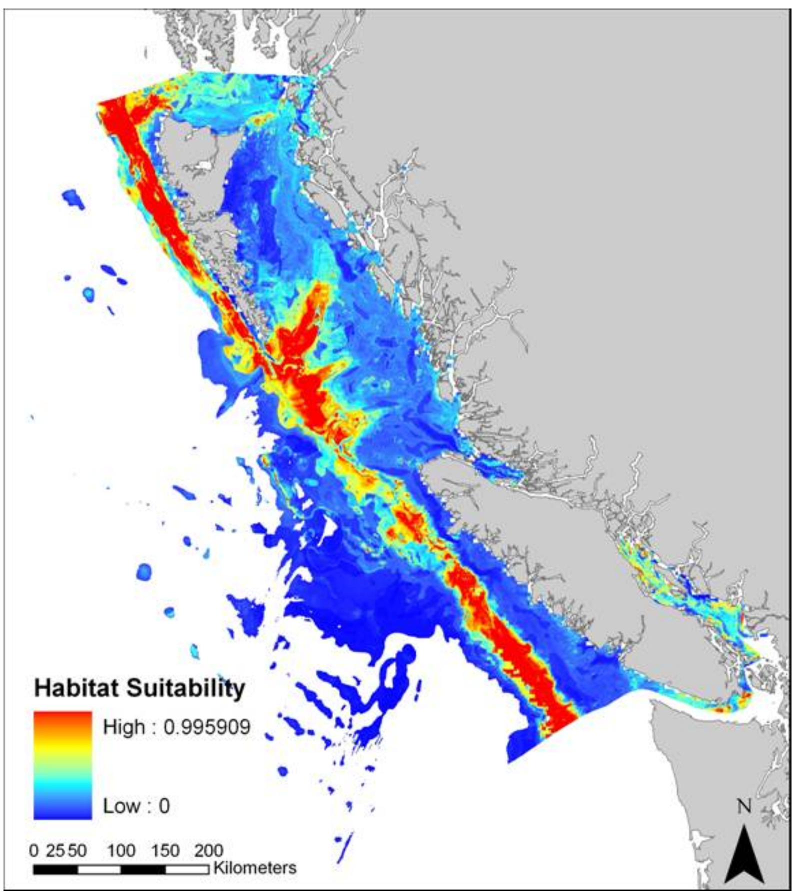

Figure 7. Predicted distribution of Alcyonacea (gorgonians and soft corals) in Pacific Canada. Warmer colours indicate more suitable habitat, while cooler colours indicate less suitable habitat.

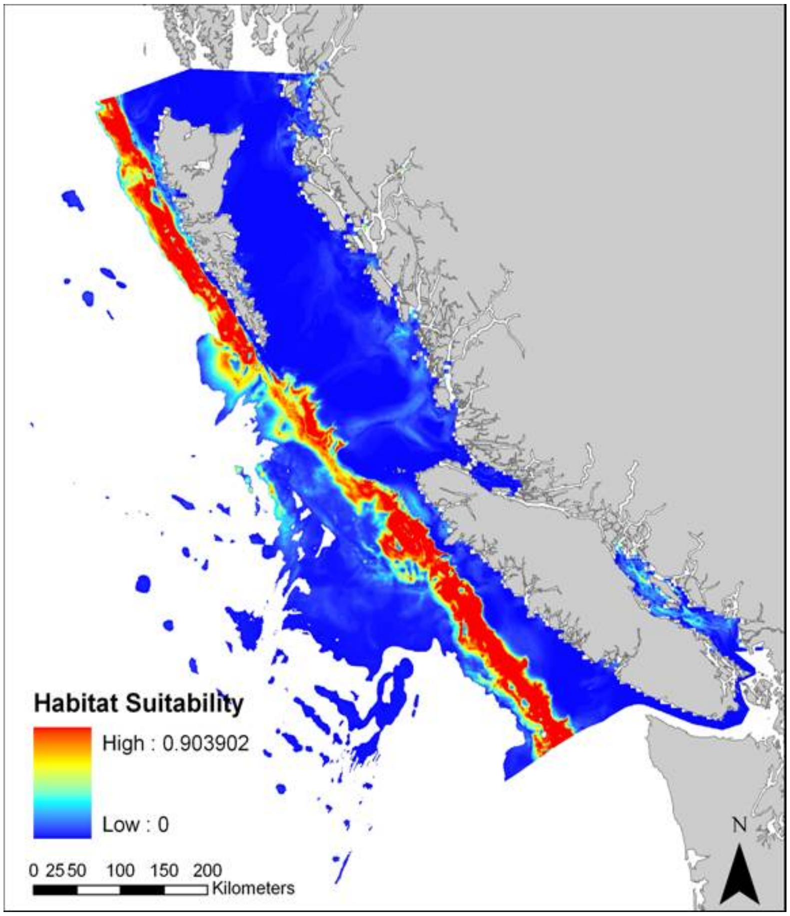

Figure 8. Predicted distribution of Antipatharia (black corals) in Pacific Canada. Warmer colours indicate more suitable habitat, while cooler colours indicate less suitable habitat.

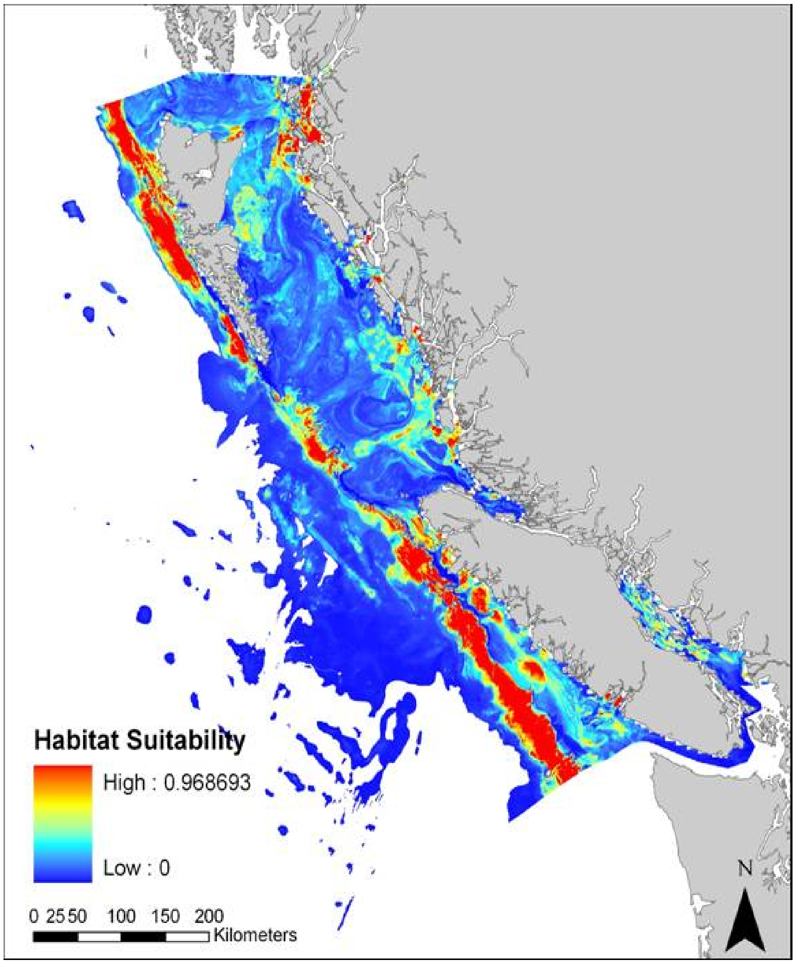

Figure 9. Predicted distribution of Pennatulacea (sea pens and sea whips) in Pacific Canada. Warmer colours indicate more suitable habitat, while cooler colours indicate less suitable habitat.

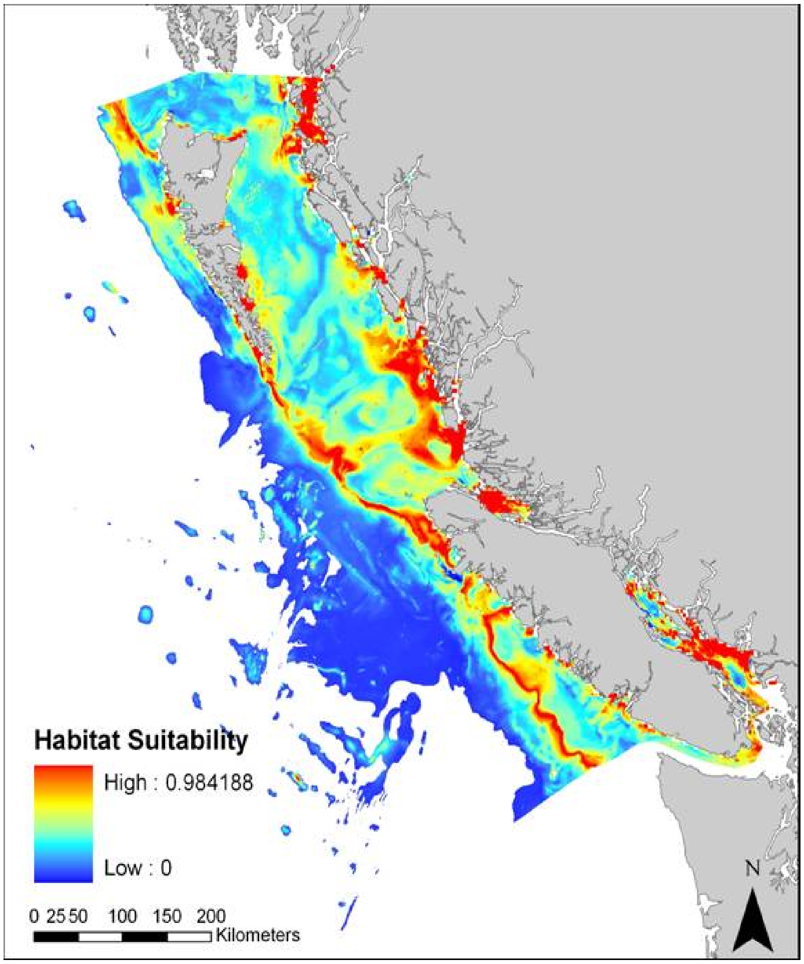

Figure 10. Predicted distribution of Scleractinia (hard stony corals) in Pacific Canada. Warmer colours indicate more suitable habitat, while cooler colours indicate less suitable habitat.

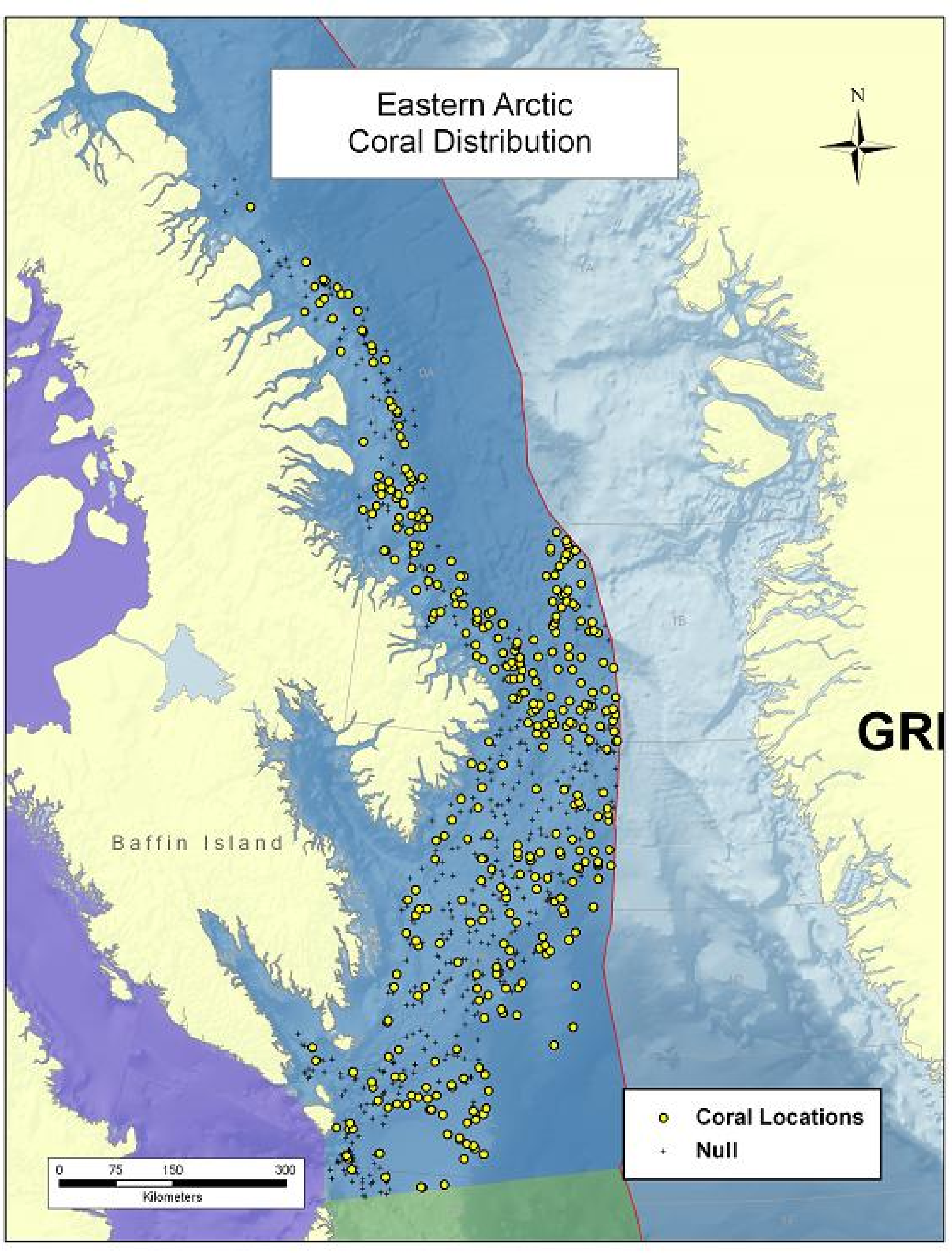

Figure 11. Presence and absence of corals in the Eastern Arctic biogeographic unit based on research vessel surveys.

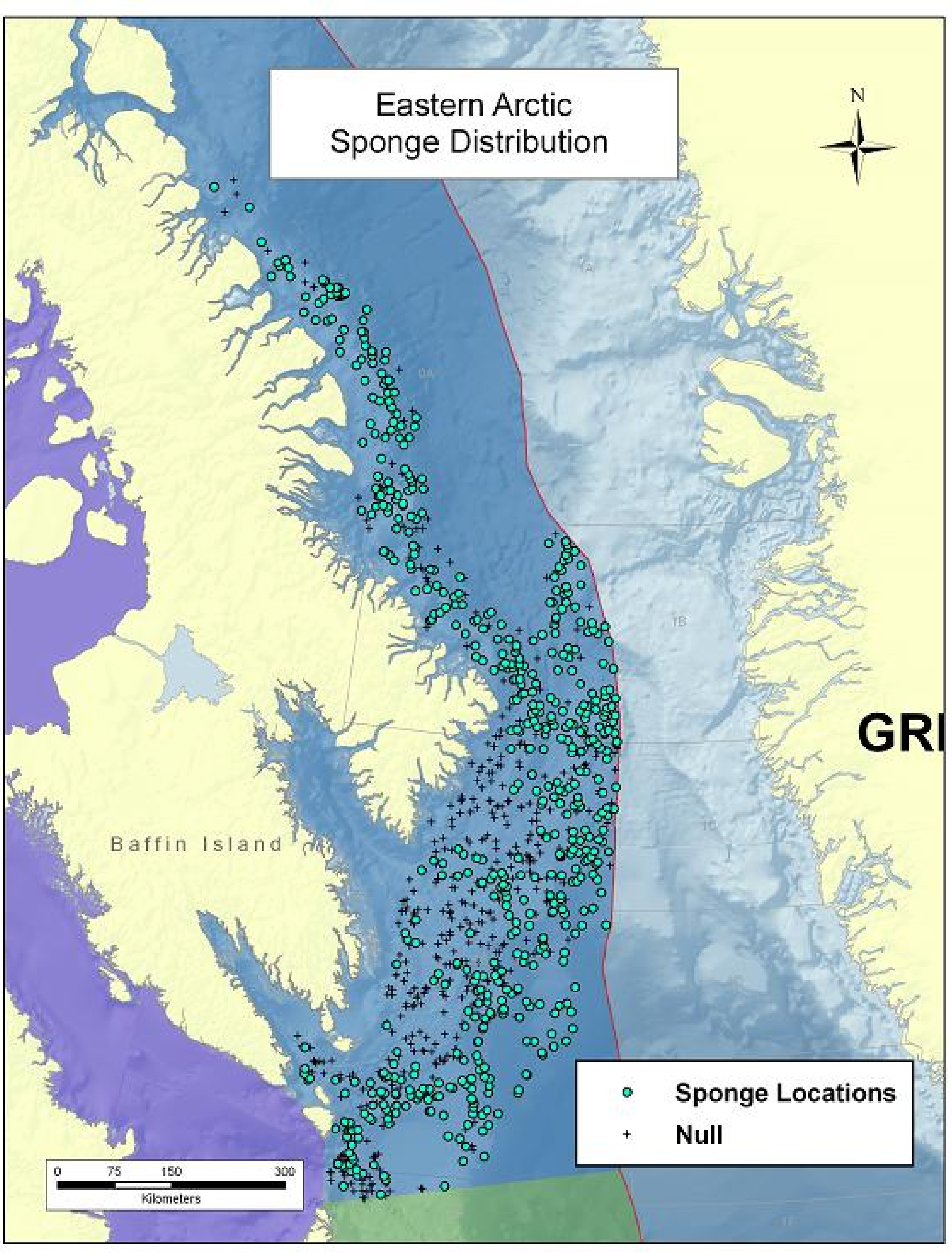

Figure 12. Presence and absence of sponges in the Eastern Arctic biogeographic unit based on research vessel surveys.

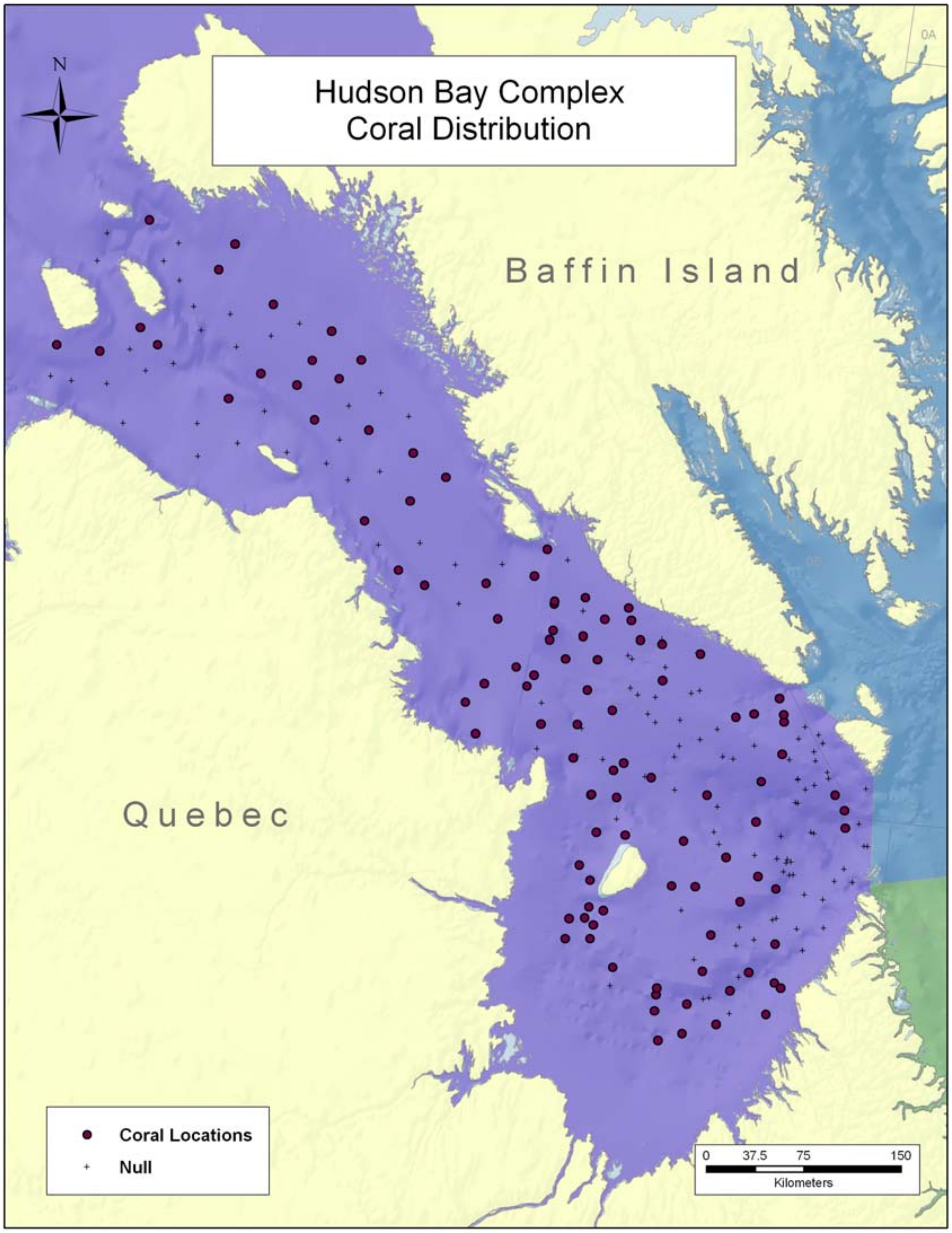

Figure 13. Presence and absence of corals in the Hudson Bay Complex biogeographic unit based on research vessel surveys.

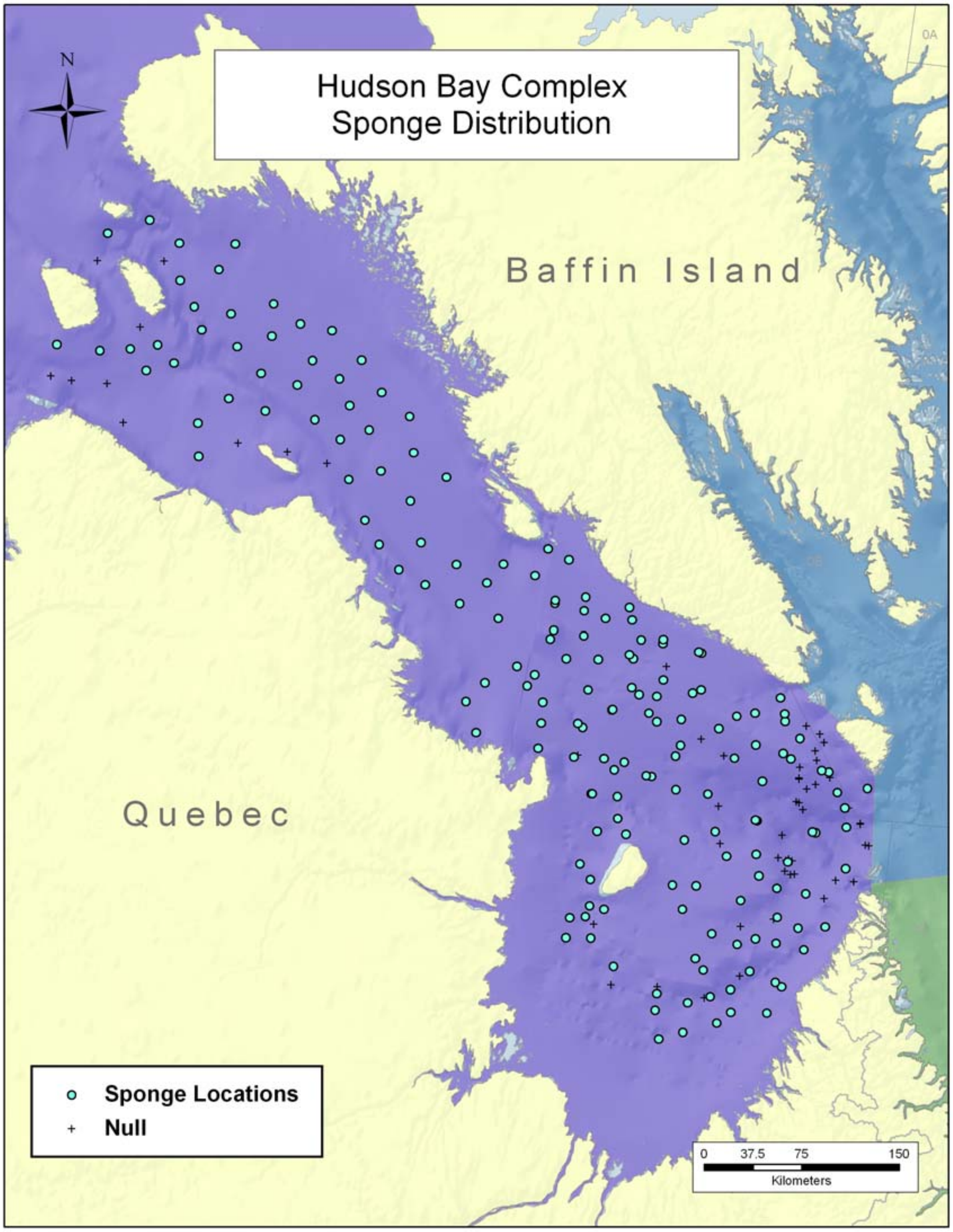

Figure 14. Presence and absence of sponges in the Hudson Bay Complex biogeographic unit based on research vessel surveys.

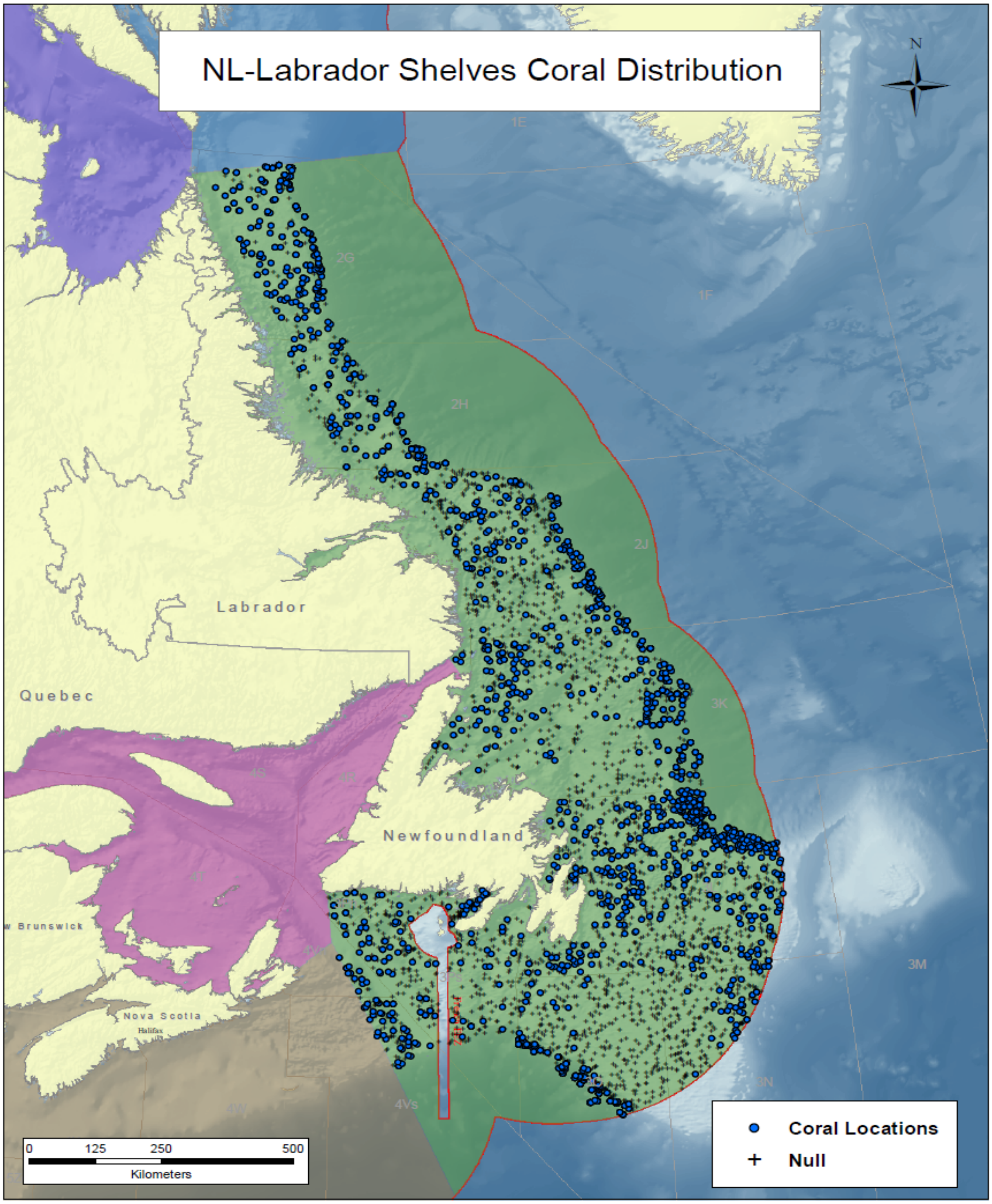

Figure 15. Presence and absence of corals in the Newfoundland-Labrador Shelves biogeographic unit based on research vessel surveys.

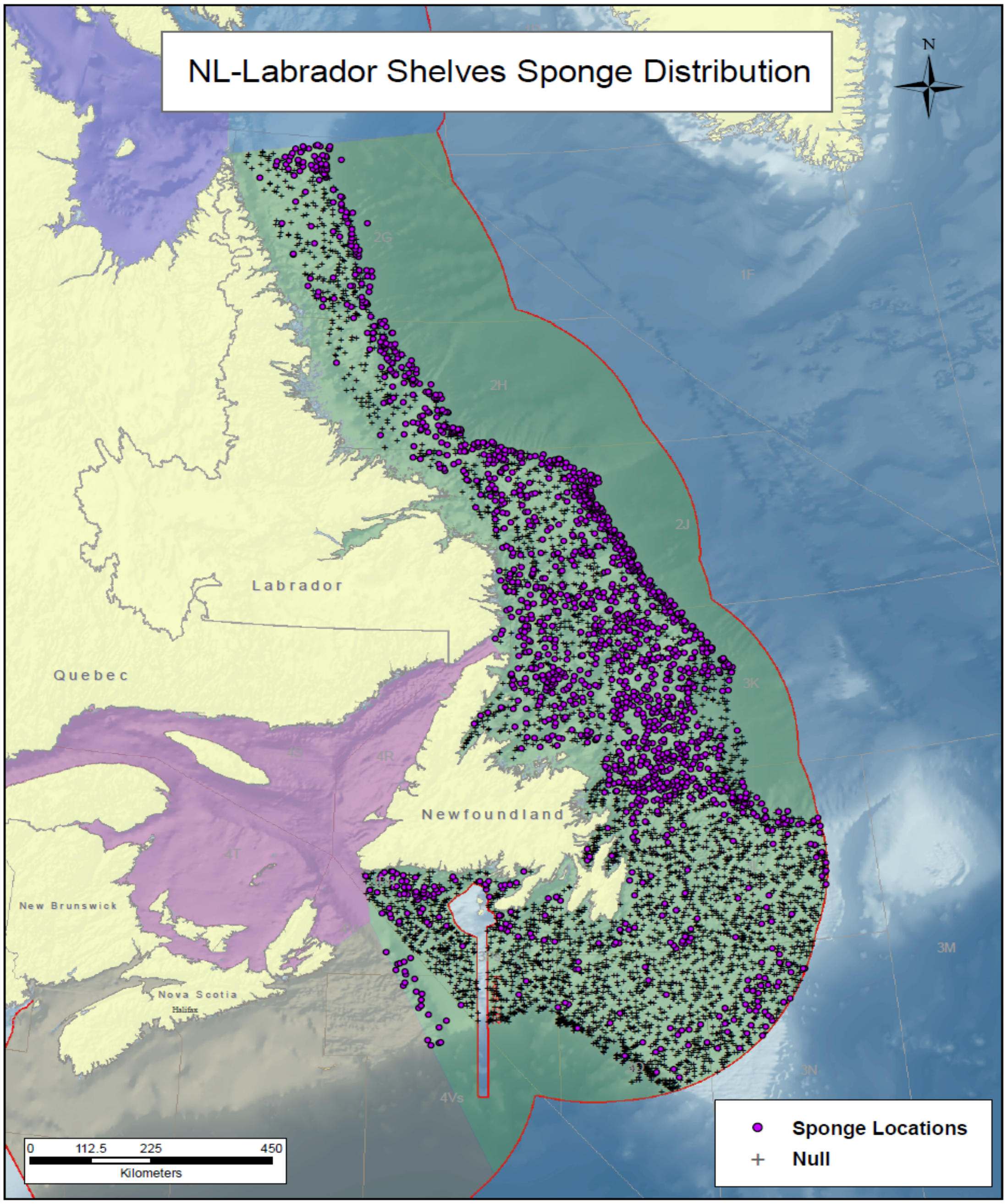

Figure 16. Presence and absence of sponges in the Newfoundland-Labrador Shelves biogeographic unit based on research vessel surveys.

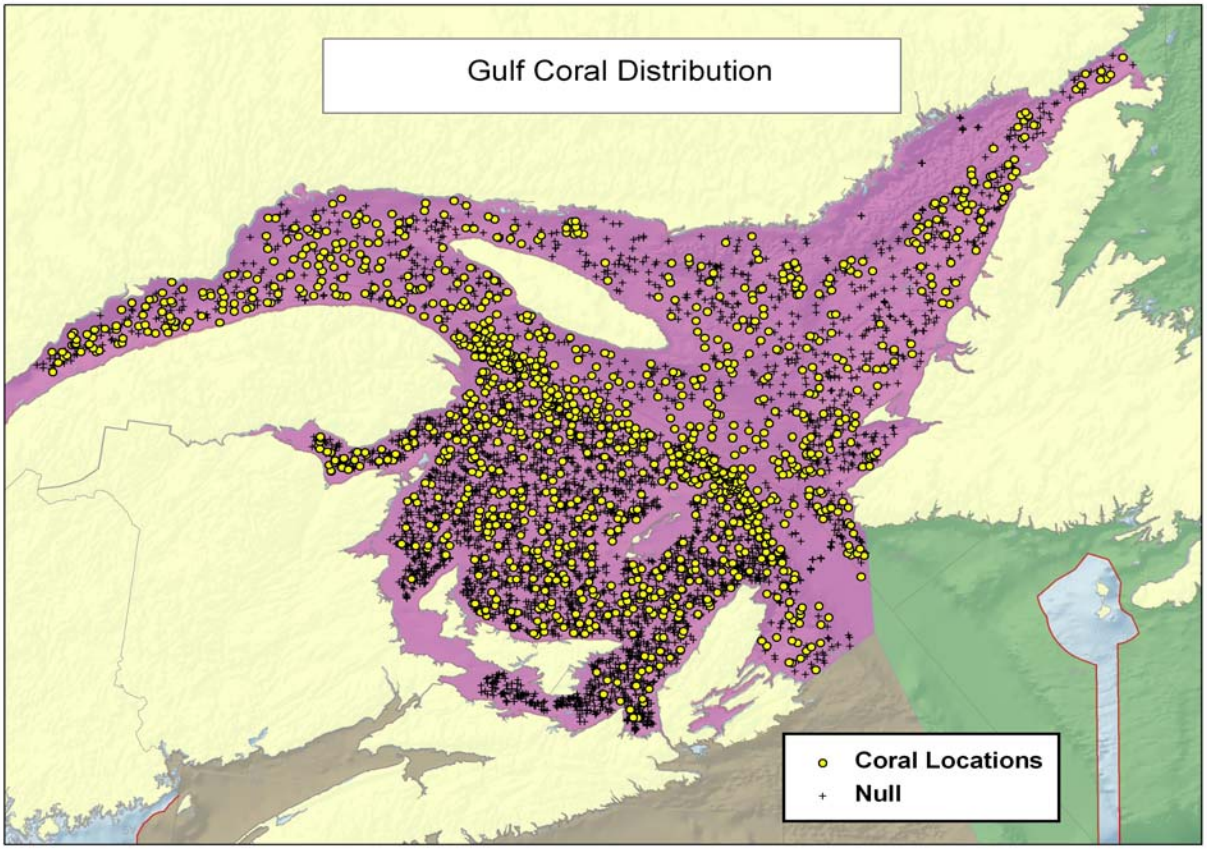

Figure 17. Presence and absence of corals in the Gulf of St. Lawrence biogeographic unit based on research vessel surveys.

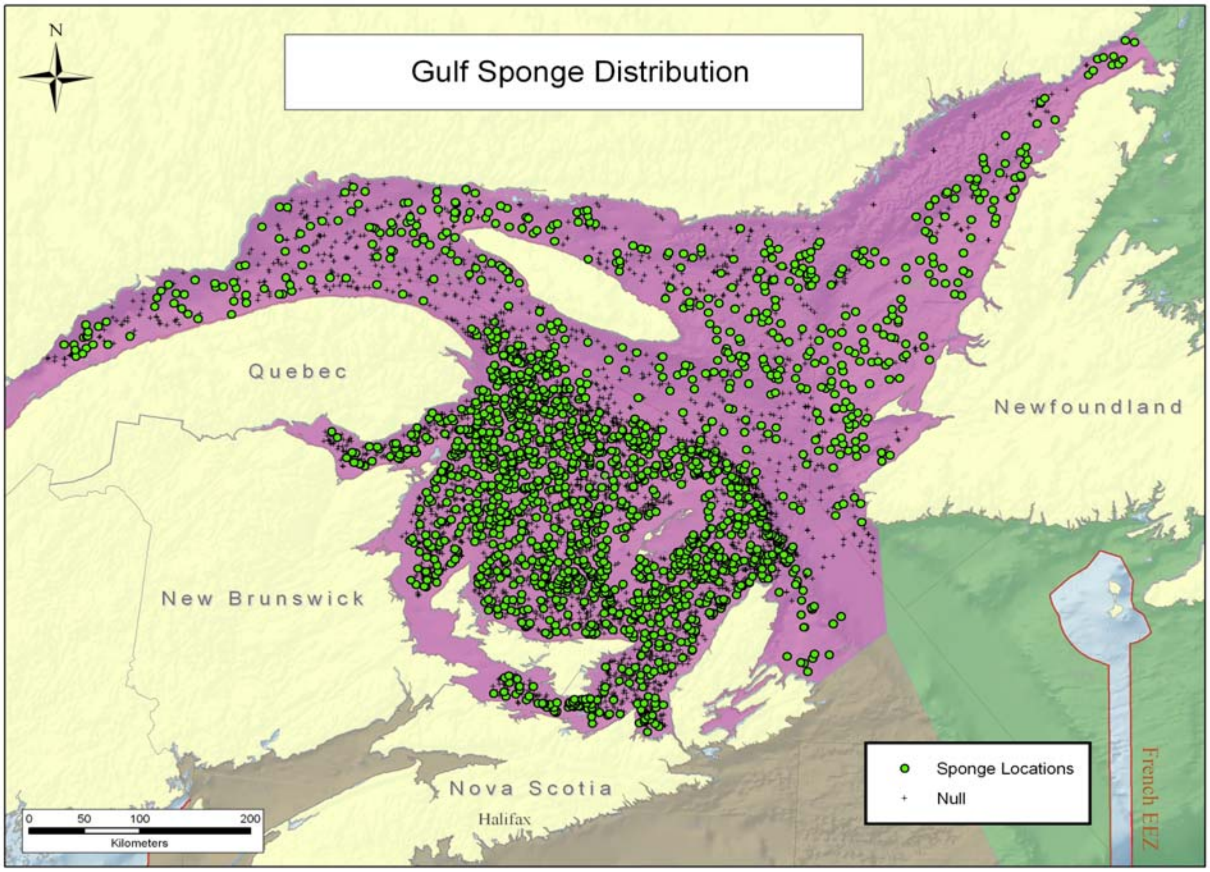

Figure 18. Presence and absence of sponges in the Gulf of St. Lawrence biogeographic unit based on research vessel surveys.

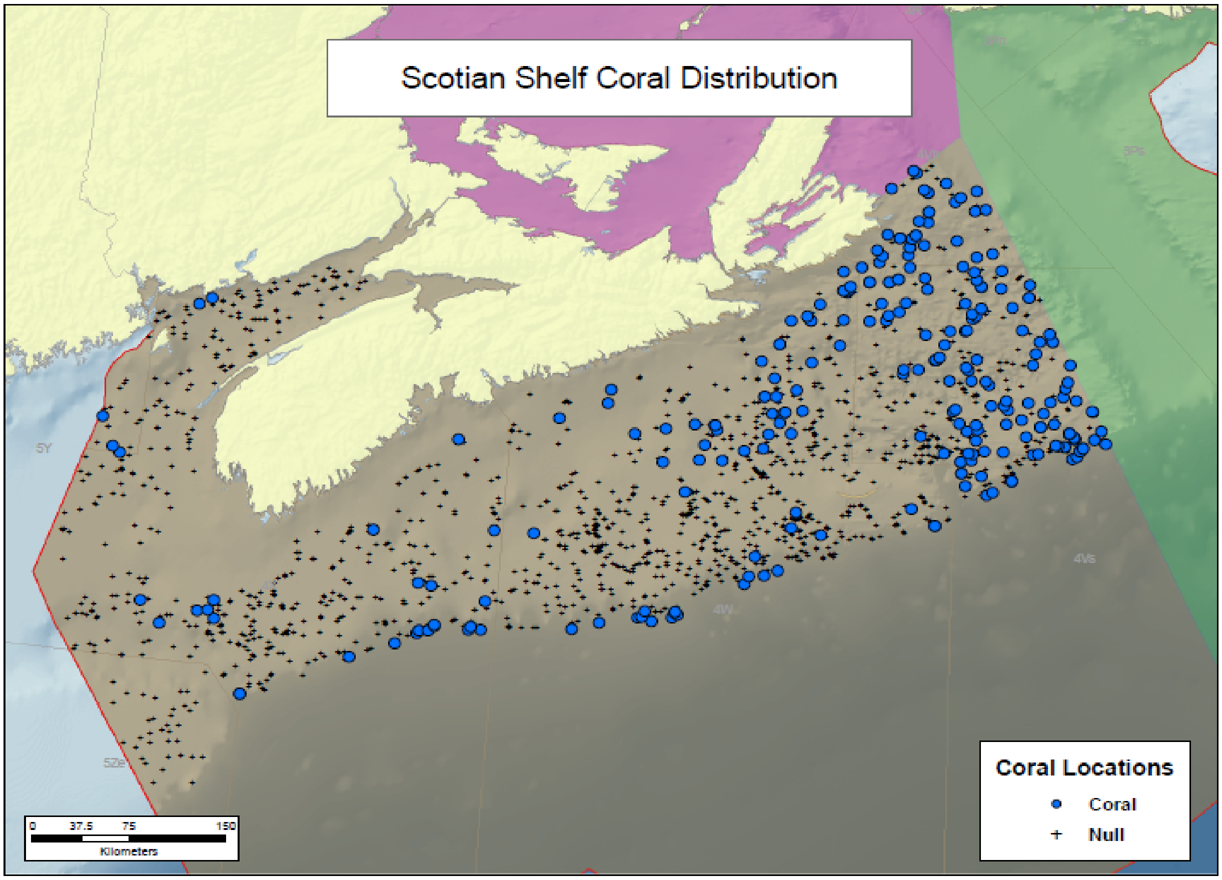

Figure 19. Presence and absence of corals in the Scotian Shelf biogeographic unit based on research vessel surveys.

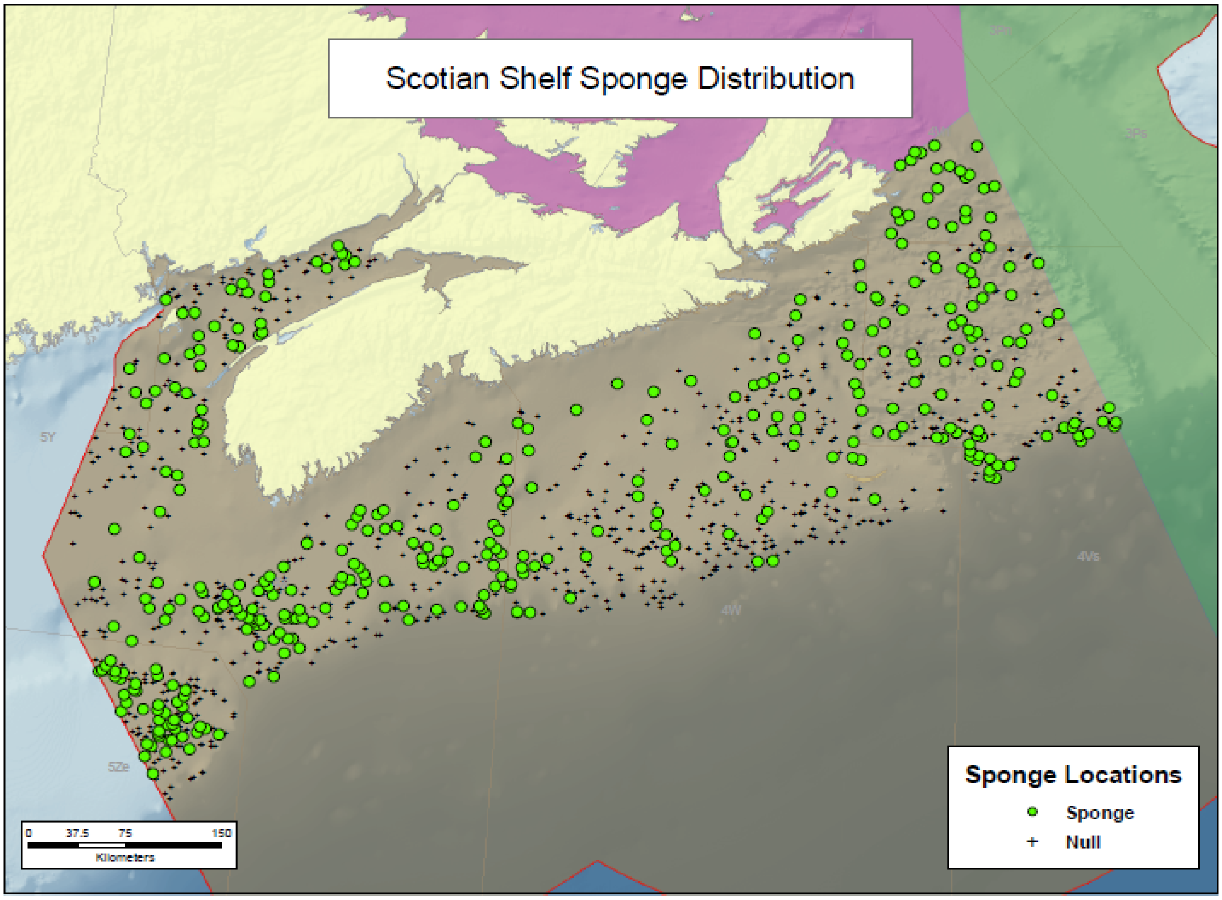

Figure 20. Presence and absence of sponges in the Scotian Shelf biogeographic unit based on research vessel surveys.

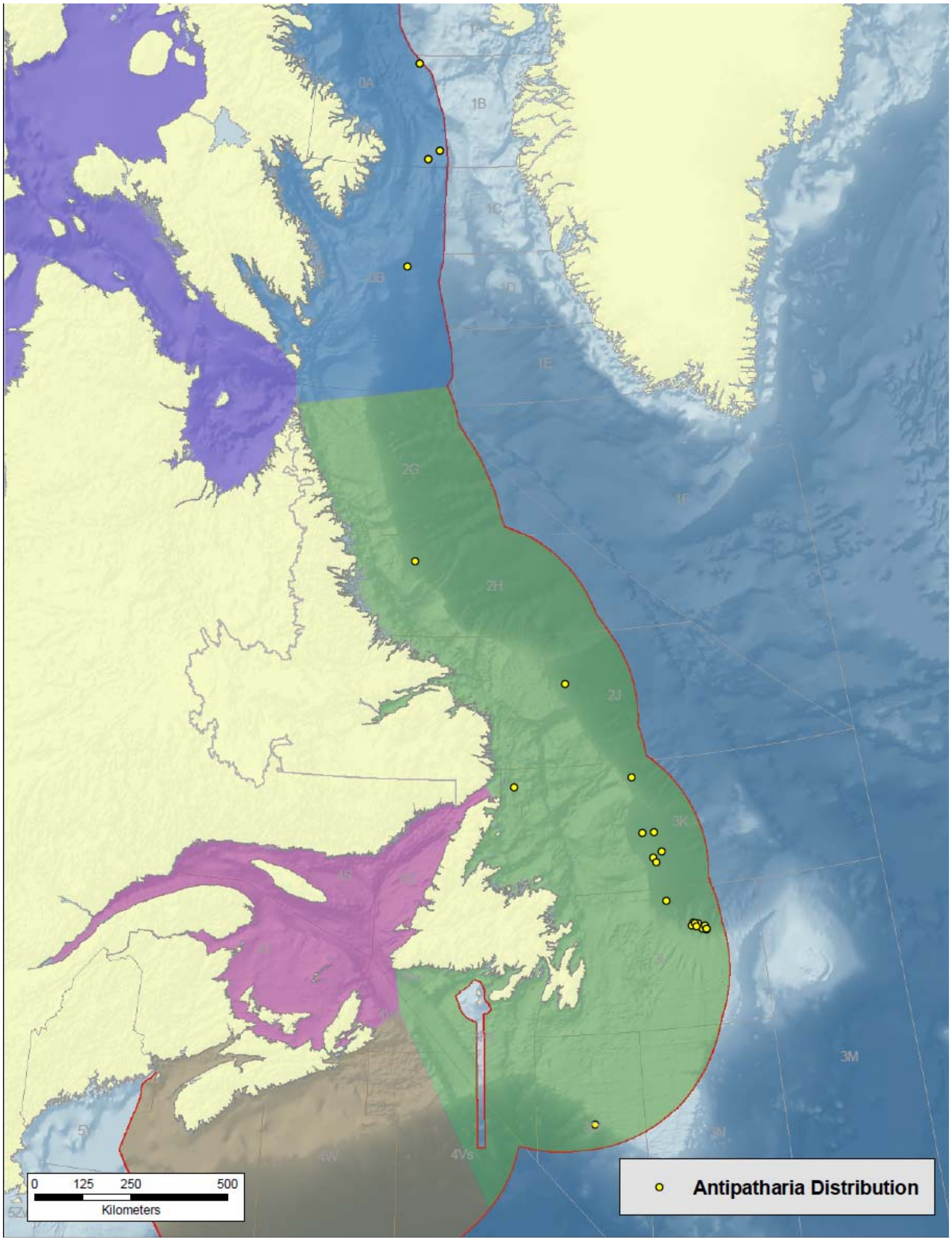

Figure 21. Known locations of Antipatharia (black corals) in the Newfoundland and Labrador Shelves biogeographic unit as determined from research vessel survey data and from commercial fishing operations through the Fisheries Observer Program.

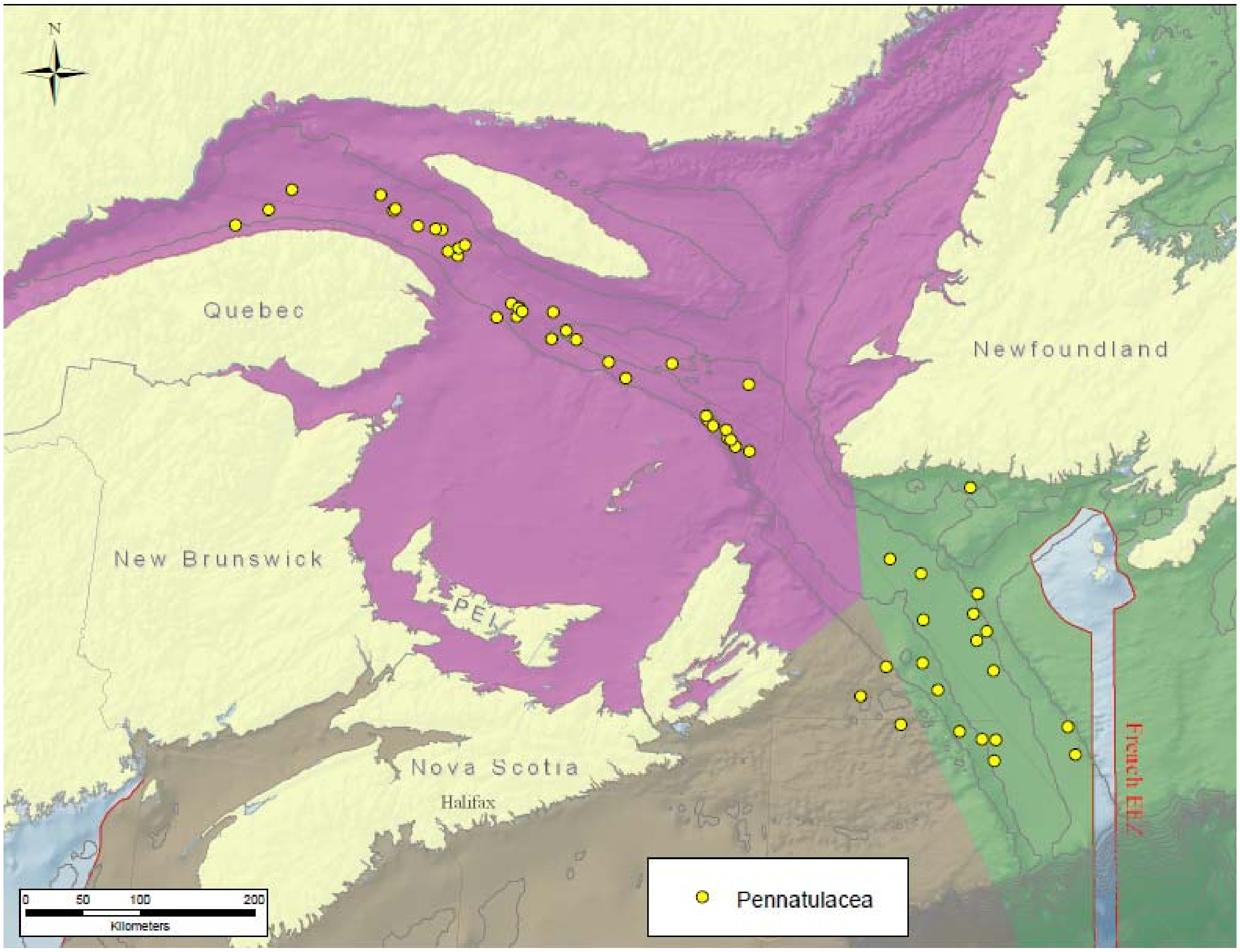

Figure 22. Aggregations of Pennatulacea (sea pens) in the Laurentian Channel based on research vessel survey data.

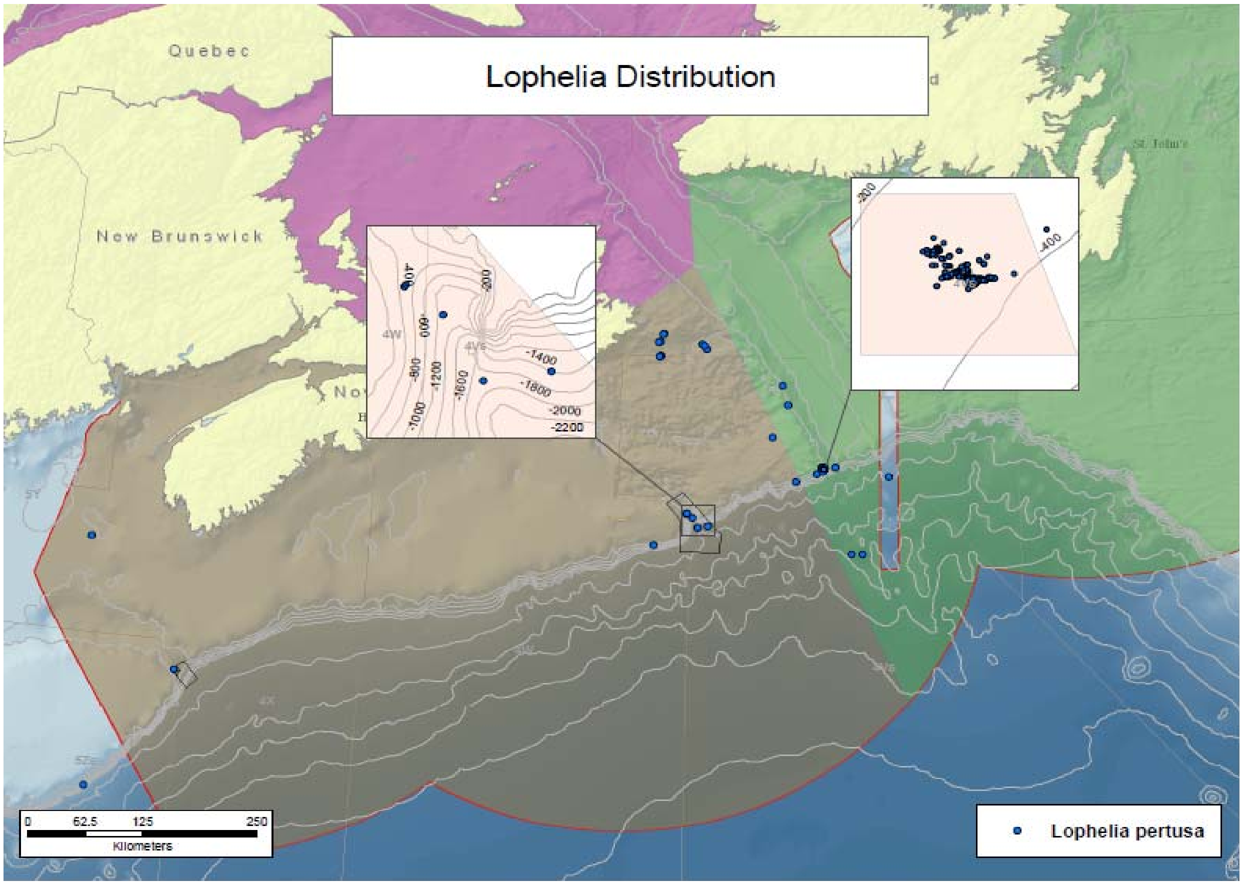

Figure 23. Known locations of Lophelia pertusa in the Scotian Shelf biogeographic unit as determined from research vessel survey data and from commercial fishing operations through the Fisheries Observer Program.

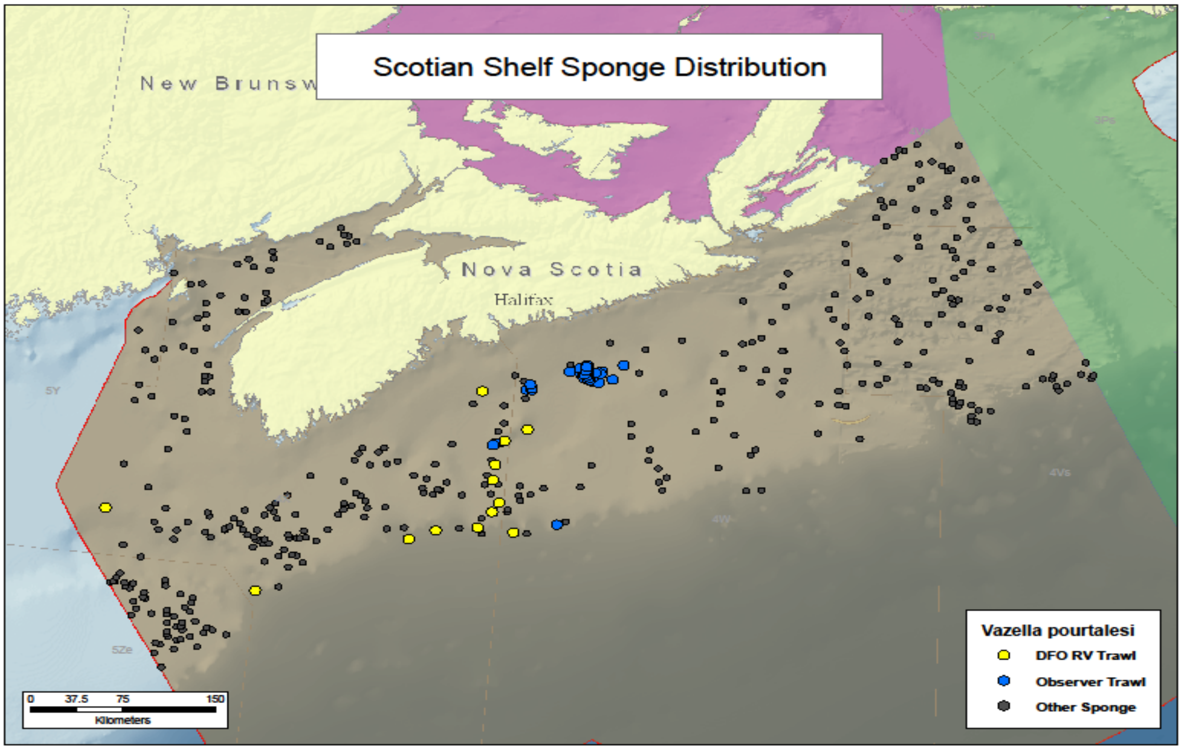

Figure 24. Locations of Vazella pourtalesi (Russian Hat) sponge in the Scotian Shelf biogeographic unit as determined from research vessel survey data and from commercial fishing operations through the Fisheries Observer Program.

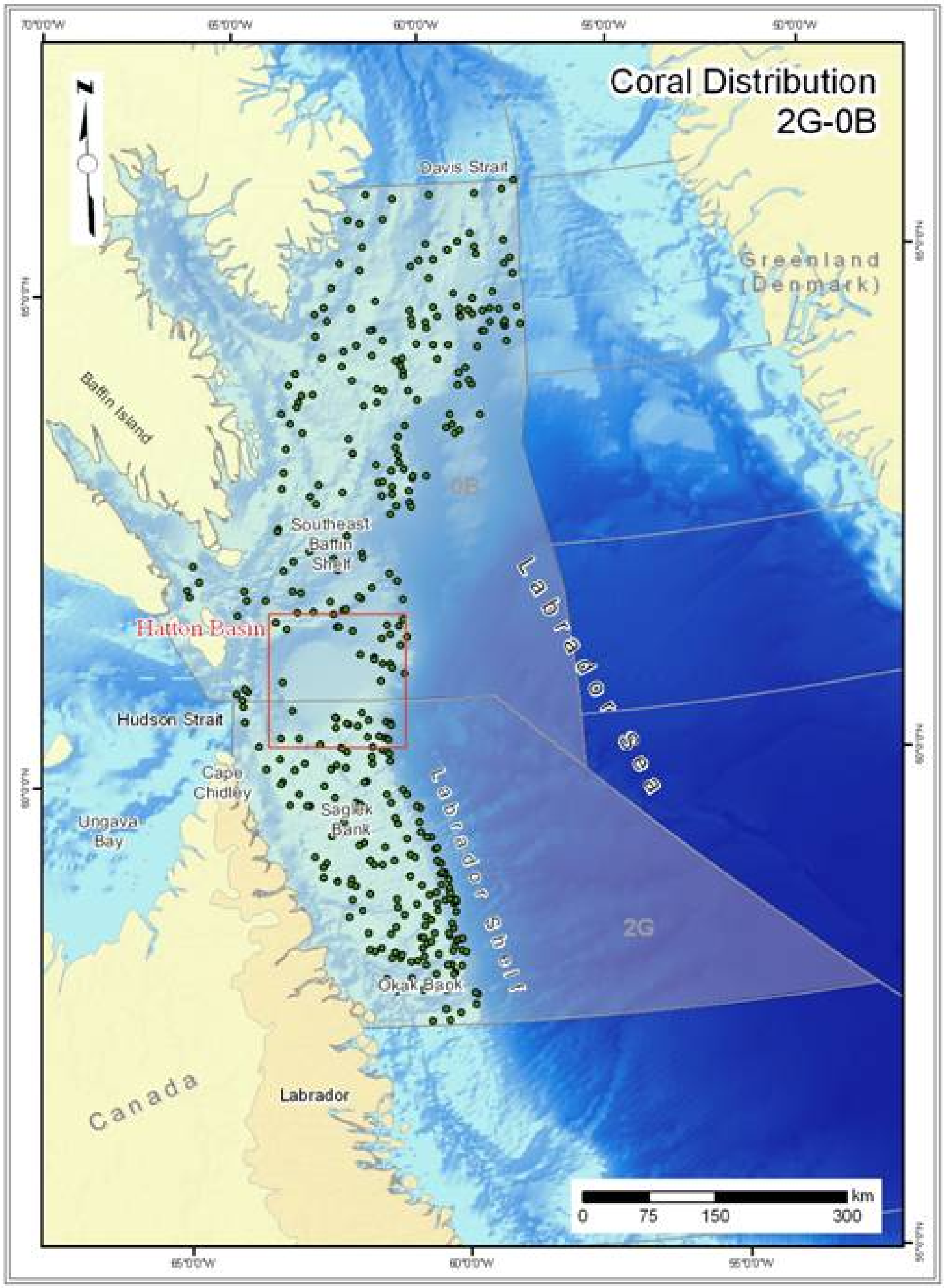

Figure 25. Presence of corals in the Hatton Basin Case Study Area based on research vessel surveys.

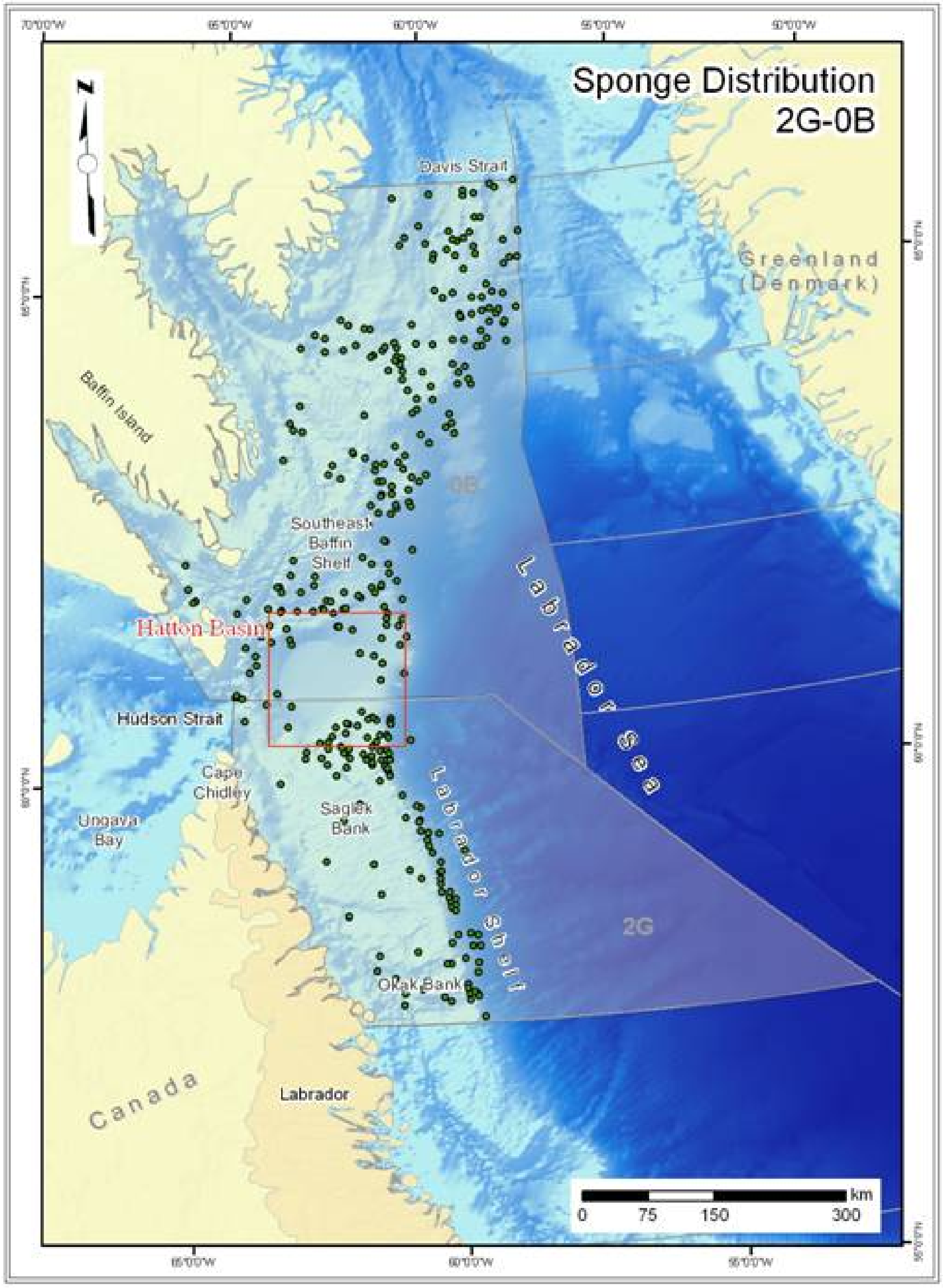

Figure 26. Presence of sponges in the Hatton Basin Case Study Area based on research vessel surveys.

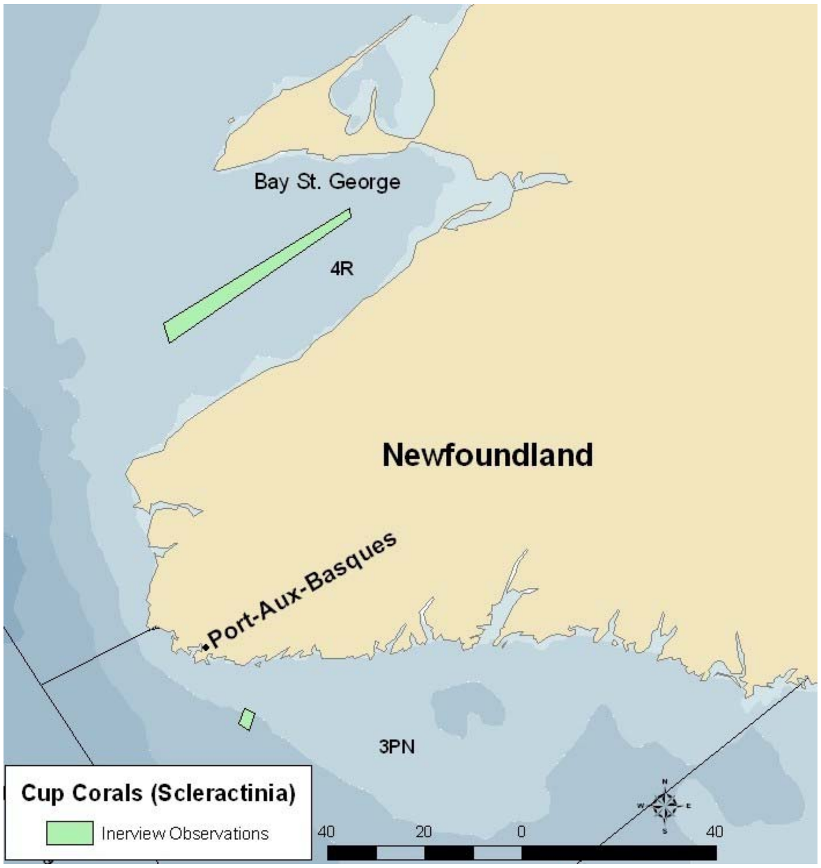

Figure 27. Areas identified through Local Ecological Knowledge (LEK) interviews of fish harvesters where Scleractina (solitary cup corals) have been caught.

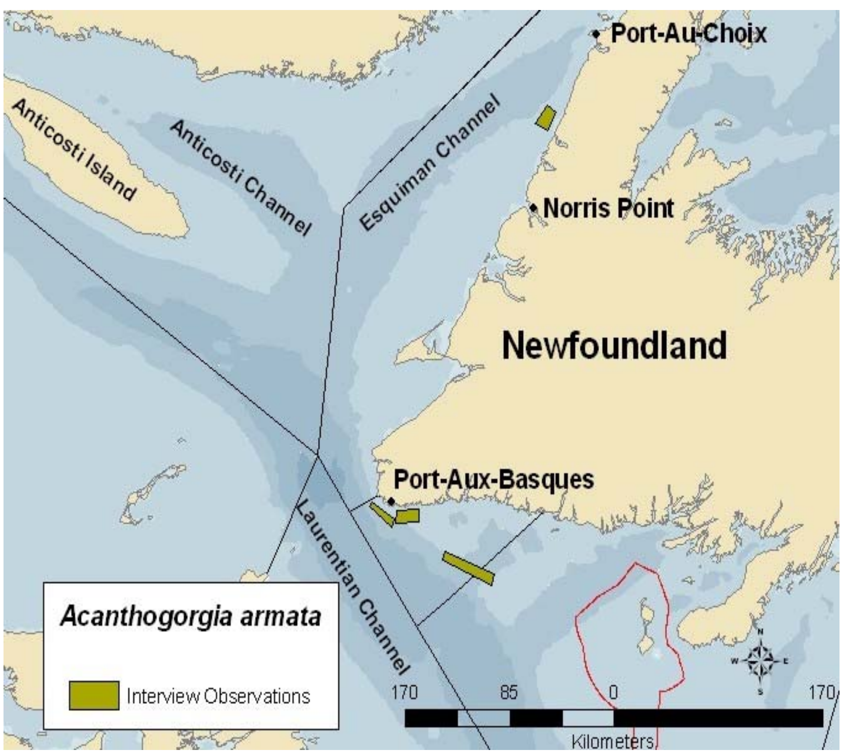

Figure 28. Areas identified through Local Ecological Knowledge (LEK) interviews of fish harvesters where the gorgonian coral Acanthogorgia armata has been caught.

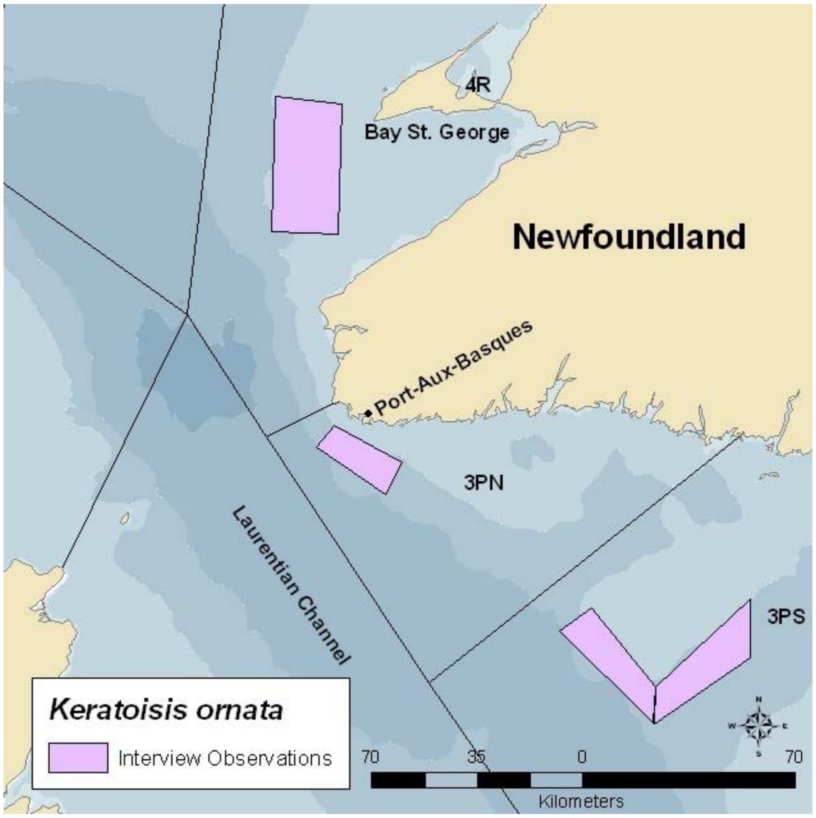

Figure 29. Areas identified through Local Ecological Knowledge (LEK) interviews of fish harvesters where the gorgonian coral Keratoisis ornate has been caught.

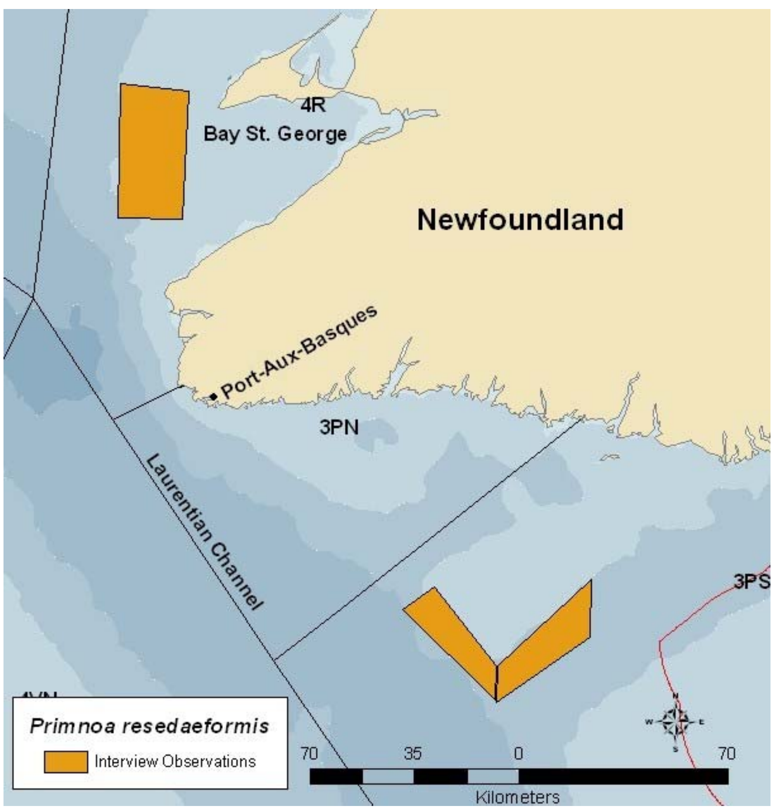

Figure 30. Areas identified through Local Ecological Knowledge (LEK) interviews of fish harvesters where the gorgonian coral Primnoa resedaeformis has been caught.

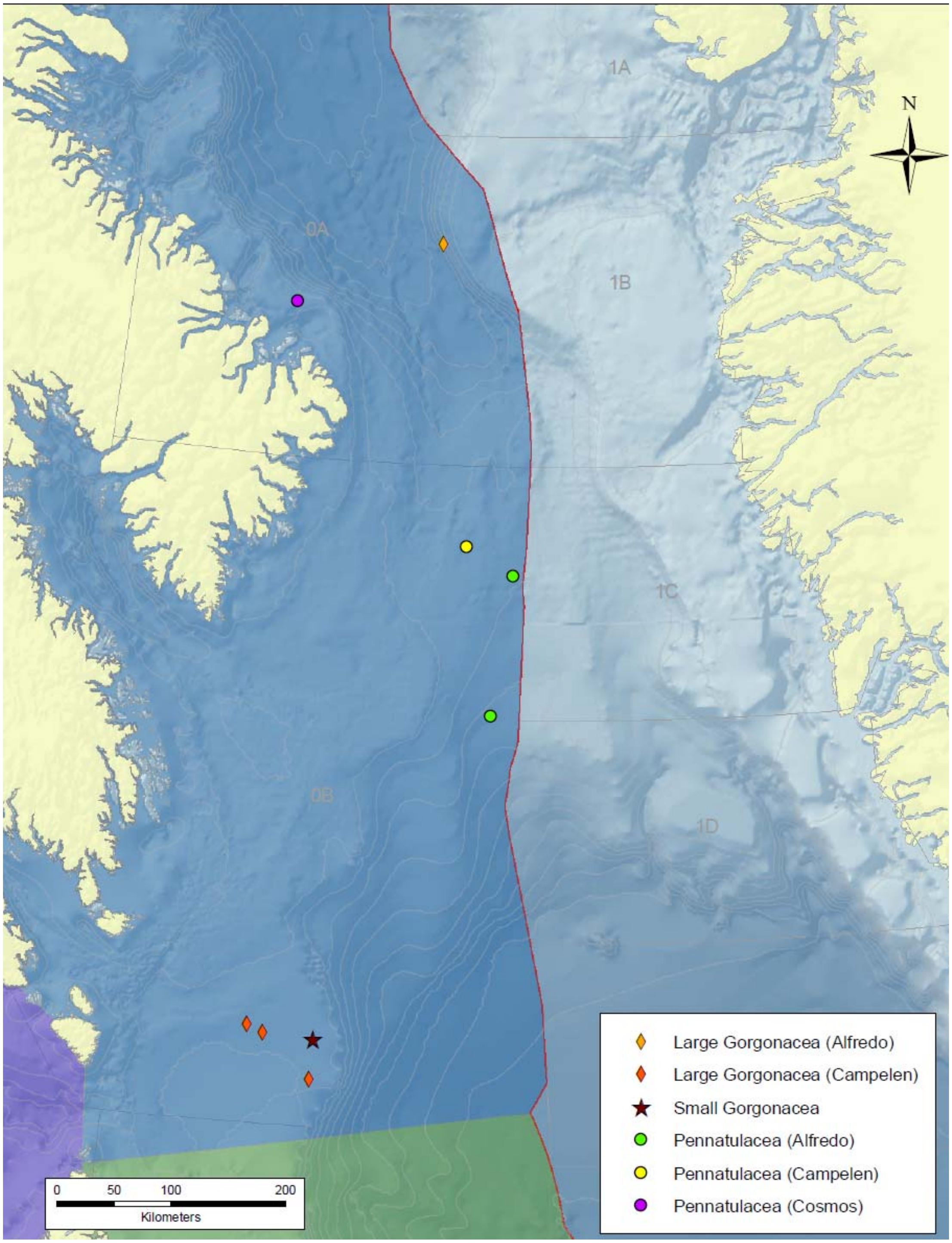

Figure 31. The positions of large catches of Pennatulacea (sea pens), small gorgonians (Acanella arbuscula) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Eastern Arctic biogeographic unit identified using the cumulative catch distribution based on research vessel survey data. The 97.5% quantile of the catch distribution was applied for sea pens and large gorgonians, and the 90% quantile for small gorgonians.

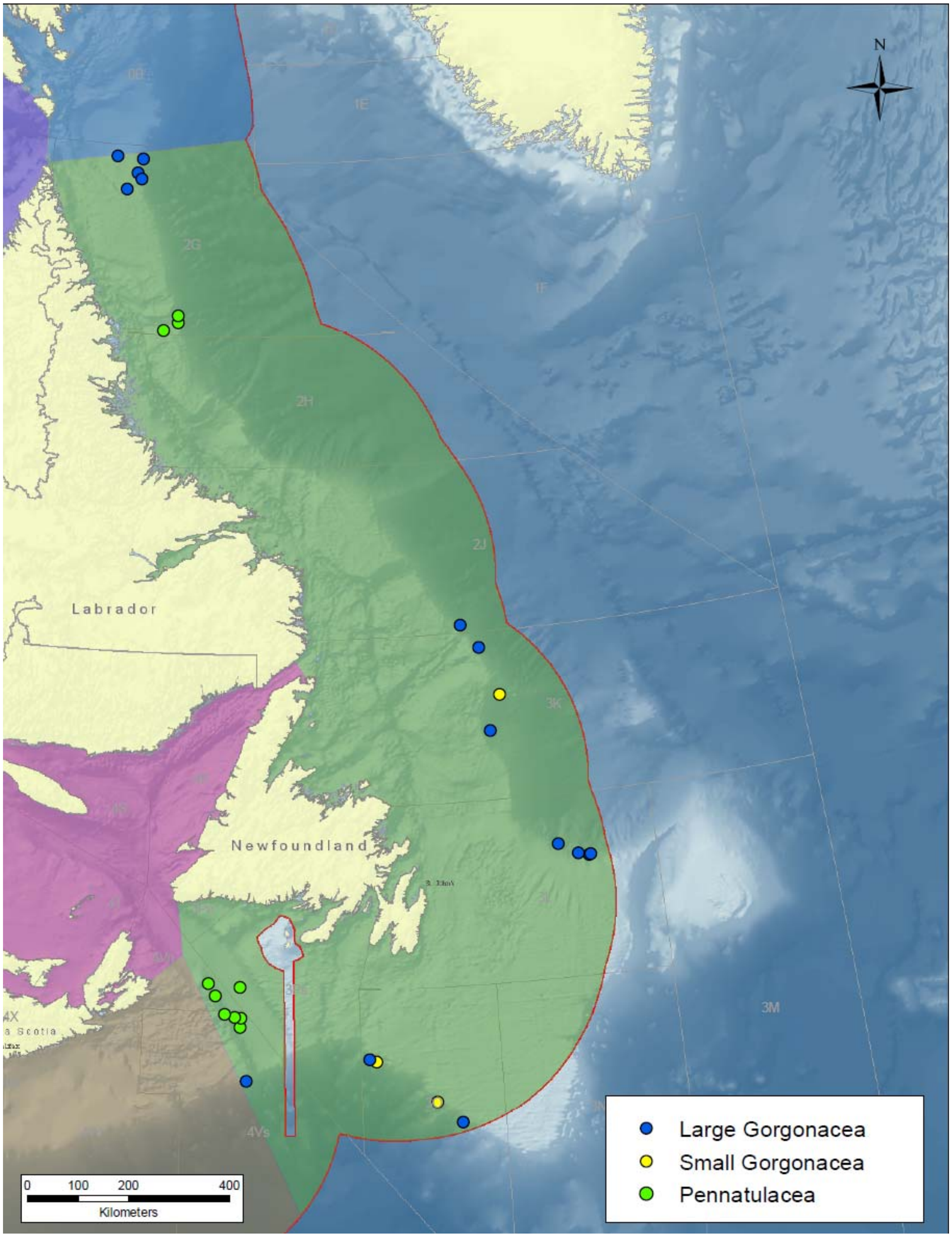

Figure 32. The positions of catches of Pennatulacea (sea pens), small gorgonians (Acanella arbuscula) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Newfoundland and Labrador Shelves biogeographic unit identified using the cumulative catch distribution based on research vessel survey data. The 97.5% quantile of the catch distribution was applied for sea pens and large gorgonians, and the 90% quantile for small gorgonians.

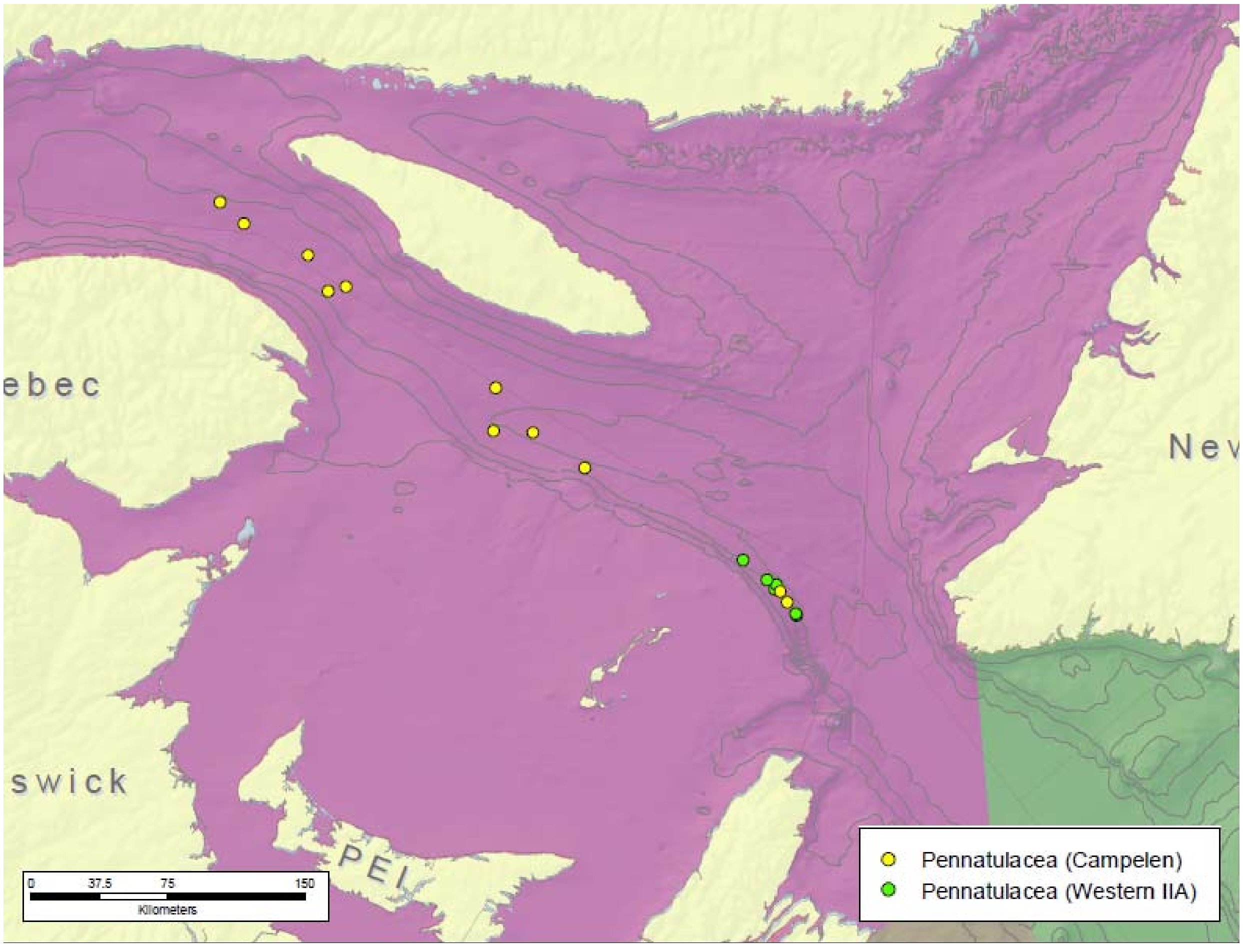

Figure 33. The positions of large catches of Pennatulacea (sea pens) in the Gulf of Saint Lawrence biogeographic unit identified using the 97.5% quantile of the cumulative catch distribution based on research vessel survey data.

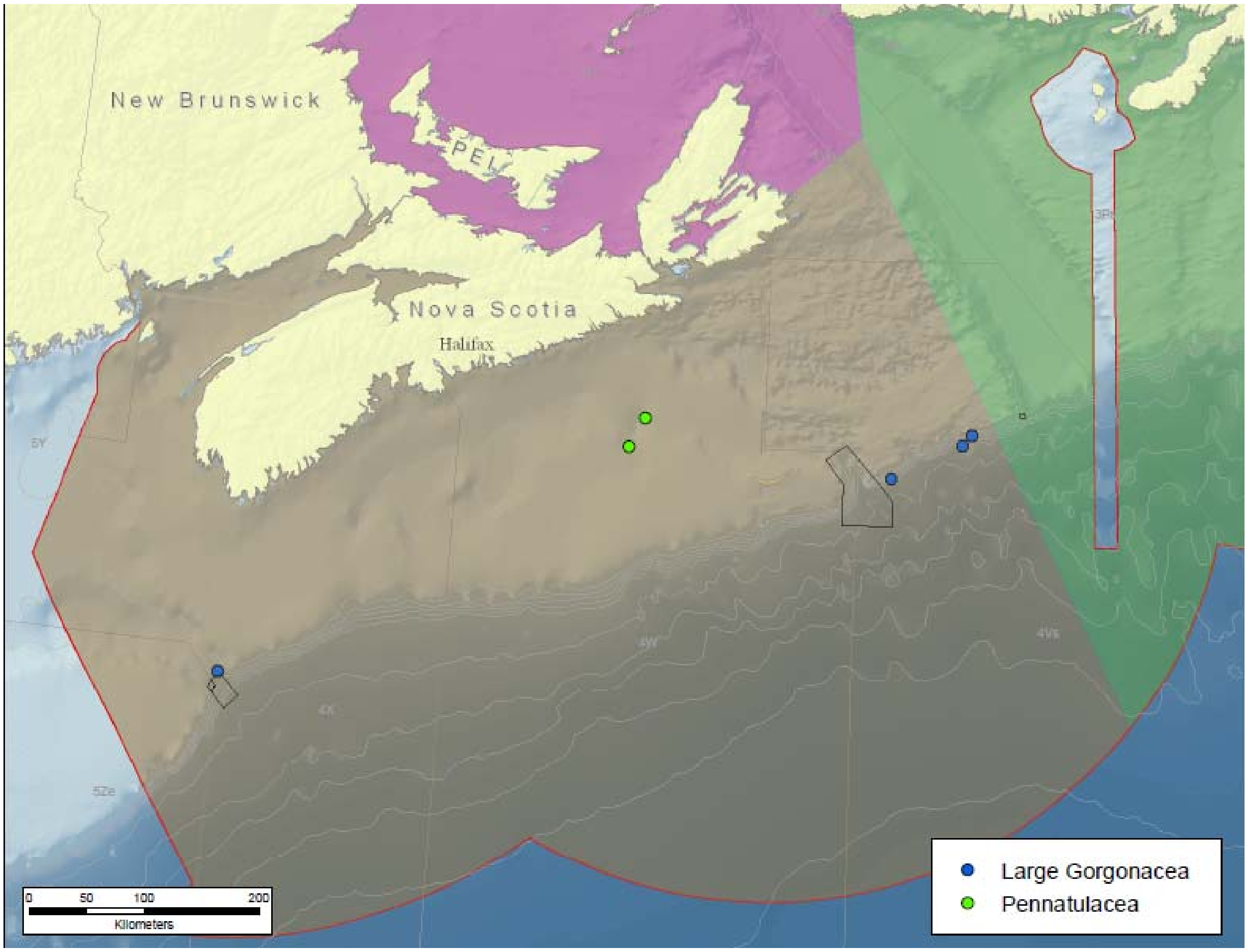

Figure 34. The positions of large catches of Pennatulacea (sea pens) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Scotian Shelf biogeographic unit identified using the cumulative catch distribution based on research vessel survey data. The 97.5% quantile of the catch distribution was applied for sea pens and large gorgonians.

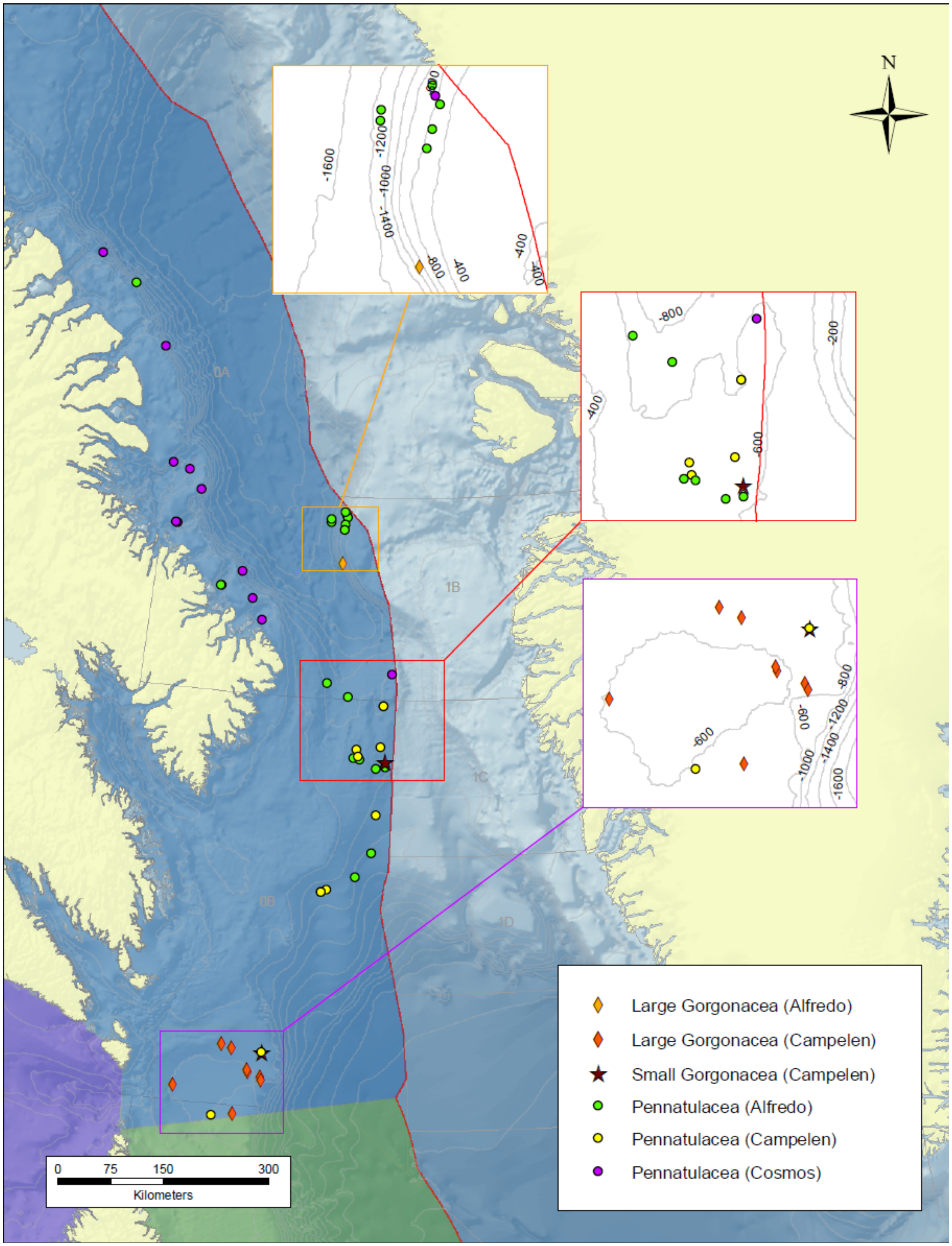

Figure 35. The positions of large catches of Pennatulacea (sea pens), small gorgonians (Acanella arbuscula) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Eastern Arctic biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 0.05 kg (Campelen trawl), 0.1 kg (Cosmos trawl), and 0.25 kg (Alfredo trawl) for sea pens; 15 kg for large gorgonians, and 0.05 kg for small gorgonians.

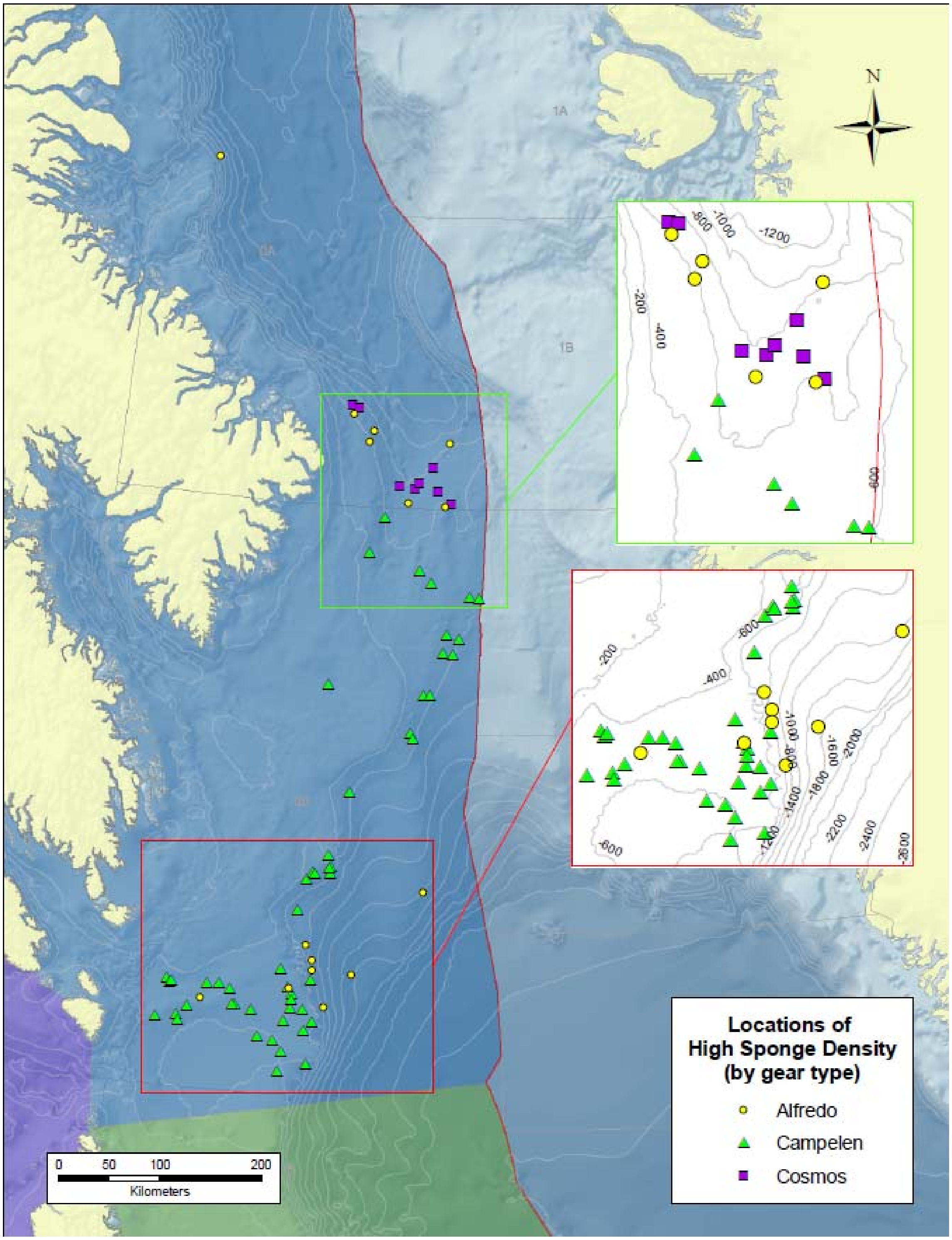

Figure 36. The positions of large catches of sponges in the Eastern Arctic biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 40 kg (Campelen and Cosmos trawl) and 70 kg (Alfredo trawl).

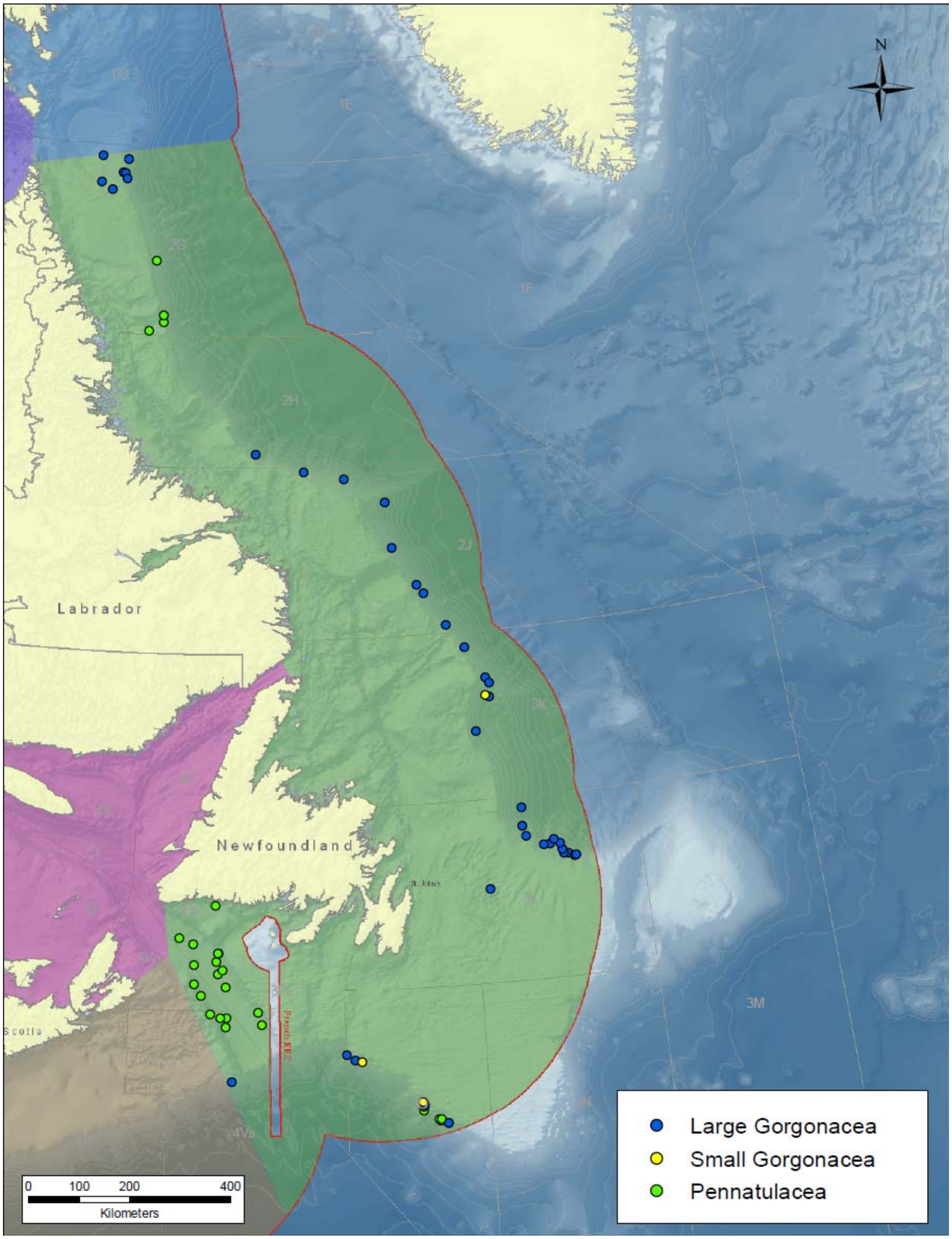

Figure 37. The positions of large catches of Pennatulacea (sea pens), small gorgonians (Acanella arbuscula) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Newfoundland and Labrador Shelves biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 0.4 kg for sea pens and 0.3 kg for small and large gorgonians.

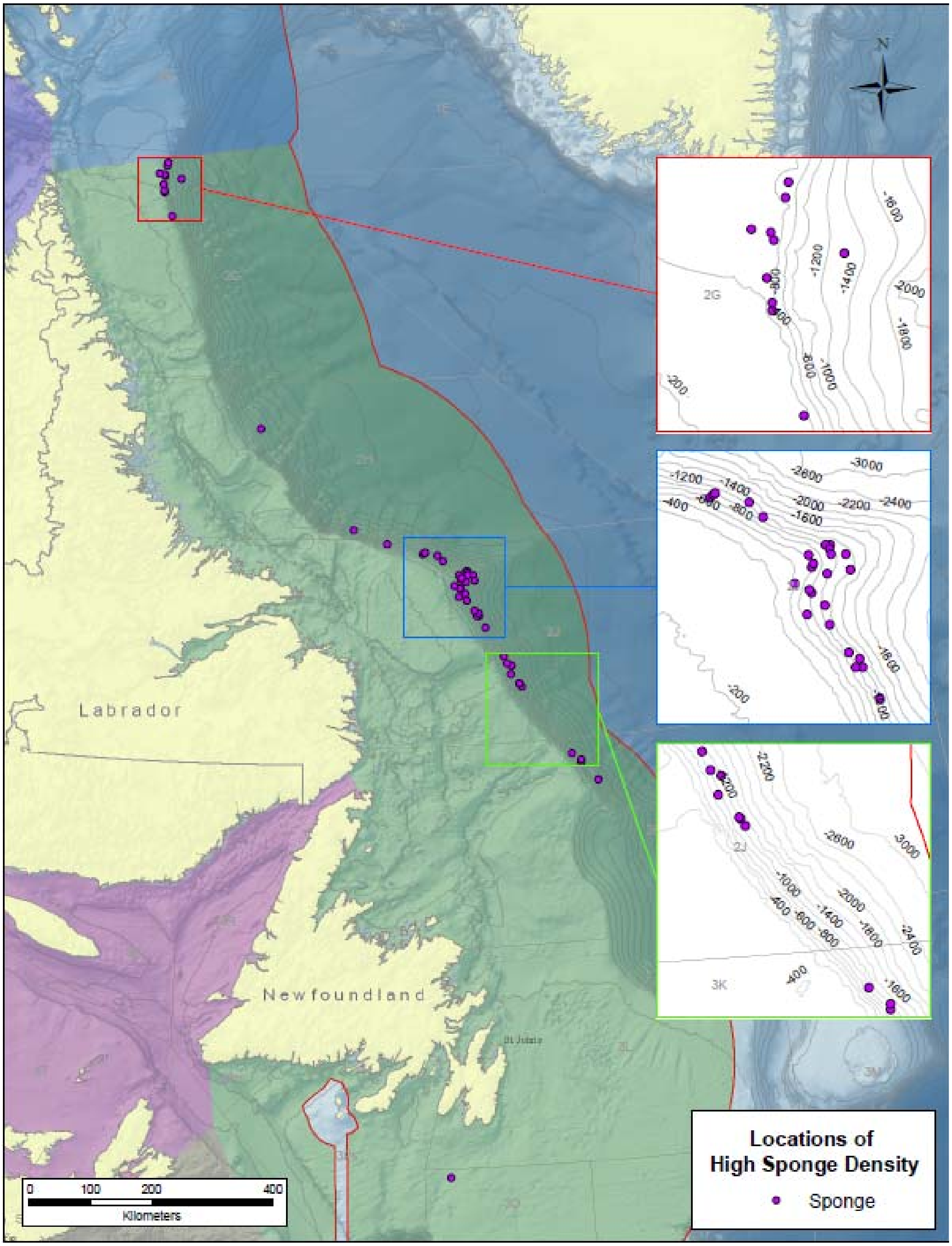

Figure 38. The positions of large catches of sponges in the Newfoundland-Labrador Shelves biogeographic unit identified using spatial analysis based on research vessel survey data. The selected threshold of 200 kg indicates the point at which the maximum change in aggregation area occurred.

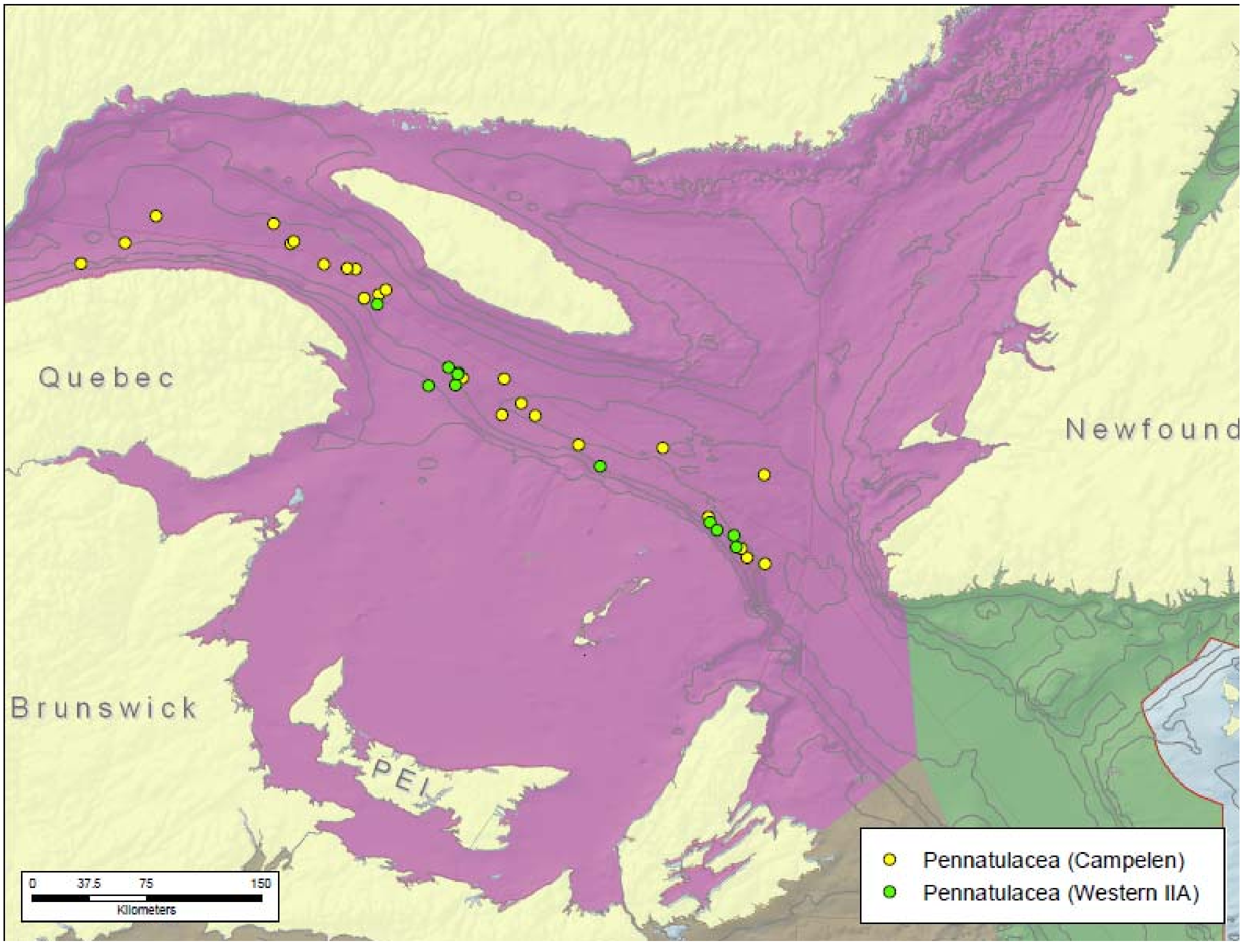

Figure 39. The positions of large catches of Pennatulacea (sea pens) in the Gulf of Saint Lawrence biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 7 kg for the Campelen trawl and 15 kg for the Western IIA trawl.

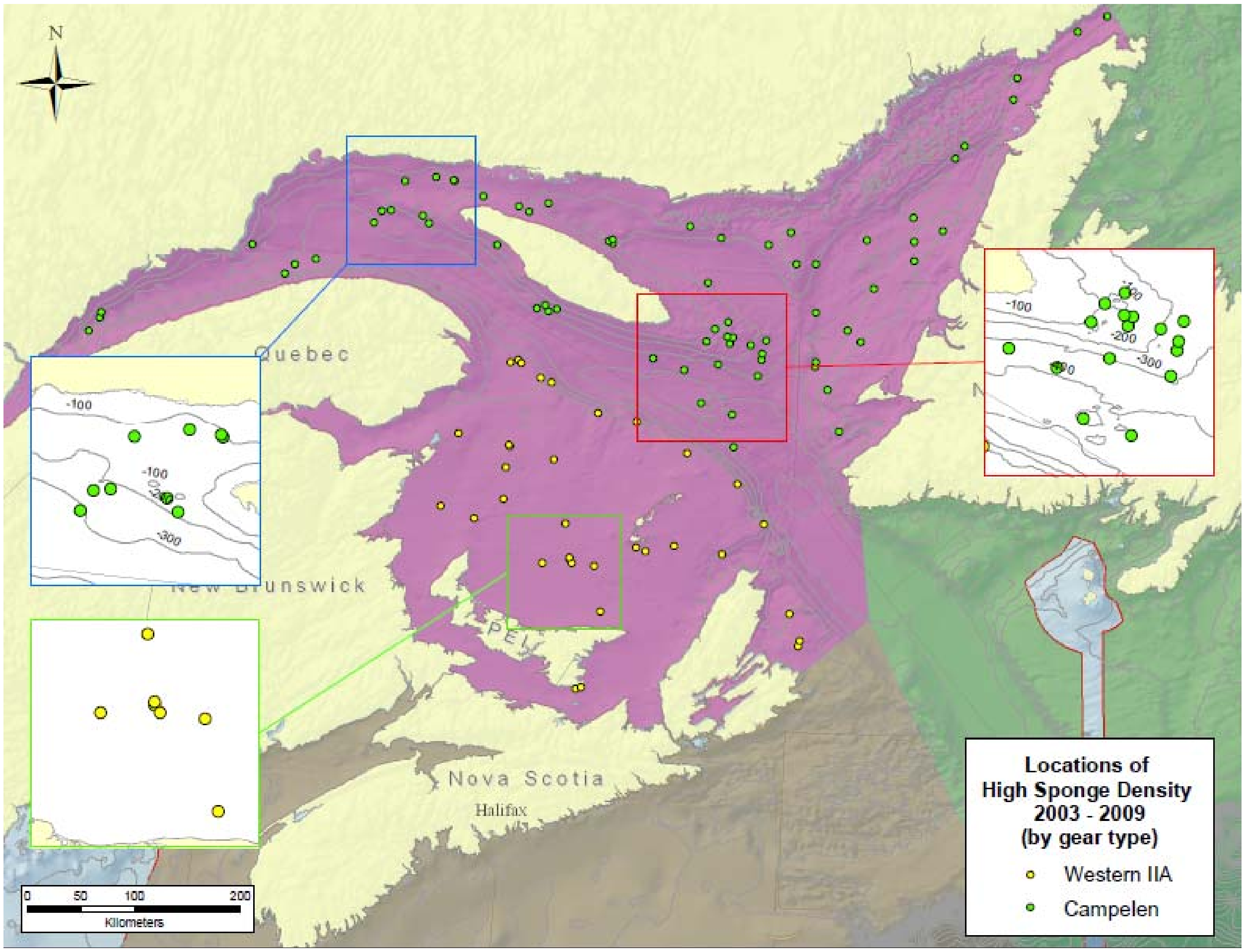

Figure 40. The positions of large catches of sponge in the Gulf of Saint Lawrence biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 3 kg for the Campelen trawl and 2 kg for the Western IIA trawl.

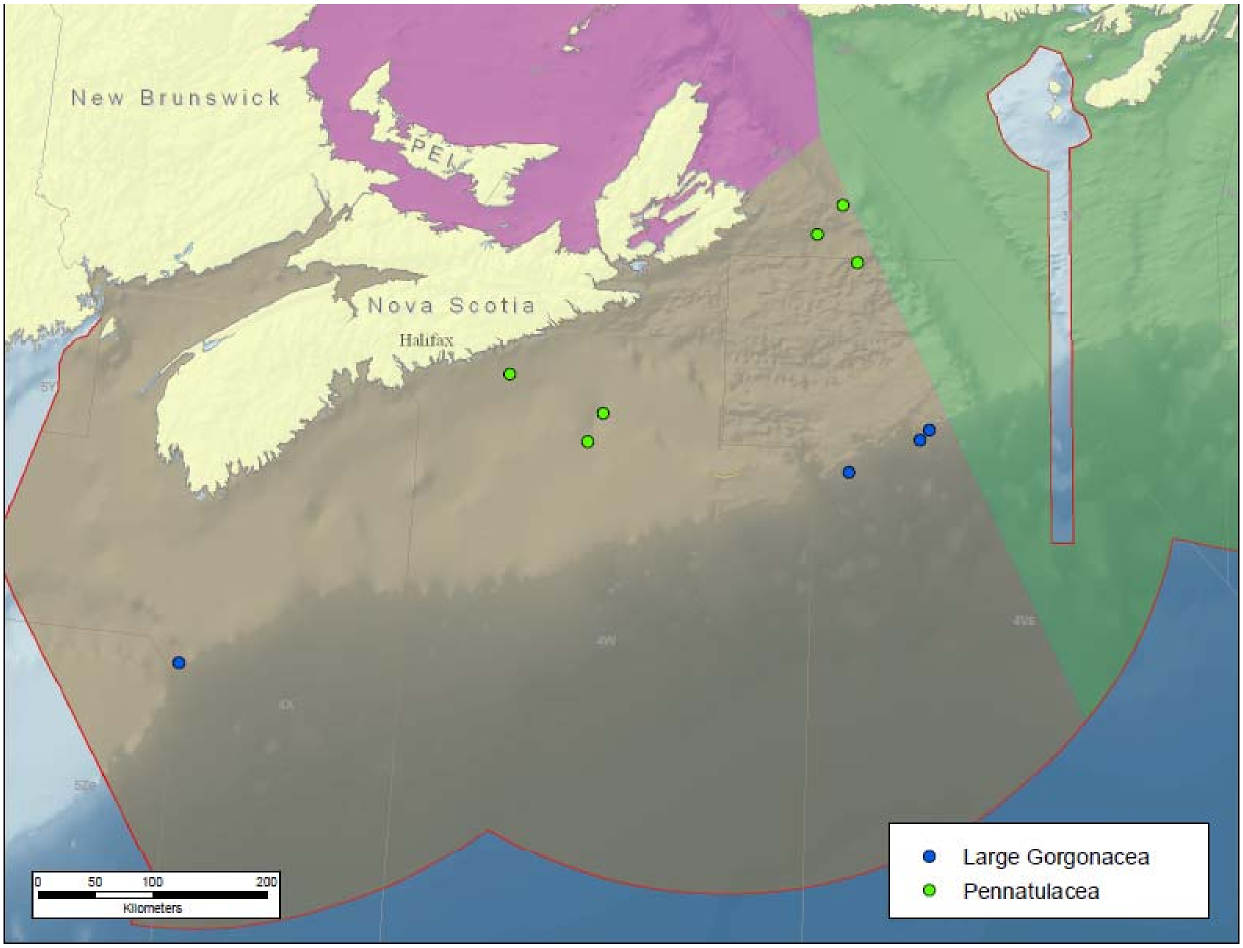

Figure 41. The positions of large catches of Pennatulacea (sea pens) and large gorgonians (sea fans; Primnoa, Paragorgia, Keratoisis, Paramuricea, Radicipes, etc.) in the Scotian Shelf biogeographic unit identified using spatial analysis based on research vessel survey data. The selected thresholds indicating the point at which the maximum change in aggregation area occurred are: 0.1 kg for sea pens and 0.5 kg for large gorgonians.

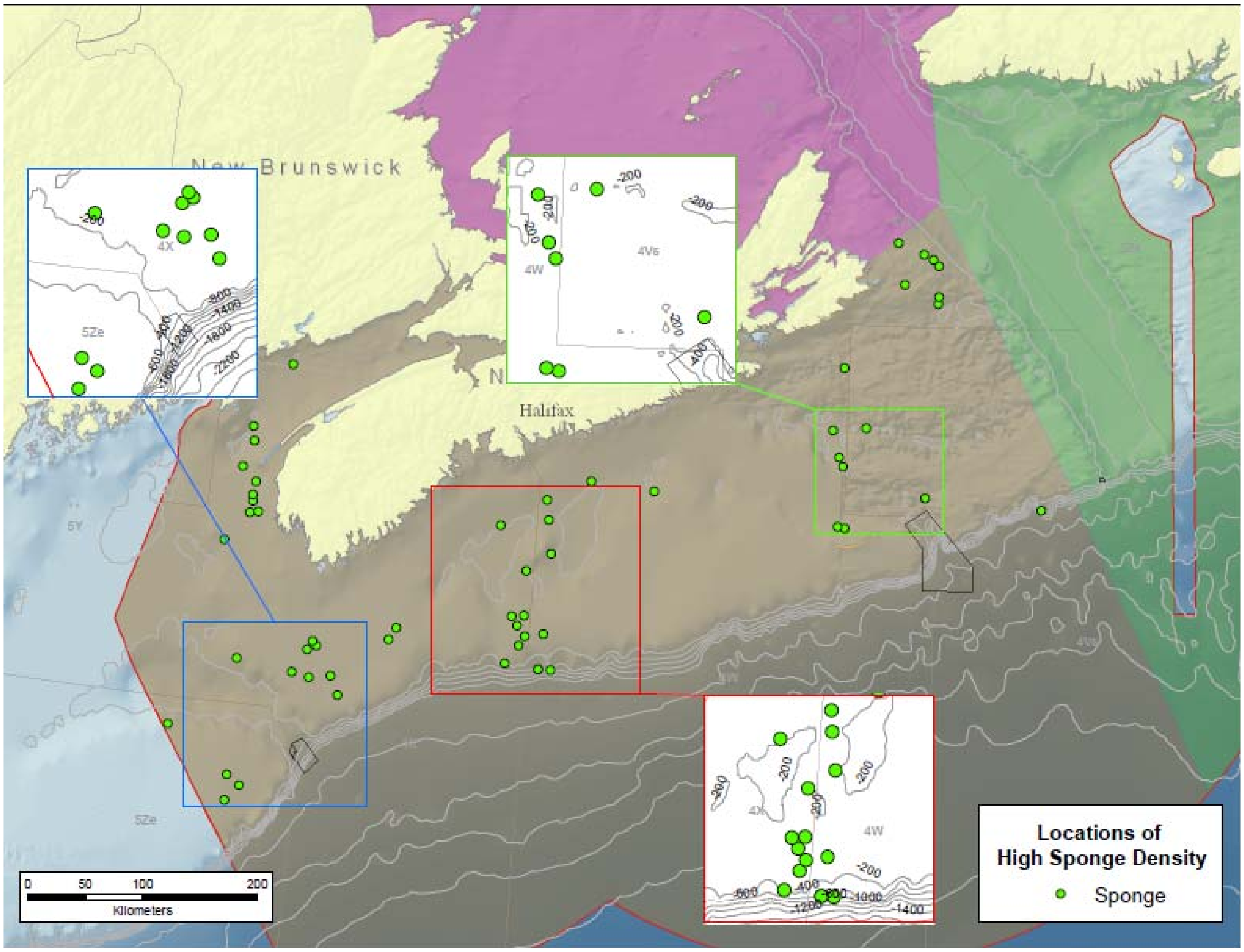

Figure 42. The positions of large catches of sponge in the Scotian Shelf biogeographic unit identified using spatial analysis based on research vessel survey data. The selected threshold (2 kg) indicates the point at which the maximum change in aggregation area occurred.

FOR MORE INFORMATION

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