An examination of the distribution, abundance, and habitat preferences of soft corals (Octocorallia: Alcyonacea) in offshore Nova Scotian waters

ENVS 4902 Environmental Science Undergraduate Honours Thesis

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Glossary

All glossary definitions are taken directly from Bayer et al. (1983)

Anthocodial: the distal part of a polyp, bearing the mouth and the tentacles; in many cases it can be retracted within the calyx, the stem, the branch (Alcyonacea), or within the cortex.

Autozooid: polyp with eight well-developed tentacles and mesenteries; the only kind of polyp in monomorphic species; the larger polyp in dimorphic species, often just termed polyp.

Capitulum: more or less disk-shaped or hemispherical, polypiferous part of an alcyonacean colony.

Capstan: rod with two whorls of tubercles or warts and terminal tufts.

Club: monaxial sclerites enlarged at one end, the head, and tapered at the other end, the handle.

Coenenchyme: the colonial tissue between the polyps, consisting of mesogloea usually containing sclerites and penetrated by the network of solenia and the larger gastrodermal canals.

Dimorphism: the presence of two kind of polyps: autozooids and siphonozooids.

Monomorphism: the presence of only one kind of polyp, the autozooid.

Needle: long, thin, nearly smooth monaxial sclerite

Pharynx: the tubular passageway between the mouth and the gastric cavity.

Pinnate tentacles: tentacles bearing pinnules.

Platelets: small flattened sclerites of diverse outline, appearing smooth in the light microscope, but having exceedingly fine sculpturing visible with the scanning electron microscope; usually smaller than 0.05 mm in greatest dimensions.

Radiate: sclerites with processes radiating in one plate or in various planes in a more or less symmetrical order.

Rods: straight or curved monaxial sclerite blunt at both ends.

Siphonozooid: a polyp with strongly developed siphonoglyph and reduced tentacles or none, commonly with reduced mesenterial filaments; usually much smaller than autozooids.

Spindle: straight or curved monaxial sclerite pointed at both ends; very common.

Stalk: In Alcyoniids, the barren basal part of the colony.

Trimorphic: the presence of three kinds of polyps, autozooids, siphonozooids, and mesozooids in addition to the primary polyp.

Abstract

Cold-water corals have been observed in Atlantic Canada since the 1800's and to date, there are 31 confirmed species. Although research on cold-water corals in Atlantic Canada has increased over the last two decades, knowledge gaps remain, especially surrounding soft corals (Octocorallia: Alcyonacea). In light of Canada's recent efforts to protect significant and representative marine ecosystems, more detailed information pertaining to soft corals is needed. This study aimed to increase our knowledge of the various species of soft corals, and specifically their distribution, abundance, and habitat preferences offshore Nova Scotia by using coral samples, interpolated geospatial surfaces, and environmental data collected between 2001-2011 and in 2017 by Fisheries and Oceans Canada during their annual multi-species bottom trawl surveys. The trawl surveys were conducted on the Scotian Shelf, Scotian Slope, and Bay of Fundy. Eight species, *Gersemia rubiformis*, *Gersemia fruticosa*, *Drifa glomerata*, *Drifa* sp.2, *Duva florida*, *Anthomastus grandiflorus*, *Heteropolypus sol*, and *Pseudoanthomastus agaricus* belonging to two families, Nephtheidae and Alcyoniidae, were identified. The majority, 62%, of sampled colonies were *Gersemia rubiformis*. The spatial distribution of all soft coral species displayed a strong affiliation with the northeastern portion of the Scotian Shelf and Scotian Slope. However, the Nephtheidae species are most common on the shelf while the Alcyoniidae species are most common on the shelf edge. This northeastern affiliation may be attributed to the colder temperatures, 1.8–4.3°C, exhibited on the northeastern Scotian Shelf and Scotian Slope compared to the warmer temperatures, 5.8–10.4°C, exhibited on the southwestern portions, and may indicate a preference of soft corals to colder temperatures.

Keywords: Soft corals, distribution, abundance, habitat preferences, Northwest Atlantic Ocean

1.0 Introduction

Cold-water corals are present in all oceans of the world, and have been observed and recorded in Atlantic Canada and adjacent waters as early as the late 1800's (Gordon and Kenchington 2007), however, little research had been done on these deep-sea organisms until 10-20 years ago (Gordon and Kenchington 2007; Wareham and Edinger 2007; Murillo et al. 2011). The development of deep-sea technologies, such as remotely operated underwater vehicles, has made *in-situ* observation possible, and in turn has increased our interest and understanding of cold-water corals (Gordon and Kenchington 2007; DFO 2015). From recent research it is now apparent that cold-water corals add complexity to deep-sea ecosystems, by providing food, shelter, habitat, and spawning sites for invertebrates and various fish species (Krieger and Wing 2002; Kenchington 2014; DFO 2015; Lagasse et al. 2015). Although our knowledge of cold-water corals has increased since the turn of the century, many unknowns remain concerning the abundance, biodiversity, and distribution of cold-water corals in the Northwest Atlantic Ocean (Wareham and Edinger 2007; Cogswell et al. 2009; Murillo et al. 2011).

Canada's Department of Fisheries and Oceans (DFO) is responsible for protecting 10% of Canada's coastal and marine areas by 2020, and is currently in the process of identifying valuable marine areas to protect (DFO 2017a). DFO aims "to protect and conserve marine species, habitats and/or ecosystems, which are ecologically or biologically significant and/or distinct" by "safeguarding and enhancing biodiversity and ecosystems through conservation and stewardship actions" (2017a). In addition to ecologically and biologically significant areas and species, DFO aims to protect representative areas (DFO 2005). DFO uses the Oceans Act, the Species at Risk Act (SARA), the Fisheries Act, the Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas and the Canada National Marine Conservation Areas Act, to make decisions on whether and to what extent an area should be protected (DFO 2017a; DFO 2017b). In the decision-making process, DFO considers ecologically and/or biologically significant areas or species as well as representative areas.

An area or species is deemed ecologically and/or biologically significant based on the level of structure and/or function that the area or species provides to the environment (DFO 2005). In other words, if a disturbance to a significant area or species occurs then the ecological and/or biological consequences (throughout the food web and ecosystem) would be greater than if the same disturbance occurred in a less significant area or to a less significant species (DFO 2005). Representative areas refer to areas that contain structures, species, and functions that are characteristic of an area (DFO 2005). These areas are not considered to be unique, to be areas containing high concentrations of particular species or habitats, or to be sites for important life history activities (DFO 2005). Also, the presence of species listed under SARA does not deem an area ecologically or biologically significant. However, their presence along with their critical habitat is considered in the marine protection process (DFO 2005). In order for DFO to meet their 2020 goal and to effectively protect the biodiversity, habitat, and ecosystems within our oceans, we need a clear understanding of the distribution, abundance, and habitat used by the organisms present in our oceans.

Collecting information on cold-water coral distribution and abundance is not easy, as they inhabit deep waters, typically 200-1000 m, and they are distributed over large areas

(Wareham and Edinger 2007; DFO 2015). Nonetheless, researchers have used a range of methods to study deep-sea environments, such as remotely operated vehicles (ROV), towed underwater camera systems, and bottom trawling (Cogswell et al. 2009). ROVs and towed underwater camera systems are used to collect photos, videos, and occasionally samples from the sea floor, and are a couple of the least invasive methods used for examining deep-sea environments (DFO 2007; DFO 2015). Although ROVs and towed underwater camera systems do not disturb the environment and organisms they are observing, they are not the ideal sample methods for examining large areas, since the data collection and video/photo analysis would be highly time intensive and costly. In addition, identifying species by video and/or photo can be difficult, especially for easily misidentified organisms, such as soft corals (Cogswell et al. 2009; Altuna et al. 2014). In comparison, bottom trawling is a more time efficient method of determining the distribution of benthic organisms over a large area, although it is destructive to the benthic environment from which it samples (Henry et al. 2003; Murillo et al. 2011; Buhl-Mortensen et al. 2017). Furthermore, the physical collection of samples, from trawling, allows for identification of specimens with greater certainty as well as more accurate measurements of biomass compared to ROV and underwater camera derived data (Cogswell et al. 2009). DFO uses bottom trawls as the sample method for examining the stock abundance, recruitment, and distribution of commercially fished organisms, such as halibut, on a large scale, in Canadian waters (DFO 2014). Bottom trawls are used for the reasons outlined above and to remain consistent in collection methods, allowing for comparability between data series, since DFO used bottom trawls for stock and distribution assessments prior to the development of technologies such as ROV (DFO 2014).

DFO has run an annual multi-species bottom trawl survey, henceforth referred to as trawl survey, on the Scotian Shelf and the Bay of Fundy since 1970, and started to include Georges Bank in the sample area in 1987 (DFO 2014). The primary aim of the trawl surveys was to estimate stock abundance and recruitment of various invertebrate and fish species for the fishing industry (DFO 2014). Abundance refers to the population size of each organism caught, and recruitment refers to the number of juveniles present in the different sample areas (DFO 2014). Currently, these trawl surveys are also being used to provide insight into the distribution, abundance, and habitat of non-commercial, benthic species including sea pens, sponges, and other cold-water corals (DFO 2014; Kenchington et al. 2016). DFO marine protected areas planners use the data collected from these trawl surveys on both commercial and non-commercial species in their consideration of ecologically and biologically significant and/or representative areas that require protection. Although the trawl surveys and targeted research surveys have shed some light on the presence and importance of cold-water corals in the Canadian Atlantic, there are still knowledge gaps pertaining to the ecological and biological roles of some cold-water corals, particularly alcyonacean corals, in this region (Altuna et al. 2014).

Alcyonacean corals belong to the subclass Octocorallia, which have polyps containing eight pinnate tentacles and most species incorporate some kind of calcium carbonate in their skeletal structure (Breedy et al. 2012). Polyps are tubular and flower-like protrusions that corals use for both feeding and reproduction (Bayers et al. 1983). The majority of alcyonaceans belong to two subgroups: soft corals or mushroom corals, which are soft-bodied and are the focus of this study, and gorgonians, which contain various arrangements of proteinaceous and calcified skeletons (Breedy et al. 2012). Alcyonacea is the most diverse order of Octocorallia because alcyonacean corals display a large variety in body plans (Breedy et al. 2012). For example some are thick incrusting colonies that feel like leather and some are branching (Breedy et al. 2012). Since all alcyonaceans greatly vary in body plans, the order is taxonomically classified by structure, colour, and sclerite arrangement and shape (Breedy et al. 2012). Soft corals in particular are identified with the aid of their sclerites. Sclerites are the calcareous structures found within coral tissue, and their arrangement and shape differs between species, making them a useful tool for identifying soft corals down to the species level (Bayer et al. 1983; Altuna et al. 2014; Jensen n.d). Although using sclerite arrangements and shapes for soft coral identification is useful, there are limited taxonomic guides available in the literature, which makes sclerite identification challenging (Altuna et al. 2014).

Alcyonaceans are cosmopolitan, however, their presence in the Northwest Atlantic Ocean has only received more attention in the past two decades (Gordon and Kenchington 2007). Breeze et al. (1997) were at the forefront of this increased interest in cold-water corals in the Northwest Atlantic Ocean, as they studied cold-water coral distribution offshore Nova Scotia. Breeze et al. (1997) collected data on the locations of corals found offshore Nova Scotia through interviews with fishermen, museum collections, discussion with researchers, and literature. From the data, they generated a distribution map for nine alcyonaceans and three scleractians, and as part of the literature review and research findings, the authors provided a list of all alcyonacean species found in Nova Scotian waters. This list included seven species belonging to the two soft coral families, Alcyoniidae and Nephtheidae (Breeze et al. 1997). Following the work done by Breeze et al. (1997), MacIsaac et al. (2001), Mortensen and Buhl-Mortensen (2004), Gass and Willison (2005), Mortensen et al. (2006), Wareham and Edinger (2007), Cogswell et al. (2009), Wareham (2009), Sun et al. (2010), Murillo et al. (2011), Altuna et al. (2014), and Gullage et al. (2017) also examined cold-water corals of the Northwest Atlantic Ocean. However, only Mortensen et al. (2006), Wareham and Edinger (2007), Cogswell et al. (2009), Murillo et al. (2011), and Altuna et al. (2014) provided information on soft coral distribution within the Northwest Atlantic Ocean.

Mortensen et al. (2006) examined the distribution of soft corals in Atlantic Canada through video surveys, bycatch from groundfish surveys, reviewing literature, and museum collections. Like Breeze et al. (1997), Mortensen (2006) identified seven species of soft corals, which were found on the Scotian Slope, the Gully, the Laurentian Channel, the Stone Fence, and the southern Grand Banks. Furthermore, Murillo et al. (2011) mapped the distribution, biomass, and species richness of soft corals as well as other cold-water corals of the Flemish Cap (FC), Flemish Pass (FP), and the Tail and Nose of the Grand Banks (GB) off Newfoundland. Murillo et al. (2011) found that soft corals were the most common type of coral, and were widespread in each of the study areas listed above (Murillo et al. 2011). Soft corals were found to inhabit a large variety of substrate types, including mud, coarse sand, pebbles, and cobbles (Murillo et al. 2011). The majority of soft corals collected in the study areas were *Anthomastus* spp., *Duva florida*, and other Nephtehids (Murillo et al. 2011). Aposterior study on the Alcyoniid species collected in these areas (Altuna et al. 2014) revealed five species of soft corals.

Both studies concluded that coral species richness was highest on the FC compared to surrounding areas and that soft corals attach to a variety of substrate types (Murillo et al. 2011; Altuna et al. 2014).

From the literature, baseline information on the distribution, abundance, and habitat types of soft corals in Atlantic Canada and adjacent waters has been established. However, the samples collected in some of the studies discussed above targeted specific areas offshore Nova Scotia, such as the Gully, which could result in a misinterpretation of the true distribution of soft corals in Atlantic Canada. Also, there is no data set showing the distribution of soft corals, by species, across the whole of offshore Nova Scotia. Thus, there are knowledge gaps surrounding their distribution, abundance, species richness, and regional habitat preference. In addition, some soft corals are still easily misidentified due to taxonomic challenges and the lack of literature, so there is a demand for the development of a comprehensive taxonomic key for Northwest Atlantic soft coral species (Altuna et al. 2014).

The objective of this study was to determine, document, and display the distribution, abundance, and habitat preference of soft corals found offshore Nova Scotia. Therefore, this research project aimed to answer the question: What species of soft coral alcyonaceans are currently found offshore Nova Scotia, and what is their distribution, abundance, and habitat preferences? The project concentrated on soft corals located on the Scotian Shelf, the Scotian Shelf edge, and the Bay of Fundy. In addition, the project was restricted temporally by using soft coral samples collected in the years 2001-2011 and 2017.

The expertise of Dr. Murillo, an invertebrate taxonomist, and available published and unpublished taxonomic keys and identification guides were used to identify the soft coral samples that were collected from offshore Nova Scotia during DFO's trawl surveys (Altuna and Murillo 2014; Altuna et al. 2014; Jensen n.d). Species-specific characteristics observed during identification were added to preexisting soft coral species descriptions to create a taxonomic guide of soft corals found offshore Nova Scotia. Additionally, the coordinates of each specimen were uploaded into ArcMap 10.5 to generate distribution maps of soft corals, by family and by species. Also, the counts of each species by location were used to create proportional abundance maps that highlighted soft coral congregations. Finally, preferred habitat types were determined by family and by species from examining interpolated temperatures and salinity levels, as well as depth measurements collected during the trawl surveys.

2.0 Literature Review

With technological advances and more interest placed on corals, coral taxonomy and understanding of their ecological and biological importance have greatly developed, which has resulted in a need for coral conservation. Although the literature does outline the basic importance of cold-water corals and their distribution, abundance, and habitats, it lacks knowledge on the order Alcyonacea, and specifically soft corals. This literature review outlines where soft corals fit within current taxonomy, the importance of cold-water corals, the current understanding of soft corals in a Northwest Atlantic Ocean context, the need for coral conservation, and the current knowledge gaps surrounding soft corals.

2.1 Coral taxonomy

Corals belong to the phylum Cnidaria, which also includes hydroids, jellyfish and sea anemones (Roberts et al. 2009). Cairns (2007) has defined corals as "animals in the cnidarian classes Anthozoa and Hydrozoa that produce either calcium carbonate (aragonitic or calcitic) secretions resulting in a continuous skeleton or as numerous microscopic, individualized sclerites, or that have a black, horn-like, proteinaceous axis". In general terms, corals are broken into two types, tropical corals, those corals with zooxanthellae that reside in warm waters at depths of less than 50 m, and cold-water corals, azooxanthellae corals that live in cold waters and are most commonly found at depths between 200-1000 m (Cairns 2007). Although tropical corals are generally more well-known, there are a greater number of azooxanthallae species than zooxanthellae corals, and new species are still being discovered (Roberts et al. 2009; Roberts and Cairns 2014). For example, the United States alone discovered 60 new cold-water corals between 2007 and 2015, which equates to 7.5 species year^{-1} (Cairns et al. 2016). Cold-water corals are taxonomically categorized as belonging to the phylum Cnidaria and class Anthozoa, and are found within four taxa including: Scleractinia, Zoanthidae, Antipatharia, and Alcyonacea (Roberts and Cairns 2014). Soft corals, the subgroup that is the focus of this study, belong to the subclass Octocorallia and order Alcyonacea, and are distinguished by their eight pinnate tentacle polyps (Table 1) (Breedy et al. 2012). In addition, soft corals have polyps contained in massive bodies and are made up of numerous individual, microscopic sclerites (Cairns 2007; Wareham and Edinger 2007).

Table 1 Classification of cold-water corals found in the Northwest Atlantic Ocean. Table adapted from Breeze et al. (1997), Molodtsova (2013), and Altuna et al. (2014). *Drifa* sp.2 could be *Drifa flavescens* (Sanmartín Payá 2004)

Taxon

Phylum Cnidaria

Class Anthozoa

Subclass Octocorallia
Order Alcyonacea
Family Alcyoniidae

Alcyonium digitatum (Linnaeus, *1758)*
Anthomastus canariensis (Wright and Studer, 1889)
Anthomastus grandiflorus (Verrill, 1878)
Anthomastus purpureus (Koren and Danielssen, 1883)
Heteropolypus sol
Pseudoanthomastus agaricus (Studer, 1890)
Pseudoanthomastus sp.

Family Nephtheidae

Drifa flavescens (Danielssen, 1887)
Drifa glomerata (Verrill, 1869)
Drifa sp. 2*
Duva florida (Rathke, 1806)
Gersemia fruticosa (Sars, 1860)
Gersemia rubiformis (Ehrenberg, 1834)

* *Drifa* sp.2 could be *Drifa flavescens* (Sanmartín Payá 2004), see section 3.4.3.

2.2 Importance of cold-water corals as habitat

Cold-water corals are found in all oceans of the world, from the tropics to the Artic and Antarctic, and are found predominantly in deep waters but occasionally in shallow waters with a direct source of oceanic water (Roberts et al. 2009). In addition, they inhabit a large variety of environments, including seamounts, inland fjords, continental shelves, slopes, offshore banks, and abyssal plains (Roberts et al. 2009). The environments cold-water corals inhabit are highly dependent on depth, substrate type, food availability, currents, and environmental conditions, such as temperature (Mortensen et al. 2006; Buhl-Mortensen et al. 2017; Gullage et al. 2017). Cold-water corals are wide ranging and can produce significant structures on the seafloor. This makes them an ecologically important part of the marine benthic environment because they provide multiple services, such as habitat, breeding grounds, food, nursery areas, and protection from predators

(DFO 2015; Lagasse et al. 2015; Buhl-Mortensen et al. 2017). A study by Pham et al. (2015) supports this statement as their results showed that total fish catches of demersal fish were higher in areas with cold-water coral aggregations than in those without, and that two species of rockfish were highly associated with the coral aggregations. In addition, Wareham and Edinger (2007) found that non-coral, sessile organisms were found growing on corals in areas with limited hard surfaces, further supporting the notion that corals provide habitat. Furthermore, Rooper et al. (2007) discovered that juvenile Pacific ocean perch, *Sebastes alutus*, use sites dominated by coral aggregations composed of alcyonaceans as nursery sites in the Aleutian Islands of Alaska. The advanced technologies used by these studies have not only furthered our understanding of the wide distribution of cold-water corals, but also their ecological importance in the marine environment (Rooper et al. 2007; Wareham and Edinger 2007; Lagasse et al. 2015; Pham et al. 2015).

2.3 Soft corals in Canadian and adjacent waters

There is a growing knowledge base on soft corals in Atlantic Canada and adjacent waters. Previous studies have focused on their distribution and abundance in waters around the Scotian Slope, offshore Newfoundland and Labrador, and the Gulf of St. Lawrence (Wareham and Edinger 2007; Cogswell et al. 2009; Murillo et al. 2011; Altuna et al. 2014). Wareham and Edinger (2007) examined the distribution of cold-water corals in the Newfoundland and Labrador region, and they collected coral data from three sources: DFO trawl surveys, the northern shrimp stock assessment survey, and observations from the Fisheries Observer Program. Overall, 28 species of cold-water coral were identified to the species level, but two additional forms were not identified down to the species level (Wareham and Edinger 2007). Of the potential 30 species, one Alcyoniid species, *Anthmastus grandiflorus*, and a minimum of two Nephtheid species, *Gersemia rubiformis* and *Capnella* (*Duva*) *florida*, were identified (Wareham and Edinger 2007). A third Nephtheid species was suspected, but Wareham and Edinger (2007) were unable to identify it to the species level due to the uncertainty and lack of knowledge surrounding Nephtheid taxonomy.

Additionally, Nephtheids exhibited the highest frequency of all species, and *Gersemia rubiformis* was the only species consistently found on the continental shelf (Wareham and Edinger 2007). Wareham and Edinger (2007) highlighted several coral hotspots within the study area, one of which was the Makkovik to Belle Isle Bank area, where soft corals as well as *Acanella arbuscula* were the most abundant taxa. Furthermore, the Nephtheids were found in shallower waters than the Alcyoniid species, which was only found on shelf edges and shelf slopes, but overall *Gersemia rubiformis* was the shallowest-occurring soft coral species (Wareham and Edinger 2007). In terms of offshore Nova Scotia, several studies on coral distribution have been conducted, and Cogswell et al. (2009) summarized the findings of these studies.

Cogswell et al. (2009) looked specifically at cold-water corals found within the Gulf of St. Lawrence, the Northeast Channel Coral Conservation Area (NECCCA), the Stone Fence *Lophelia* Conservation Area (LCA), and the Gully Marine Protected Area (the Gully) by using videos and still images, collections from DFO trawl surveys, and bycatch data. From examining the combined data, five soft coral taxa, *Drifa glomerata*, *Anthomastus* spp., *Anthomastus grandiflorus*, Nephtheidae spp., and *Gersemia rubiformis*, were identified and were found either in or around the conservation areas. In addition, soft corals were found on a variety of substrates, including cobbles, pebbles, boulders, cliffs, and mud, and similar to Wareham and Edinger (2007) suggested, Nephtheids were found in shallower waters than Alcyoniids (Cogswell et al. 2009). Examinations of soft corals on the FC (offshore Newfoundland, outside Canada's EEZ) conducted by Murillo et al. (2011) revealed similar species to Wareham and Edinger (2007) and Cogswell et al. (2009), but discussed their habitat, specifically substrate and depth, in more detail.

Murillo et al. (2011) examined the distribution of cold-water corals of the FC, the FP, and the GB of Newfoundland and adjacent waters by examining coral bycatch collected during Spanish/European Union (EU) bottom trawl surveys. The authors found that the highest biomass of soft corals occurred between 600-900 m, and all species were found deeper than 600 m except for *Duva florida* and *Gersemia rubiformis*, which could be found both shallower and deeper than 600 m (Murillo et al. 2011). Also, the highest species richness was found on the FC (Murillo et al. 2011). Murillo et al. (2011) came to a similar conclusion as Wareham and Edinger (2007) and Cogswell et al. (2009) in that soft corals were attached to a variety of substrate types, specifically mud, sand, sand with granules, coarse sand, and sometimes live gastropods.

Altuna et al. (2014) improved the alcyoniid identifications made by Murillo et al. (2011), as they found five species from three different genera at depths between 348 – 1351 m while re-trawling the same study area as Murillo et al. (2011). The five species included, *Anthomastus canariensis*, *Anthomastus grandiflorus*, *Heteropolypus sol*, *Pseudoanthomastus agaricus*, and *Pseudoanthomastus* sp. with *Heteropolypus sol* being the most abundant (Altuna et al. 2014). This study confirmed that the FC contains the greatest species richness compared to the FP and the GB and that the corals were found on a variety of substrates (Altuna et al. 2014). However, *Heteropolypus sol* was the only species that was observed living directly anchored to the sediment (Altuna et al. 2014). Although our understanding of soft corals in Atlantic Canada and adjacent waters has greatly increased in the recent past, there are still knowledge gaps pertaining to soft corals distribution on the Scotian Shelf, Scotian Slope, and Bay of Fundy as these areas have received little attention in regards to soft corals. In addition, there are still questions regarding the habitat preferences, including temperature, salinity, and depth, of soft corals in Atlantic Canada.

2.4 Coral conservation

2.4.1 Cold-water coral conservation

Canada recognizes the environmental importance and the slow growing nature of cold-water corals as well as the need to further our understanding of these benthic organisms, and has tasked DFO with conserving, protecting, and researching them (Gordon and Kenchington 2007; DFO 2017b). DFO has generated the Coral and Sponge Conservation Strategy for Eastern Canada, herein referred to as the strategy, in order to meet their objective of conserving, protecting, and researching corals (DFO 2017b). Firstly, the strategy states its conservation objective: "to conserve the health, composition, and function of coral and sponge species, communities, and their habitat in support of healthy ecosystems" (DFO 2015). Secondly, the strategy states its management objective: "to manage human activities with impacts on coral and sponge communities efficiently and effectively in support of healthy ecosystems and sustained economic benefits, within a risk assessment framework" (DFO 2015). Thirdly and finally, the strategy states its research objective: "to support decision making through the provision of scientifically based peer-reviewed advice on the location of corals and sponges, human caused impacts on these species, the health and integrity of corals and sponges, and their contributions to the conservation of healthy ecosystems" (DFO 2015). Furthermore, DFO wants to ensure that they protect ecologically and biologically significant areas and species as well as representative areas (DFO 2005). These objectives will be met by the targets and actions outlined in the strategy, in addition to DFO's more recent goal of protecting 10% of Canada's coastal and marine environments by 2020 (DFO 2017a; DFO 2017b).

The protection and conservation of corals uses the Fisheries Act, the Oceans Act, the SARA, the Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas, and the Canada National Marine Conservation Areas Act to regulate protected areas in the ocean (DFO 2017a; DFO 2017b). The listed legislation is used to provide a uniform protocol for the conservation of the different coastal and ocean regions across Canada. The Acts also allow for convictions of individuals that violate regulations applied to a particular area, such as bottom trawling in a no-trawl protected area (DFO 2017b). Canada has already established several marine conservation areas under these acts within the Atlantic. These areas include, but are not limited to, the NECCCA (Fisheries Act), the Stone Fence LCA (Fisheries Act), the Gully (Oceans Act), and the St. Anns Bank Marine Protected Area (Oceans Act) (Cogswell et al. 2009; Ford and Serdynska 2013; DFO 2018).

The areas listed above cover 424 km^2, 15 km^2, 2364 km^2, and 4364 km^2 respectfully, and are protected because they contain high diversity and high concentrations of corals, and/or commercial species, such as halibut, or non-coral invertebrates, such as sponges, in some cases (Cogswell et al. 2009; Ford and Serdynska

2013; DFO 2018). The LCA and the Gully are only about 160 km apart and are connected by a southwestern current, and this connection allows for the LCA to share genetic diversity and biodiversity with the Gully by larva dispersal (Cogswell et al. 2009). Also, the NECCCA has experienced partial recovery, since being established as a conservation area with deep-sea fishing restrictions, as existing corals are showing recovery and growth, however there are limited signs of recruitment (DFO 2015; Bennecke and Metaxas 2017). This means that there is limited connectivity between the NECCCA and other coral aggregations, resulting in slower recovery (Bennecke and Metaxas 2017). In addition, the St. Anns Bank Marine Protected Area (MPA) is a new MPA in Atlantic Canada, and was protected because it contains high levels of biodiversity and important habitat for a large variety of species, such as redfish, Atlantic cod, sponges, and corals (Ford and Serdynska 2013; DFO 2018). In terms of corals, St. Anns Bank MPA houses a variety of alcyonacean corals, including soft corals, but their status and species composition, along with other organisms found in this area, has not yet been reviewed (Cogswell et al. 2009; DFO 2018). The discovery of important coral habitats has resulted in protected areas that either face reduced fishing pressures or none at all, and that continue to provide ecological services to the surrounding environment (Cogswell et al. 2009; Lagasse et al. 2015).

2.4.2 Soft coral conservation

The focus of cold-water coral research and protection has revolved primarily around the larger coral species, for example scleractinians like *Lophelia pertusa* and alcyonaceans like *Primnoa resedaeformis* and *Paragorgia arborea* (Gass and Willison 2005; Gordon and Kenchington 2007; Cogswell et al. 2009; Bennecke and Metaxas 2017). This focus on larger species has left other groups of corals, especially soft corals, out of the conservation discussion; this is not to say that soft corals are not protected. Currently, soft corals reside in all four previously mentioned conservation areas, NECCCA, the LCA, the Gully, and St. Anns Bank MPA (Cogswell et al. 2009; Ford and Serdynska 2013). Although soft corals are currently protected, they were not the target species being observed or protected in any of these areas, as they are seen as less vulnerable to fishing methods, such as bottom trawling, than other groups of corals, such as scleractinians (Henry et al. 2003; Cogswell et al. 2009; Ford and Serdynska 2013; Benneck and Metaxas 2017). Rather, the presence of soft corals in the protected areas was considered an additional benefit and justification for the protected areas (Cogswell et al. 2009; Bennecke and Metaxas 2017). One of the major problems concerning soft coral conservation in Atlantic Canada is the fact that there is limited knowledge on their distribution, abundance, and habitat preferences.

The aim of the strategy is to consider and examine the distribution, diversity, and abundance of all sessile species, which by that definition includes soft corals (DFO 2015). Although soft coral gardens, which are dense aggregations of individuals or colonies of a single species or multiple species of soft corals over areas $\geq$25 m^2, have been deemed ecologically and biologically significant by DFO, we still lack the baseline information on where soft corals are found, in what numbers, and why (Kenchington 2014). Without further examination of the distribution, abundance, and habitat preferences of soft corals in offshore Nova Scotia, there is potential that ecologically and biologically significant soft coral gardens are not protected. Therefore the strategy calls for more soft coral research and, depending on the results of the research, the protection of soft coral inhabited areas (DFO 2015).

2.5 Knowledge gaps

Although cold-water coral knowledge has greatly increased in the past 15 to 20 years, there is still little information on their global distribution (Roberts and Cairns 2014). Our knowledge base is much greater for some taxonomic groups of cold-water corals than others, and soft corals are one subgroup that has not received much attention (Murillo et al. 2011; Altuna et al. 2014). This lack of attention can be attributed to several reasons, mainly that soft corals are difficult to identify and there is limited taxonomic literature to refer to (Wareham and Edinger 2007; Murillo et al. 2011; Altuna et al. 2014). Most of the research containing information on soft corals did not focus solely on them, but rather cold-water corals in general and usually there is an emphasis on larger alcyonaceans and scleratians and very little to no directed studies on soft corals (Breeze et al. 1997; Gass and Willison 2005; Wareham and Edinger 2007; Cogswell et al. 2009; Murillo et al. 2011; Bennecke and Metaxas 2016). Also, the information collected on these corals is predominantly from areas around Newfoundland and Labrador (Wareham and Edinger 2007; Murillo et al. 2011; Altuna et al. 2014), the Gulf of St. Lawrence (Cogswell et al. 2009), and the Scotian Shelf and slope (Breeze et al. 1997; Gass and Willison 2005; Gordon and Kenchington 2007; Cogswell et al. 2009). In addition, there are limited studies that have thoroughly examined the habitat preferences of soft corals, so there is limited information on each species temperature, salinity, and depth preferences (Cogswell et al. 2009; Murillo et al. 2011; Altuna et al. 2014). This has resulted in particularly limited information regarding the distribution, abundance, and habitat preferences of soft corals on the Scotian Shelf and Slope, and Bay of Fundy. Therefore, there is a need to explore these areas for soft corals to increase our understanding and knowledge base of soft corals in these regions.

In addition to lack of information pertaining to soft coral distribution, abundance, and habitat, little is known about their role in the benthic ecosystems, and there is confusion pertaining to the taxonomy of some of the species (Murillo et al. 2011; Altuna et al. 2014; Jensen n.d). Although not well examined in the literature, soft corals have been found with fish, basket stars, juvenile Northern shrimp, snow crabs, and polychaetes on, beneath or located near to them (Patent 1970; Rooper et al. 2007; Cogswell et al. 2009; Altuna et al. 2014; Kenchington 2014). However, this is not enough information to determine their role in the benthic environment.

Ten species of soft corals have been documented in the literature from offshore Atlantic Canada, however there is still debate concerning the taxonomy of some species (Campbell and Simms 2009; Altuna et al. 2014; Jensen n.d). For example, some researchers believe that there is only one species of *Gersemia*, *Gersemia rubiformis* (Jensen n.d), while others believe that there may be two, *Gersemia rubiformis* and *Gersemia fruticosa* (Sanmartín Payá 2004; Altuna et al. 2014). Also, there is confusion surrounding the number of Alcyoniid species in Atlantic Canada and adjacent waters. However, work done by Molodtsova (2013) and Altuna et al. (2014) have reduced some of the confusion surrounding Alcyoniid taxonomy in the North and Northwest Atlantic Ocean. In summary, there is a great need for clarifying the areas that soft corals inhabit and the development of a taxonomic guide for soft coral species found in Atlantic Canada.

This literature review has identified the current taxonomy of soft corals, the importance of cold-water corals, the current state of knowledge surrounding soft corals, the conservation of cold-water corals and soft corals, and the knowledge gaps surrounding soft corals in Atlantic Canada. Soft corals are cold-water corals belonging to the order Alcyonacea, and mainly reside in waters deeper than 200 m on a variety of substrates, including mud and coarse sand, pebbles, and cobbles (Cairns 2007; Wareham and Edinger 2007; Murillo et al. 2011; Breedy et al. 2012; Altuna et al. 2014). Little is known about this subgroup due to the fact that they are hard to identify and they have been greatly ignored in the past (Wareham and Edinger 2007; Altuna et al. 2014). The majority of the information pertaining to the distribution, abundance, and habitat preference of soft corals in Atlantic Canada and adjacent waters has focused on areas around Newfoundland and Labrador, Gulf St. Lawrence, and small sections of the Scotian Slope (Gordon and Kenchington 2007; Wareham and Edinger 2007; Cogswell et al. 2009; Murillo et al. 2011; Altuna et al. 2014). In addition, little is known about their role in the benthic environment, and there is still confusion surrounding their taxonomy (Murillo et al. 2011; Altuna et al. 2014; Kenchington 2014). In order for DFO to properly protect and fully understand the ecologically and biologically significant areas and species in Atlantic Canada a better understanding of the distribution, abundance, habitat preference, and role of soft corals is needed.

3.0 Methods

3.1 Overview

Soft coral samples were collected on an opportunistic basis during DFO’s annual stratified random multi-species bottom trawl surveys (hereafter referred to as trawl surveys) from 2001-2011 and in 2017 (DFO 2017c). The primary goal of the trawl surveys is to estimate stock abundance and recruitment of commercial invertebrates and fish, such as lobster and cod (DFO 2014). DFO's trawl surveys follow a probabilistic, proportionate stratified random sampling technique, with a 30 minute tow duration (DFO 2017d). The collected coral specimens were visually identified, and identified based on sclerite size and shape when visual identification was not possible or uncertain, and plotted into distribution and abundance maps based on recorded trawl start coordinates. In addition, interpolated average minimum and average maximum temperatures, interpolated average minimum and average maximum salinities (Beazley et al. 2017), and depth, based on environmental data collected during the survey trawls, were used to determine habitat preferences.

3.2 Study area

This project focused on the distribution of soft corals on the Scotian Shelf, Scotian slope, and the Bay of Fundy, as these were the areas trawled by DFO in 2001-2011 and 2017. DFO divides the survey area into three regions according to oceanographic conditions and biogeography: Eastern Scotian Shelf, Western Scotian Shelf, and Gulf of Maine/Bay of Fundy (Clark and Emberley 2011). The three regions are further divided into strata, which represent different depths and habitat types (Figure 1) (DFO 2017c). The Scotian Shelf is a 700 km portion of continental shelf offshore Nova Scotia, with its eastern boundaries being the Laurentian Channel and the Cabot Strait, and its western boundary being the Gulf of Maine (Beazley et al. 2017). The Scotian Shelf exhibits offshore banks, deep basins, troughs, channels, and has a 116 m average depth (Beazley et al. 2017). Temperature and salinity on the Scotian Shelf varies considerably due to heat transfer between the ocean and atmosphere, variation in bottom topography, inflow from the Gulf of St. Lawrence and Newfoundland Shelf, exchange with offshore slope waters, freshwater runoff, direct precipitation, local mixing, and melting sea ice during the spring (Beazley et al. 2017).

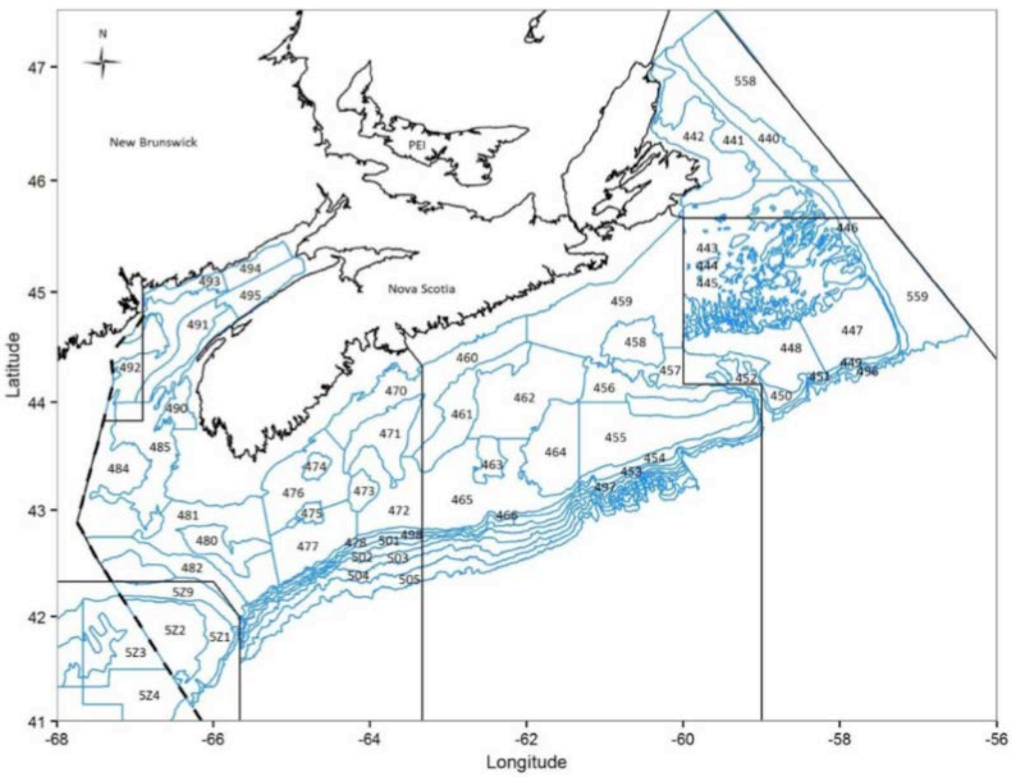

Figure 1 Project study area including the Eastern Scotian Shelf, the Western Scotian Shelf, and the Gulf of Maine/Bay of Fundy. Image from DFO 2017c.

3.3 Sampling Design and Rational

The trawl surveys followed DFO's standardized survey and sampling protocols (DFO 2017a). The CCGS *Alfred Needler*, CCGS *Teleost*, and CCGS *Wilfred Templeman* research vessels were equipped with a Western IIA bottom trawl for sample collections (Clark and Emberley 2011). Prior to each collection, DFO used a proportional random stratified technique to determine the location, known as a primary station, to trawl in each stratum, and the coordinates of the stations were recorded (DFO 2017b). In the case that a primary, random station could not be trawled due to fixed fishing gear for example, alternate or reserve-alternate stations were trawled instead, and the new coordinates were noted (DFO 2017a).

Once at the predetermined station, the vessel trawled the specified area for 30 minutes at 3.5 knots at depths ranging from 30-1,800 m (Clark and Emberley 2011; DFO 2017c). At successfully fished stations, hydrographic observations were collected, specifically profiles of temperature, conductivity, depth, oxygen concentration, irradiance, fluorescence, and salinity (Clark and Emberley 2011). These measurements were taken using a SBE-25 Conductivity, Temperature, and Depth (CTD) meter, an ORION 842 bench meter to measure oxygen concentration, a Turner-Designs fluorometer, and a Guildline 'Portasal' salinometer (Clark and Emberley 2011). While the environmental conditions were recorded, the soft coral samples collected from the trawl were separated from the rest of the catch, identified, when possible, and preserved onboard. The majority of the soft coral samples were frozen at sea later transferred to formalin, 70% ethanol, or 95% ethanol. The samples were then brought back to the Bedford Institute of Oceanography (BIO) for further analyses in the laboratory.

The laboratory analysis was done at BIO using the same laboratory protocol and procedure for sclerite preparation and sclerite mounting as Janes and Wah (2007). The isolation of sclerites from the various soft coral species was used to identify the specimens when visual identification, using Bayer (1981), Bayer et al. (1983), Sanmartín Payá (2004), Altuna and Murillo (2014), Altuna et al. (2014), Jensen (n.d), and consolation with Dr. Murillo for reference, was not possible or uncertain. When identification required the use of sclerites, sclerites were taken from different locations of a coral specimen. The sample locations depended on the genus of coral being sampled, but generally samples were taken from one or several of the following parts of the coral: polyp, tentacle, branch, trunk, base, or sac, see Figure 2. Sclerite samples were taken from different parts of a visually unidentifiable specimen because the sclerites differ in

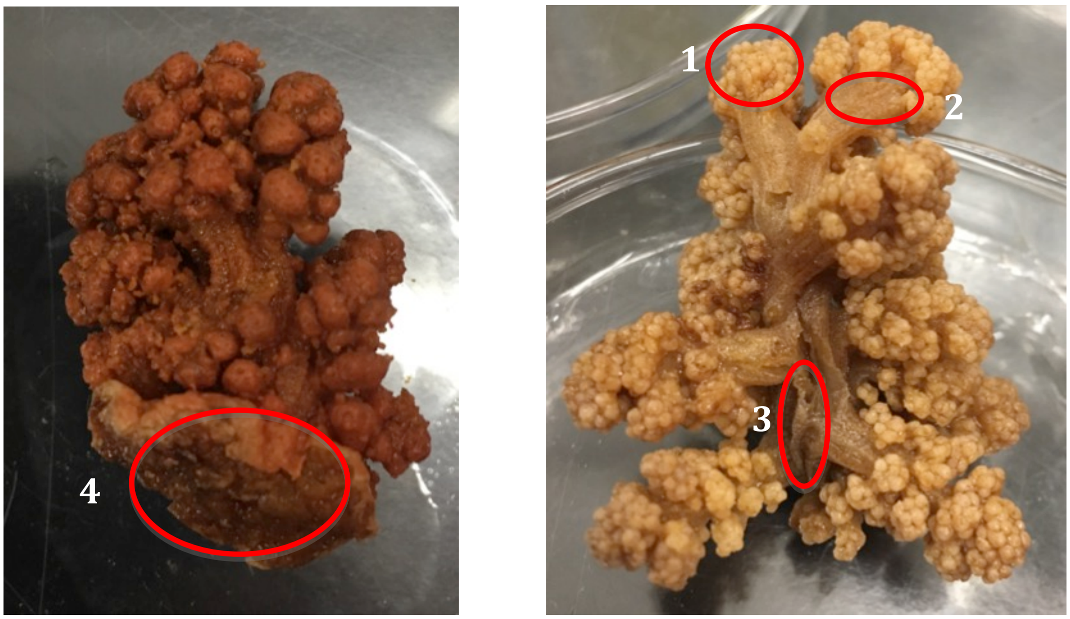

Figure 2 The circles display the different locations on the corals that sclerite samples were taken from. '1' indicates polyps and tentacles, '2' indicates a branch, '3' indicates the trunk, and '4' indicates the sac or stalk. The left image is a *Gersemia rubiformis* and the right image is a *Drfia glomerata* specimen. Photos by: Lauren Ballantyne.

size and shape depending on their location in the coral body (Altuna et al. 2014). The sclerites were examined using light microscopy, and images of species representative sclerites were taken using a manual Nikon microscope for future referral and comparison. In addition, the representative sclerites were made into permanent slides for future referral (Appendix B). Sclerite shapes and sizes were compared against those documented by Altuna and Murillo (2014), Altuna et al. (2014), and Jensen (n.d).

The results lead to the generation of a taxonomic guide specific to the soft corals of the Scotian Shelf, Scotian Slope and the Bay of Fundy, which includes written descriptions and visuals of each identified soft coral species, see section 3.4.

The survey trawl method of sampling has been carried out and/or used by Gass and Willison (2005), Wareham and Edinger (2007), Murillo et al. (2011) Altuna et al. (2014), DFO and others to determine the distribution of coral species in Atlantic Canada and adjacent waters. The use of stratified random sampling to collect soft coral specimens gives a representation of the soft coral species found within an area, their general abundance, and insight into their habitat. The advantages of this method over other methods, such as ROV and underwater cameras, is that trawl surveys can more efficiently cover large areas and specimen collection allows for more accurate identification (Cogswell et al. 2009). Visual assessment and sclerite sampling can be a time consuming method of identification, but it is the most assured method of identifying soft coral down to the species level (Wareham and Edinger 2007; Altuna et al 2014; Jensen n.d). However, trawling is destructive to benthic environments (Murillo et al. 2011; Ford and Serdynska 2013; Benneck and Metaxas 2017), so the use of less invasive methods, like ROVs, is better suited for sampling within protected areas.

3.4 Identification features by species

3.4.1 *Anthomastus grandiflorus*

Description:
Colonies were red and had a distinct transition between the stalk and capitulum. The autozooids, found on the capitulum, were large, ridged, and abundant (Altuna et al. 2014). Distinctive sclerites were found in the tentacles and these sclerites had rounded/ovular ends and a narrow middle, see figure 3b (Altuna et al. 2014).

Colony and sclerites:

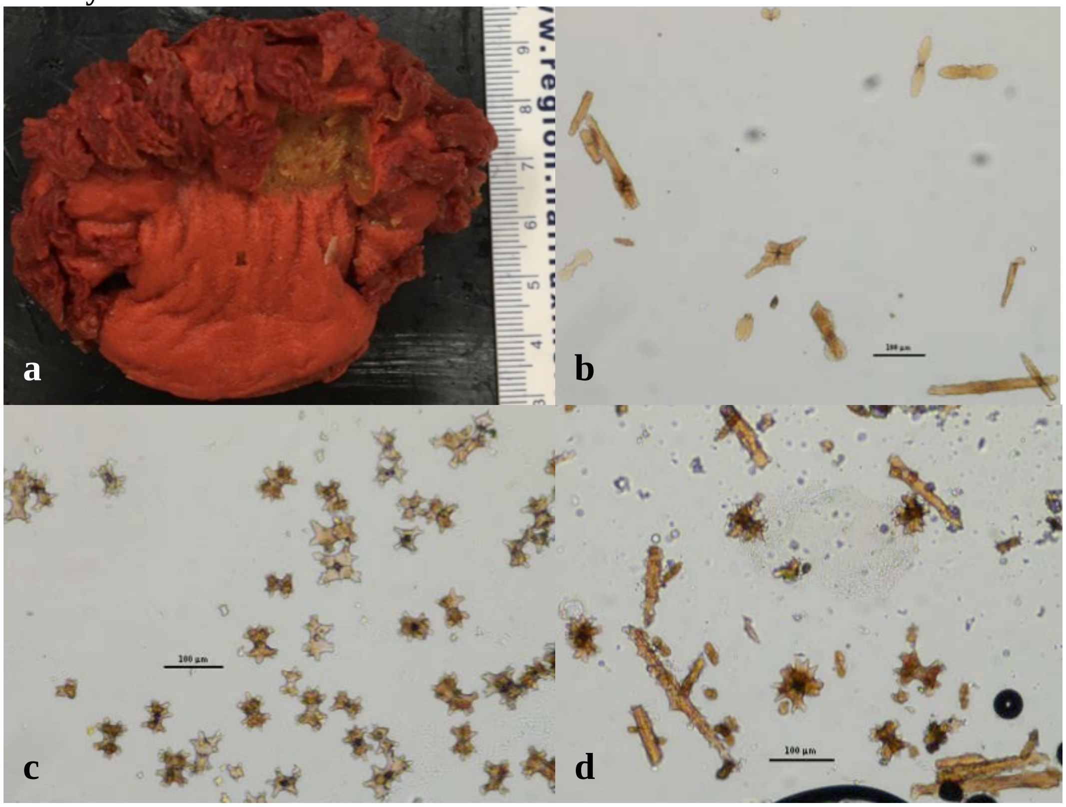

Figure 3 *Anthomastus grandiflorus*. a) Side view of colony (scale in cm), b) sclerites sampled from entire autozooid, c) sclerites sampled from the stalk, and d) sclerites sampled from the capitulum (surface and undersurface). Photos by: Lauren Ballantyne.

3.4.2 *Drifa glomerata*

Description:
Small, non-retractile polyps in crowded clusters found along and at the end of the numerous, small branches. The polyps contained robust clubs (dominant) and spindles and rods, which were predominantly found at the base of polyps (Jensen n.d). Sclerites were uniformly distributed throughout the polyp, but the uniform distribution of the polyp sclerites did not create visible ridges along the polyps. The trunk tissue felt rough, and it contained symmetrically whorled radiates (Jensen n.d). Typically, the preserved tissue colour was white, tan, or occasionally brown.

Colony and sclerites:

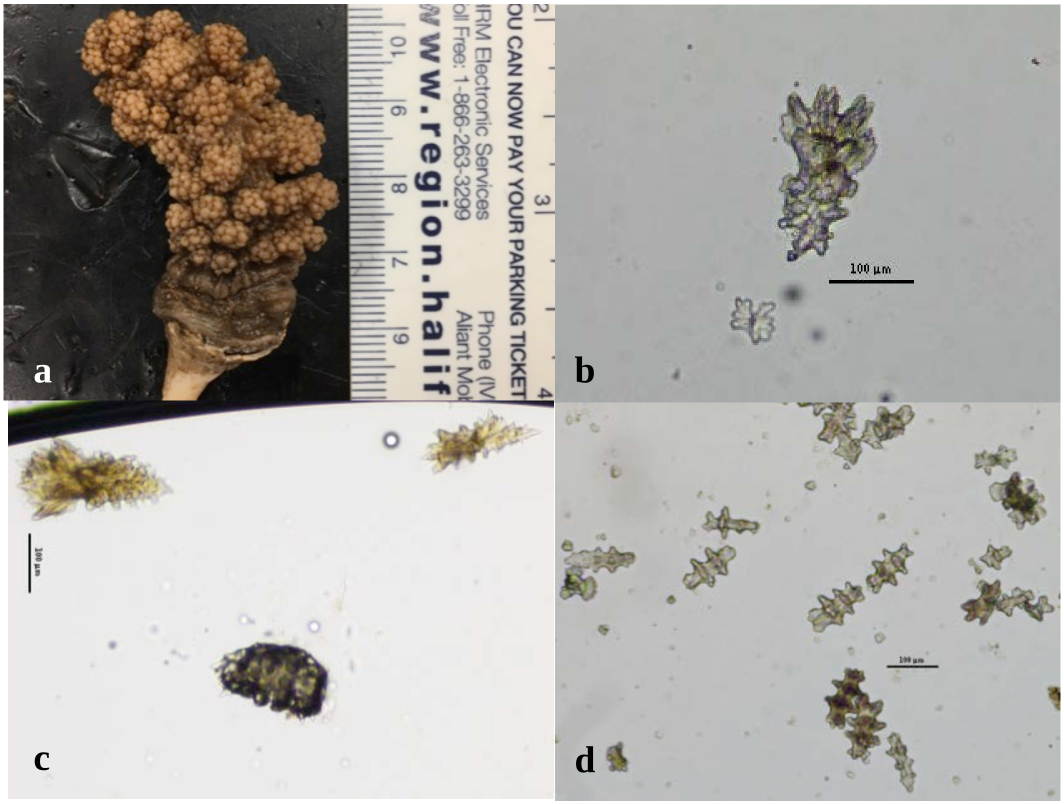

Figure 4 *Drifa glomerata*. a) Side view of colony (scale in cm), b) sclerite (club) sampled from an entire polyp, c) sclerites (clubs) sampled from an entire polyp, and d) sclerites (radiates) sampled from the trunk (surface and undersurface). Photos by: Lauren Ballantyne.

3.4.3 *Drifa* sp.2

Description:

Large, non-retractile, long, and ridged polyps that occurred in loose clusters along the branches. Polyps contained slender clubs (dominant) with clear foliated tops and spindles (Jensen n.d). Trunk contained both radiates and short clubs. The preserved colonies were tan in colour. The colonies sclerites were similar to those of *Drifa flavescens* (Sanmartín Payá 2004), but the small size of the polyps give reason that further examination of this colony is required in order to assign it to a species.

Colony and sclerites:

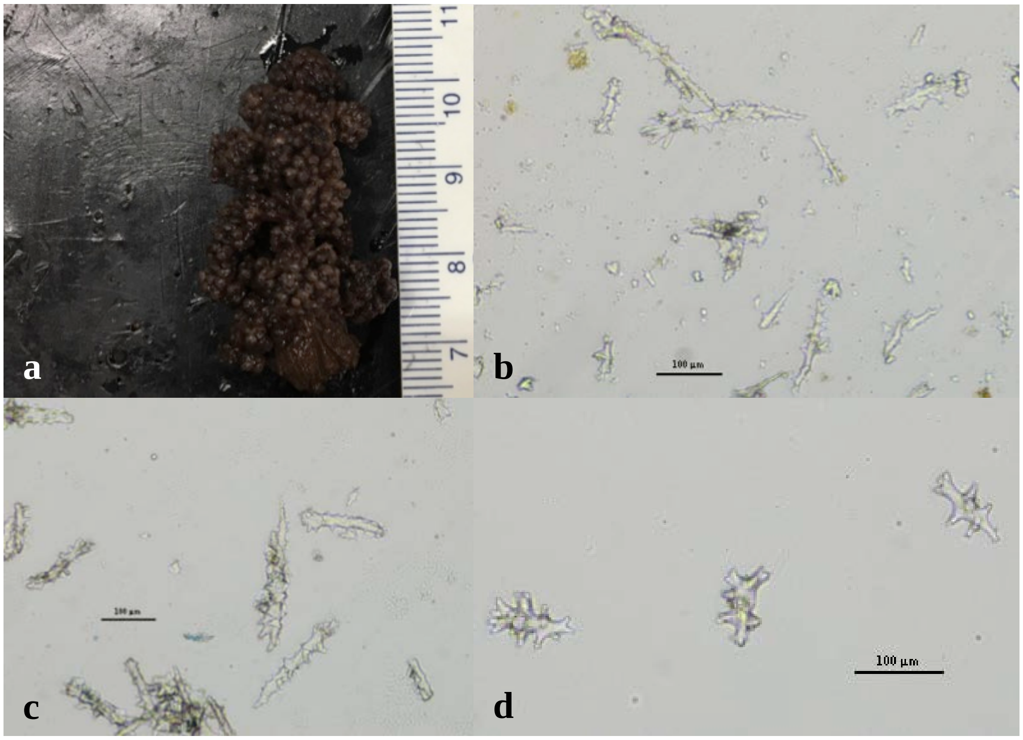

Figure 5 *Drifa* sp.2. a) Side view of colony (scale in cm), b, c) sclerites (clubs and spindles) sampled from an entire polyp, and d) sclerites (clubs and radiates) sampled from the trunk (surface and undersurface). Photos by: Lauren Ballantyne.

3.4.4 *Duva florida*

Description:

Tree-like colonies. The large branches broke into smaller, thinner branches, which further broke into even small branches and these small branchlets bore the polyps at their tips (Altuna and Murillo 2014). The polyps were cylindrical in shape and appeared in clusters of three to seven, and the polyps were connected at the base (Jensen n.d). Polyps contained blunt and pointed rods, and the trunks contained short clubs and radiates with few, but large whorls. Preserved tissue colour ranges from white to black, but the majority of analyzed specimens were black and brown.

Colony and sclerites:

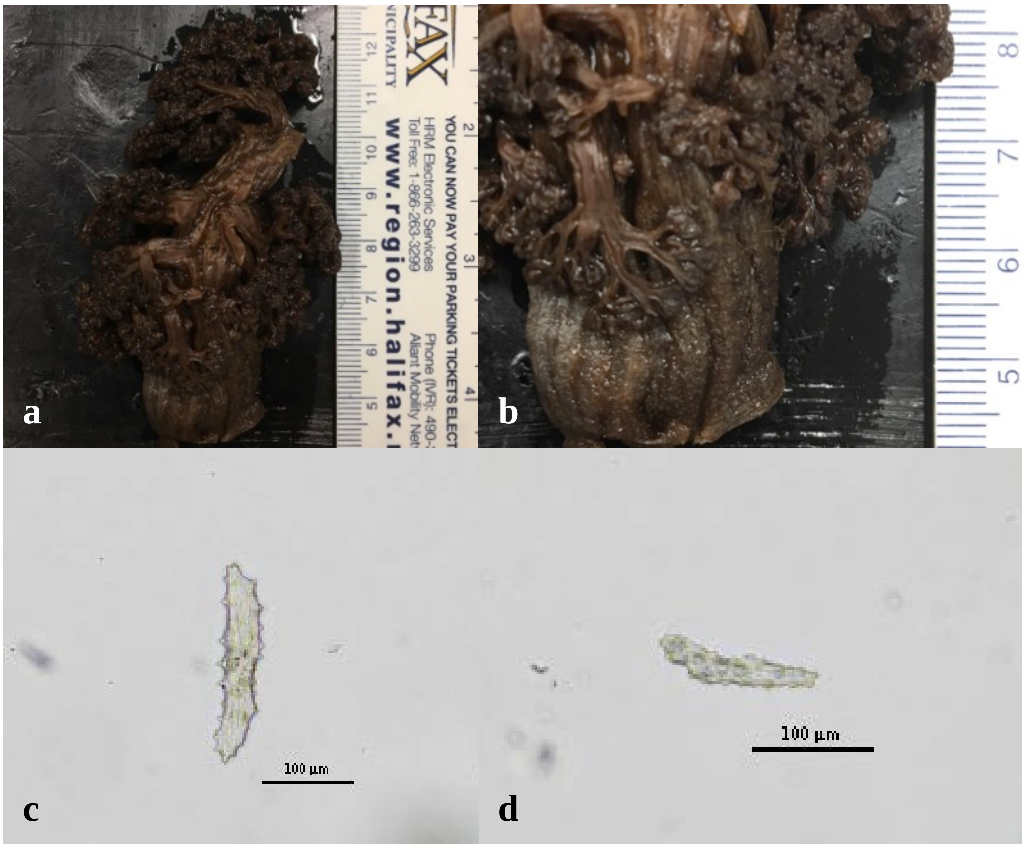

Figure 6 *Duva florida*. a) Side view of colony (scale in cm), b) side view of colony with a close up on the polyp clusters (scale in cm), and c, d) sclerites (rods) sampled from an entire polyp. Photos by: Lauren Ballantyne.

3.4.5 *Gersemia fruticosa*

Description:

Long polyps are present along and at the end of branches, and a few of the polyps are retractile. The polyps appeared ridged to the naked eye, and this ridging was due to the arrangement of the polyp sclerites, which are spindles and rods (Jensen n.d). The majority of the specimens had wrinkled trunks, and the trunks contained an abundance of radiates while the branches contained capstans (Sanmartín Payá 2004; Altuna and Murillo 2014; Jensen n.d). The sacs were thin, and many of the specimens used the sac to engulf small rocks and sediment. The majority of colonies were tan in colour.

Colony and sclerites:

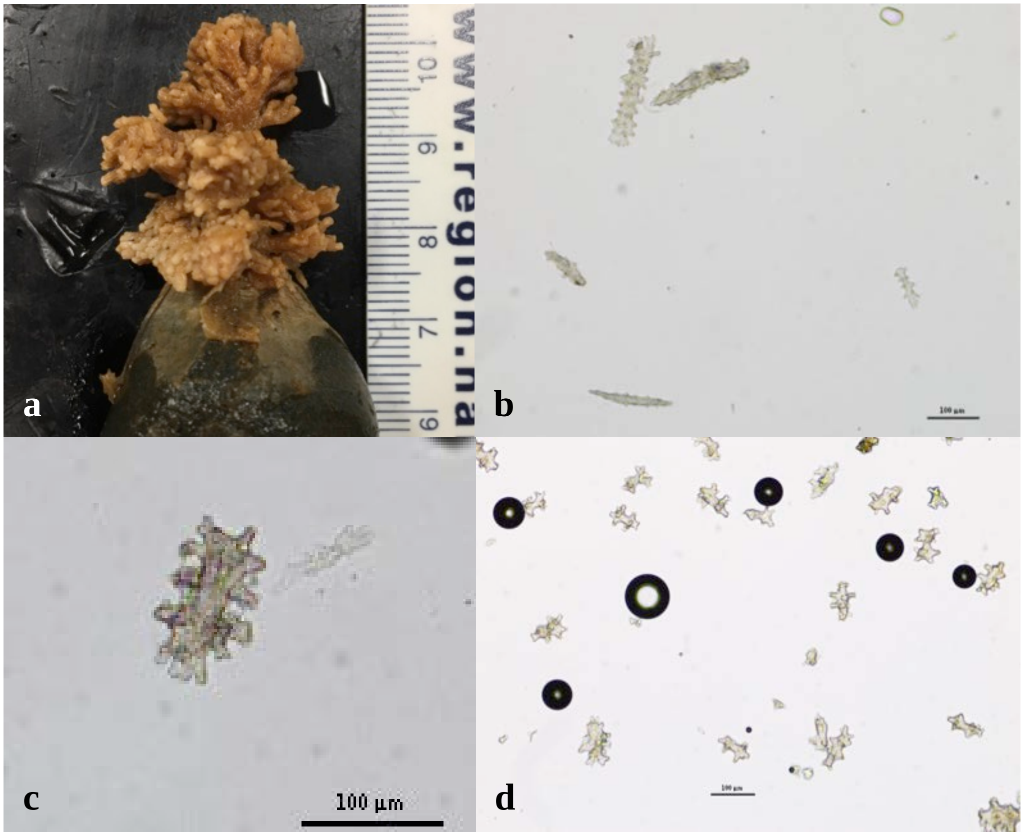

Figure 7 *Gersemia fruticosa*. a) Side view of colony (scale in cm), b) sclerite (spindles and rods) sampled from an entire polyp, c) sclerite (capstan) sampled from branch, and d) sclerites (radiates) sampled from the sac. Photos by: Lauren Ballantyne.

3.4.6 *Gersemia rubiformis*

Description:

Colonies had small, retractile polyps located on bulbous capitulums located at the end of the branches. The polyps contained spindles (dominant) and rods, the trunk was made up of radiates, which were highly abundant, and the branches contained both capstans and spindles (Sanmartín Payá 2004; Altuna and Murillo 2014). Colonies had discoidal sacs, and the colonies appeared in a variety of colours, including: yellow, pink, red, and brown (Sanmartín Payá 2004; Altuna and Murillo 2014).

Colony and sclerites:

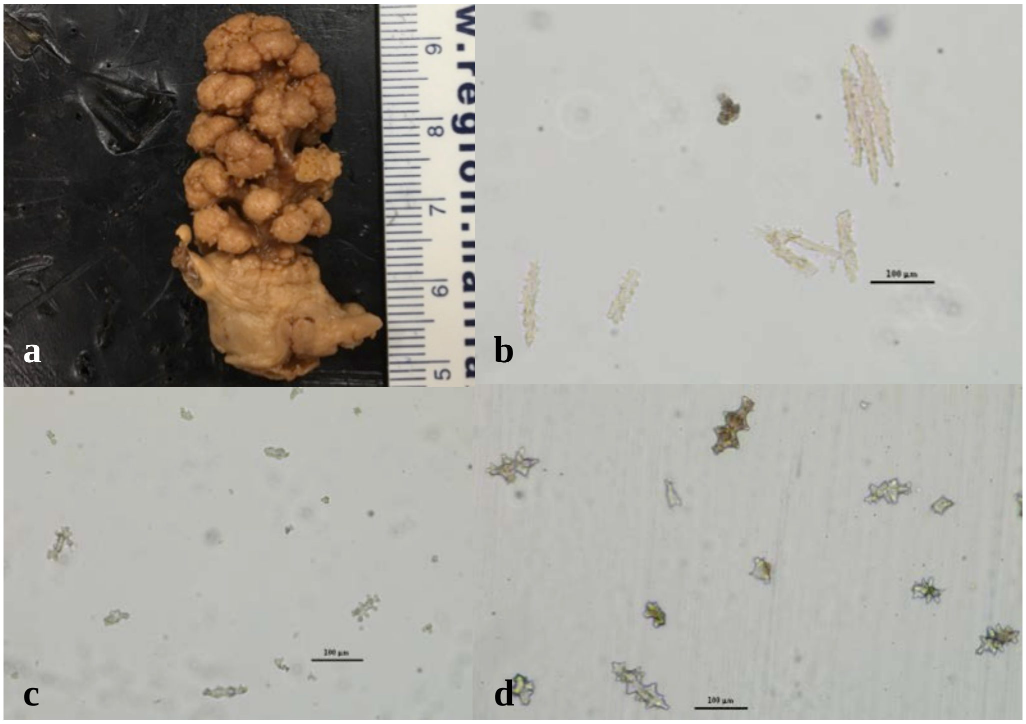

Figure 8 *Gersemia rubiformis*. a) Side view of colony (scale in cm), b) sclerites (spindles and rods) sampled from an entire polyp, c) sclerites (capstans and spindles) sampled from a branch, and d) sclerites (radiates) sampled from the sac. Photos by: Lauren Ballantyne.

3.4.7 *Heteropolypus sol*

Description:

Stalk was cone-shaped and had distinctive rootlets at its base, which the coral uses to anchor into sediment (Altuna et al. 2014). The majority of the autozooids were found on the periphery of the capitulum, and the capitulum appeared granular due to the numerous siphonozooids (Altuna et al. 2014). In addition, the autozooids were large, long, and ridged, and the capitulums was irregularly shaped rather than circular (Altuna et al. 2014). Stalks were pale red and the capitulum and polyps were darker red.

Colony and sclerites:

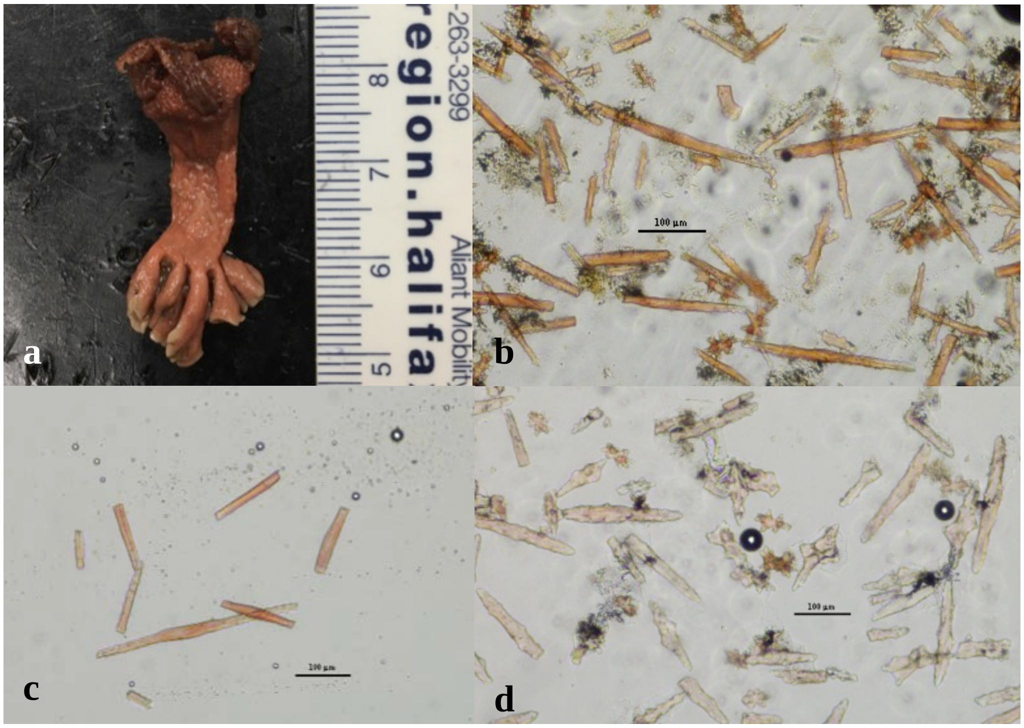

Figure 9 *Heteropolypus sol*. a) Side view of colony (scale in cm), b) sclerites (needles and clubs) sampled from an entire anthocodiae, c) sclerites (needles) sampled from the capitulum (surface and undersurface), and d) sclerites (spindles and clubs) sampled from the stalk. Photos by: Lauren Ballantyne.

3.4.8 *Pseudoanthomastus agaricus*

Description:

Clear distinction between the stalk and capitulum, and the stalks were either white or pink while the capitulums were red (Altuna et al. 2014). Also, the autozooids were large, long, and ridged.

Colony and sclerites:

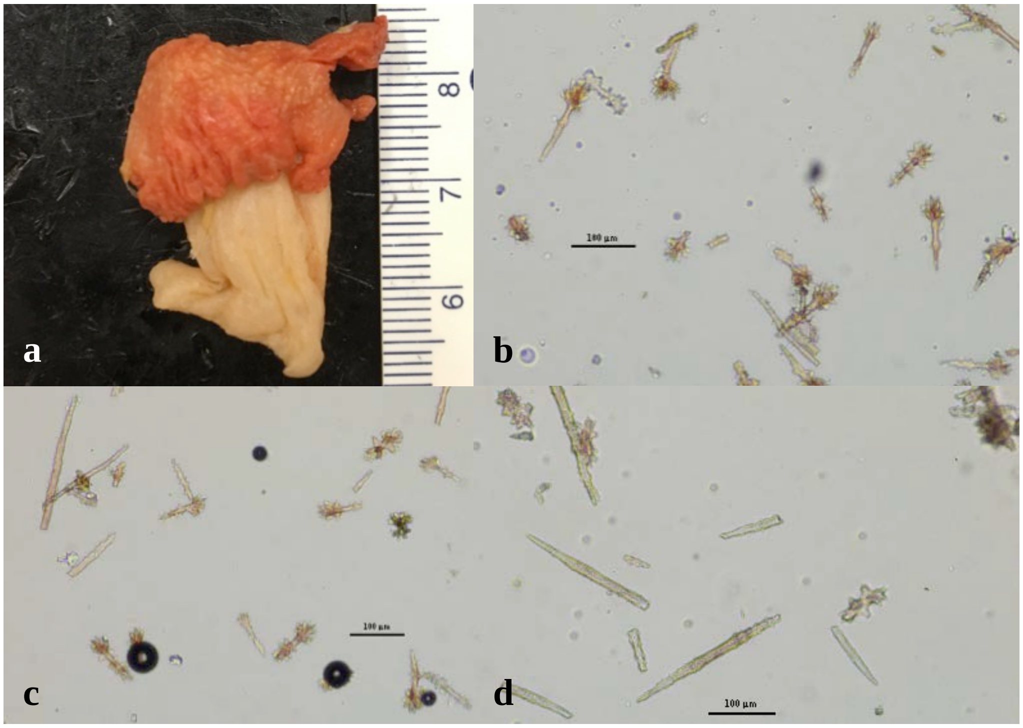

Figure 10 *Pseudoanthomastus agaricus*. a) Side view of colony (scale in cm), b, c) sclerites sampled from an entire anthocodiae, and d) sclerites (needles and radiates) sampled from the stalk. Photos by: Lauren Ballantyne.

3.5 Analysis

The goal of this project was to map and document the distribution, abundance, and habitat preferences of soft corals on the Scotian Shelf, Scotian Slope, and in the Bay of Fundy. Firstly, soft coral distribution maps, by family and by species, were generated by inputting the start coordinates associated with each specimen into ArcMap 10.5 to display the locations across the study area, similar to Gass and Willison (2005) and Cogswell et al. (2009). Secondly, species-specific proportional abundance maps based on soft coral colony counts, per station, were generated using ArcMap 10.5. The counts were determined by counting the number of individuals of each species in the sample collection. In the case that a sample jar contains more than one coral colony an individual was defined as a specimen that had a clear sac or stalk. Finally, maps and boxplots displaying the depth range and the average minimum and the average maximum temperatures and salinities, of each species, were generated to display the habitat preferences of soft corals found offshore Nova Scotia. The depth ranges were based off of the minimum and maximum depths measured in each successfully trawled station using the SBE-25 CTD meter. The average minimum and the average maximum temperatures and salinities were based off of spatial interpolations, the values of which were extracted from the Global Ocean Reanalyses and Simulations, generated by Beazley et al. (2017) using ordinary kriging. Beazley et al. (2017) archived the interpolations into a common (raster) format, and these raster layers were uploaded into ArcMap 10.5 to generate temperature and salinity distribution maps (Figures 18, 20, 22, and 24). Additionally, the temperature and salinity values displayed in the temperature and salinity boxplots were extracted from the raster layers using the spatial analyst tool ‘extract values to points’ in ArcMap 10.5 (Figures 19, 21, 23, and 25).

3.6 Limitations and Delimitations

This study, as with all other studies, has associated limitations and delimitations. Limits of this study include: time, misidentification, and trawling as the sample method. Time was a limitation for this study in terms of time available for data analysis. With more time, this study could have broadened its analysis to include things such as preferred substrate type of soft corals. Preferred substrate type could be determined by comparing species locations with substrate type maps of offshore Nova Scotia as well as noting the substrate, if any, a specimen came up from the trawl still attached to. However, with the time provided for data analysis, the study addressed the most urgent knowledge gaps, which are soft coral distribution, abundance, and habitat preferences on the Scotian Shelf and Slope, and in the Bay of Fundy.

In addition to time, misidentification of samples was a possible limitation to the study, as identification keys and general taxonomic information on soft corals are limited (Altuna et al. 2014). However, the supervision of taxonomist, Dr. Murillo, reduced the possibility of misidentifications. Thirdly, the field sampling method was limited because there were no dedicated scientists on board the early trawls, 2001-2011, to sort through the catch. Without a dedicated scientists on board there was potential that coral samples were mistaken for another organism and discarded, resulting in an underestimate of soft coral distribution and abundance. However, this was not the case during the 2017 cruises as Dr. Murillo was on board sorting the trawl contents and preserving the coral specimens. Finally, the start coordinates used to map the distribution and abundance of each species was limited because each station was trawled for ~3 kilometers. The start coordinate for the station that a specimen was collected in was used for mapping, since it most accurately depicts the location of the station. The use of the start coordinates for the location of the collected specimens means that the exact location of the soft corals is unknown. However, the start coordinate combined with the end coordinate and the trawl path taken for each station provides an important, although general, picture of where soft corals are located offshore Nova Scotia.

The main delimitation of this study was that the study area is confined to offshore Nova Scotia. However, the broadening of the spatial study area is beyond the scope of this project, and the analysis of multiple environments, such as the Pacific and the Atlantic, would be difficult given the variations between the areas.

4.0 Results

4.1 Species allocation

DFO conducted numerous cruises throughout 2001-2011 and in 2017, and 18 of those cruises were analyzed in this study. These trawls covered the Scotian Shelf, Scotian Slope, and Bay of Fundy. In total eight species, *Gersemia rubiformis*, *Gersemia fruticosa, Drifa glomerata, Drifa* sp.2*, Duva florida, Anthomastus grandiflorus, Pseudoanthomastus agaricus, and Heteropolypu sol*, from two families, Nephtheidae and Alcyoniidae, were identified from the collected samples (Table 2). All together 1355 individual colonies were identified to the species level, only 904 of those individuals had associated coordinates and environmental data for mapping and analysis. These 904 individuals are outlined in Table 2. The NED2017020 cruise had the highest species richness with six species, *G. rubiformis, G. fruticosa, D. glomerata*, *Drifa* sp.2*, D. florida*, *H. sol*, collected and the highest number of individuals, 453, while the TEL2004530 cruise had the lowest species richness with only one species, *D. florida*, collected and the lowest number of individuals, two. Further examination of the

Table 2 List of the species identified, the total number of individuals sampled, and the availability status of absence data for each cruise.

Cruise Number	Species	Total Count	Absence Data Available
NED2001004	*G. rubiformis*, *D. glomerata*, D. florida, *A. grandiflorus*	10	No
NED2002040	*G. rubiformis*, *D. glomerata*	23	No
NED2003003	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *D. florida*	18	No
NED2003042	*G. rubiformis*, *D. glomerata*, *D. florida*, *A. grandiflorus*	30	Yes
TEL2004530	*D. florida*	2	No
NED2005034	*G. rubiformis*, *D. glomerata*,	3	No
TEL2005633	*G. rubiformis, G. fruticosa*, *Drifa glomerata*, *D. florida*	83	Yes
NED2006002	*G. rubiformis*, *G. fruticosa*, *D. glomerata*	17	Yes

NED2006036	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *A. grandiflorus*, *P. agaricus*	13	Yes
TEL2006615	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *D. florida*	54	Yes
TEL2007745	*G. rubiformis*, *D. glomerata*,	50	Yes
TEM2007686	*G. rubiformis*, *G. fruticosa*, *D. florida*	28	Yes
TEL2008805	*G. rubiformis*, *G. fruticosa*, *D. glomerata*	34	Yes
TEM2008830	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *D. florida*	44	Yes
NED2009027	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *D. florida*	19	Yes
NED2010002	*G. rubiformis*, *G. fruticosa*	3	Yes
NED2011025	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *D. florida*	20	Yes
NED2017020	*G. rubiformis*, *G. fruticosa*, *D. glomerata*, *Drifa* sp.2, *D. florida*, *H. sol*	453	No

*Cruise number includes vessel name (NED, TEL, and TEM), cruise year (2001-2011 and 2017), and voyage number, for example ‘004’. ‘NED’ represents the CCGS *Alfred Needler*, ‘TEL’ represents the CCGS *Teleost*, and ‘TEM’ represents the CCGS *Wilfred Templeman*.

individual colony numbers shows that the majority (%) of the identified colonies belong to the Nephtheidae family (Figures 11-13). Specifically, 62% of the identified colonies, those with associated coordinates and environmental data, are *G. rubiformis* (Figures 11-13). In comparison, the least abundant species include: *Drifa* sp.2 and *P. agaricus* with only one and two individual colonies identified, respectfully (Figure 11-13).

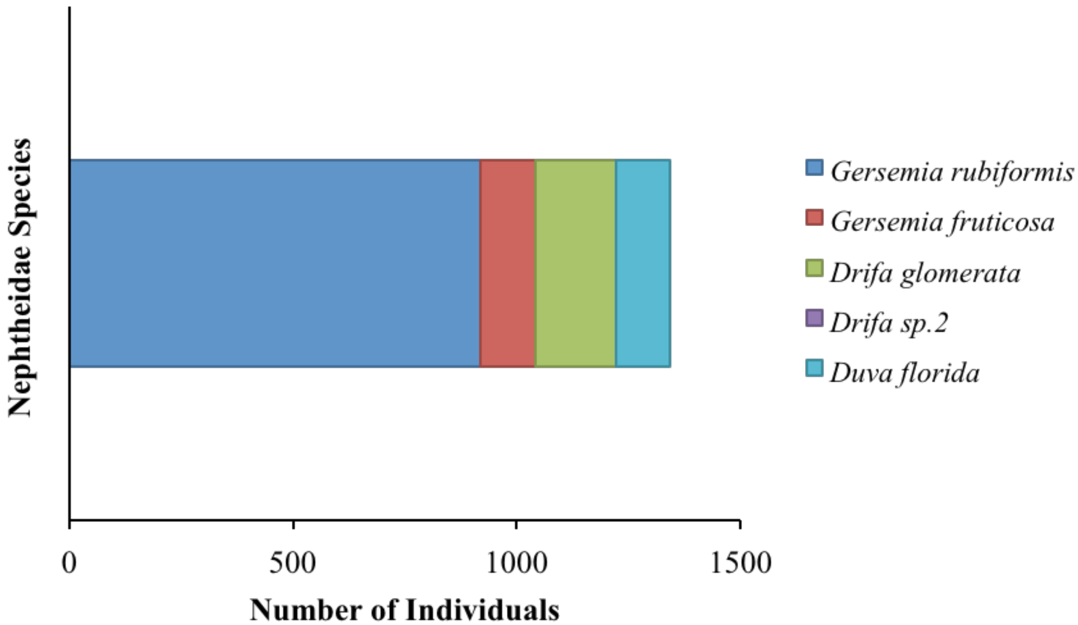

Figure 11 Number of individual colonies of each species identified within the Family, Nephtheidae. Includes individuals that did and did not have associated coordinates and environmental data are plotted.

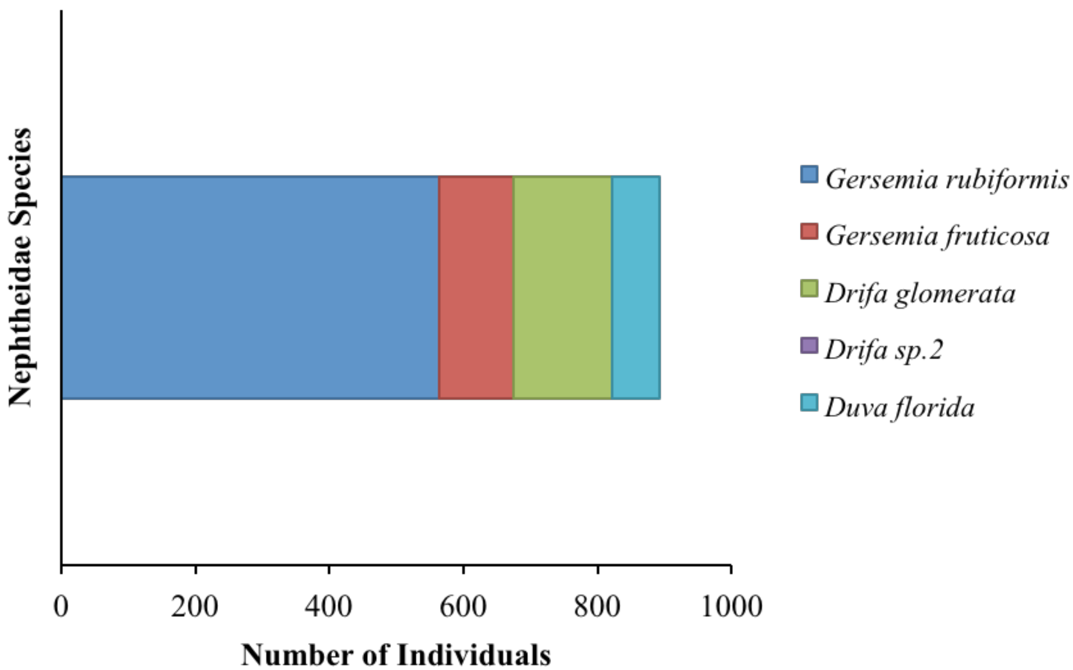

Figure 12 Number of individual colonies of each species identified within the Family, Nephtheidae. Only colonies that had associated coordinates and environmental data are plotted.

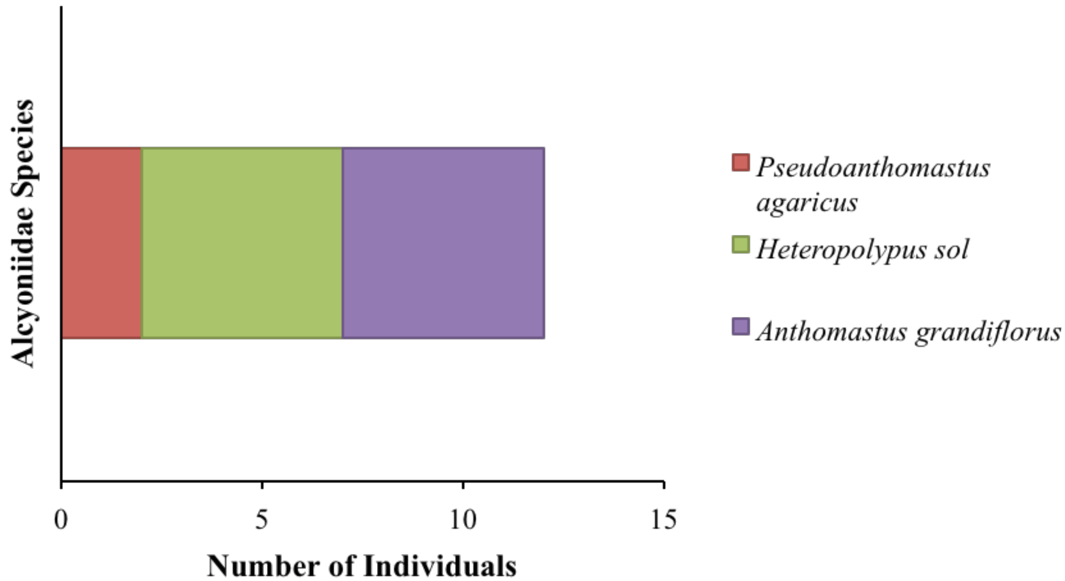

Figure 13 Number of individuals of each species identified within the Family, Alcyoniidae. Only colonies that had associated coordinates and environmental data are plotted.

4.2 Spatial distribution of soft corals

4.2.1 Distribution by family

The family based distribution map of the identified coral colonies shows a difference in the distribution between the two families, Nephtheidae and Alcyoniidae (Figure 14). Specifically, the majority of the Nephtheidae species are located on the Scotian Shelf while the majority of the Alcyoniidae species are found in deeper waters along the Scotian Shelf edge (Figure 14). However, there are some similarities between the two families, mainly that there is a strong affiliation, of all species, to the northeastern portion of the Scotian Shelf and Scotian Shelf edge (Figures 14 & 15). Although, there are patches of corals on the middle section of the Scotian Shelf and shelf edge, and on the southwestern portion of the Scotian Shelf, on Browns Bank (Figure 15).

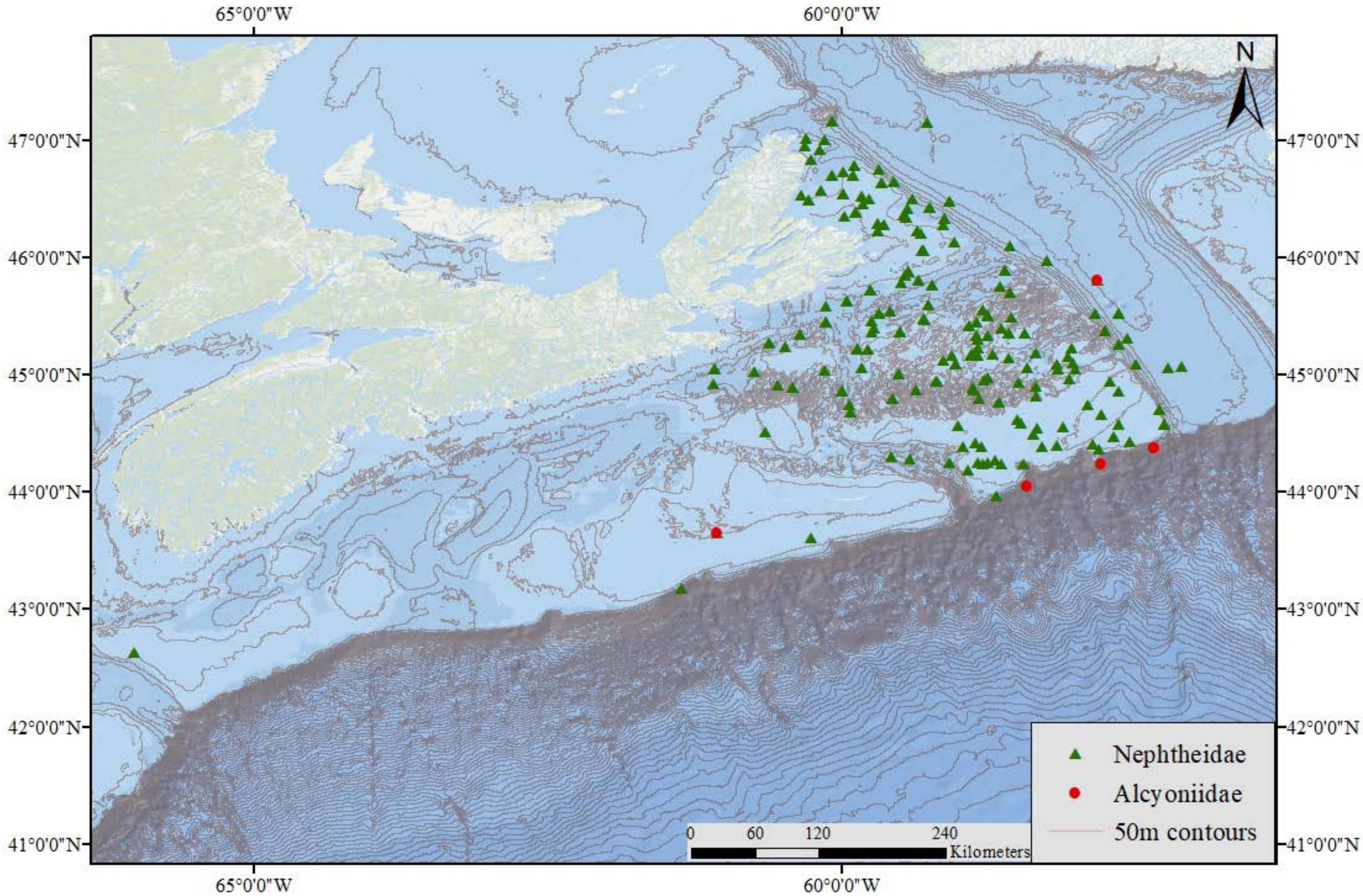

Figure 14 Distribution map showing the distribution of the two soft coral families, Nephtheidae and Alcyoniidae, collected during 2001-2011 and in 2017 during DFO's trawl surveys.

4.2.2 Distribution by species

As stated earlier, *G. rubiformis* was the most abundant species collected during the 2001-2011 and 2017 trawl surveys. In addition to its high abundance, *G. rubiformis* displays the widest distribution across the Scotian Shelf (Figure 15). The majority of *G. rubiformis* colonies were found on the northeastern portion of the Scotian Shelf and shelf edge, but colonies also appear sporadically on the eastern side of the Sable Island Bank and on the western side of Browns Bank (Figure 15; Figure 16.1a). Other notable species-specific distribution patterns include the presence of *G. fruticosa*, *D. florida*, and *H. sol* in the

Laurentian Channel while the other species only colonize the Scotian Shelf and Scotian Shelf edge (Figure 16.1b; Figure 16.2a & c). The presence of *G. fruticosa*, *D. florida*, and

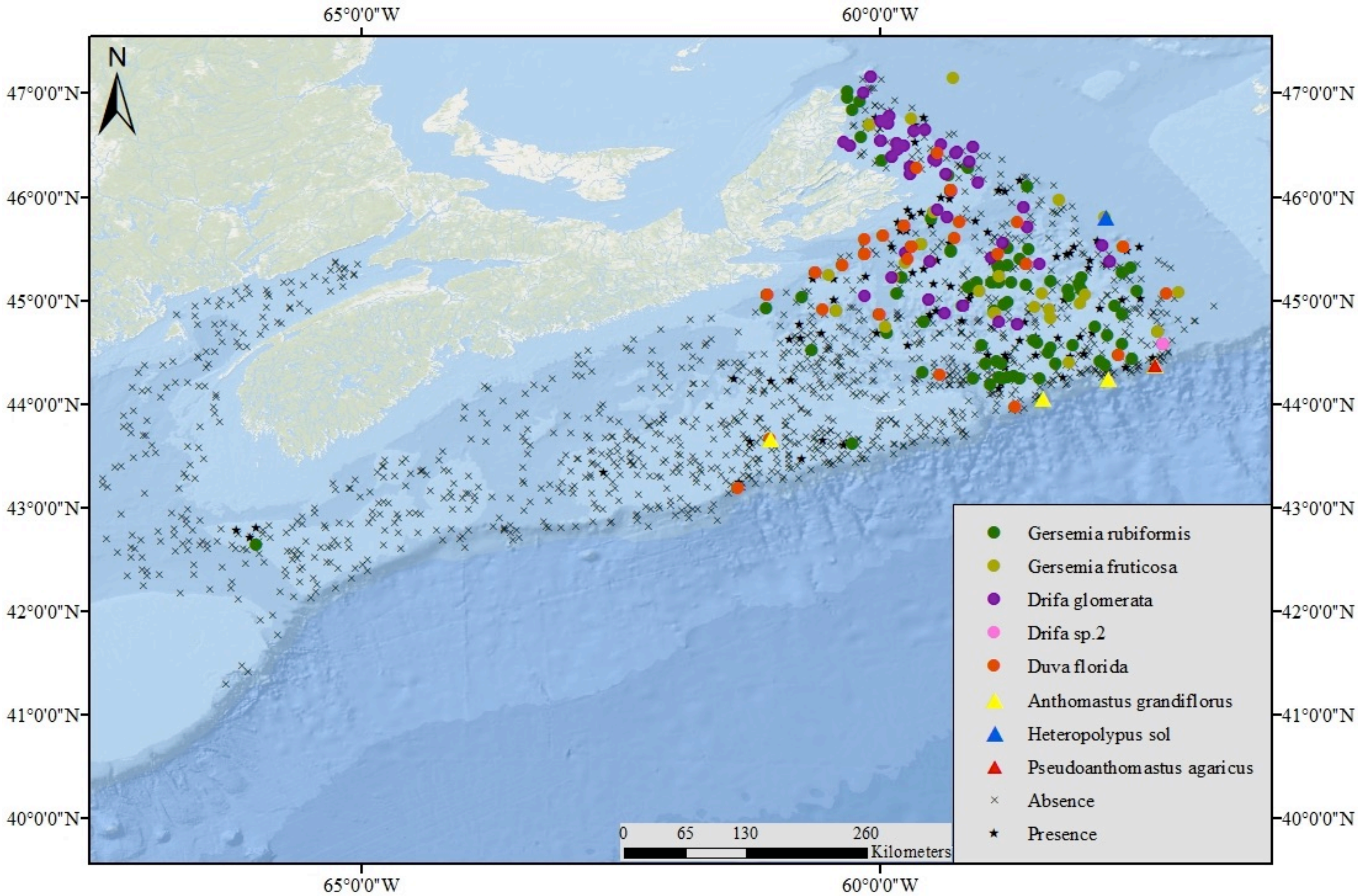

Figure 15 Multispecies distribution map displaying the species caught during 2001 – 2011 and in 2017. 'Presence' represents a station that soft corals were found but no samples were available for identification, and 'absence' represents stations that were trawled but no soft corals were found.

H. sol in the Laurentian Channel is notable as this areas environmental conditions, temperature, salinity, and depth, vary from those on the Scotian Shelf, see Figures 18, 20, 22, and 24. The variation of temperature, salinity, and depth exhibited across the Scotian Shelf, Scotian Slope, and Bay of Fundy may explain the strong affiliation of all eight soft coral species to the northeastern portion of the Scotian Shelf and Scotian Shelf edge, which experiences more stable environmental conditions (Figures 18-24).

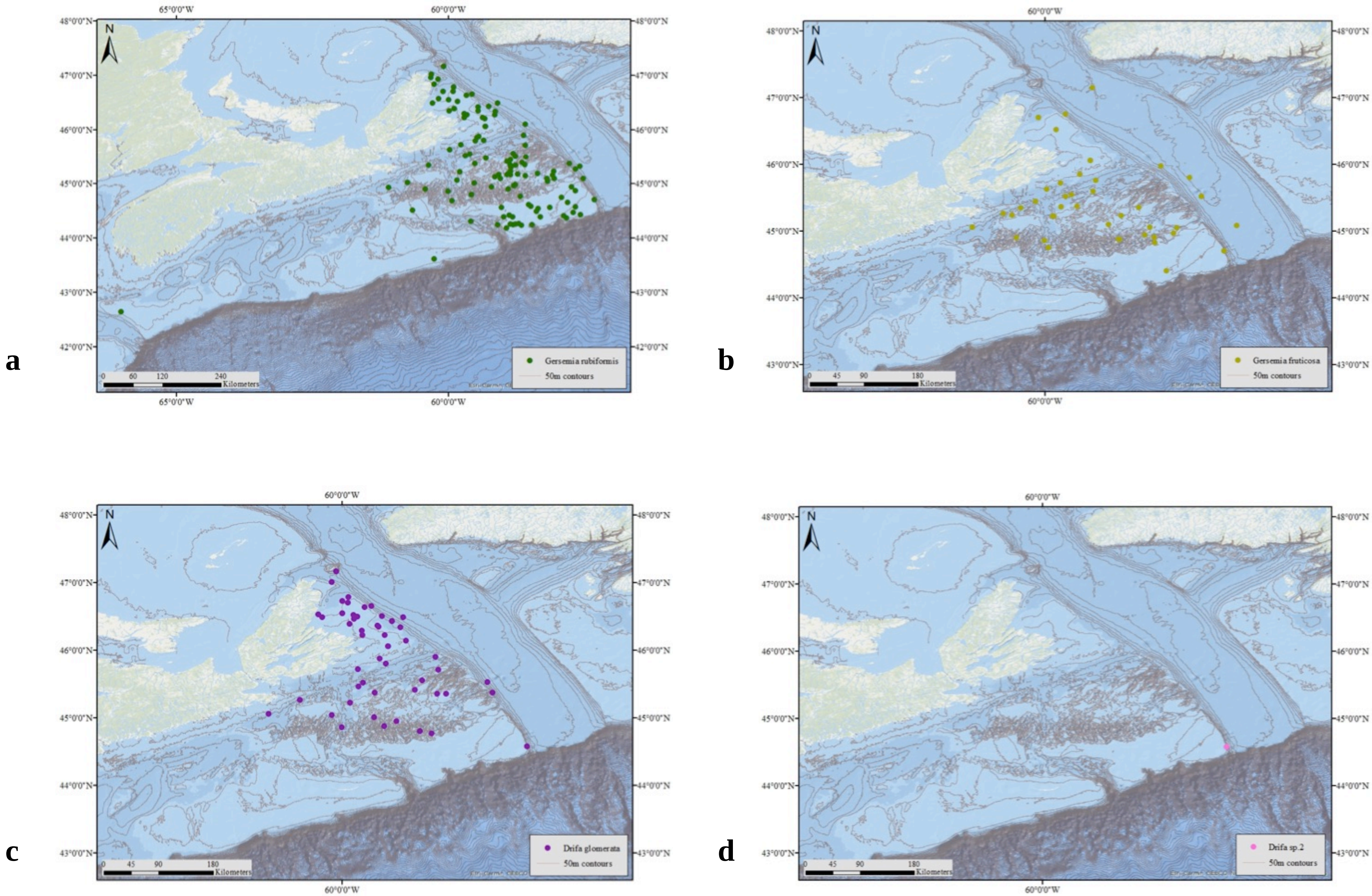

Figure 16.1 Individual distribution maps of *Gersemia rubiformis* (a), *Gersemia fruticosa* (b), *Drifa glomerata* (c), and *Drifa* sp.2 (d) based on collected and identified colonies from the 2001-2011 and 2017 DFO trawl surveys.

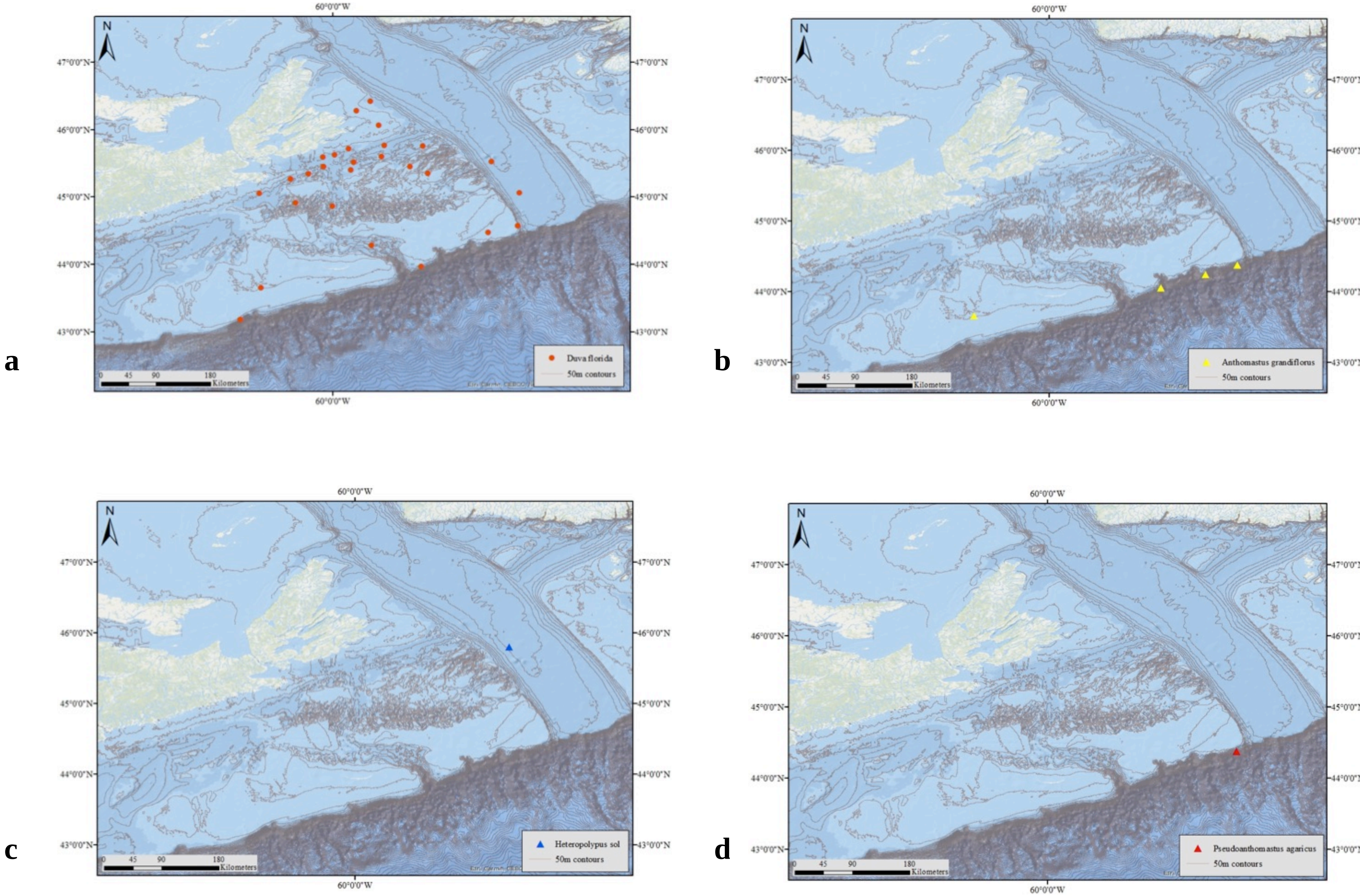

Figure 16.2 Individual distribution maps of *Duva florida* (a), *Anthomastus grandiflorus* (b), *Heteropolypus sol* (c), and *Pseudoanthomastus agaricus* based on collected and identified colonies from the 2001-2011 and 2017 DFO trawl surveys.

4.3 Abundance of soft corals

The proportional abundance maps for this study are based on the 2017, NED2017020, samples and data, as this was the only cruise of the examined cruises that had a dedicated invertebrate taxonomist on board. The taxonomist ensured that all collected colonies were noted and counted, and any discarded colonies were noted.

Soft corals appear to colonize particular areas of the Scotian Shelf more than others. The highest abundance, based on colony counts, was found off northern Cape Breton on and around Sydney Bight (Figure 17). The Sydney Bight area houses four of the eight identified species, with *G. rubiformis*, the most abundant, *G. fruticosa*, *D. glomerata*, and a few records of *D. florida*. In addition to the Sydney Bight area, there are congregations of soft corals between St Anns Bank and Misaine Bank as well as between Canso Bank and French Bank (Figure 17). The area between St Anns Bank and Misaine Bank contains *G. rubiformis*, *G. fruticosa*, and *D. glomerata* while the area between Canso Bank and French Bank contains congregations of *D. florida*, the most abundant, *D. glomerata*, and *G. fruticosa* (Figure 17). Furthermore, only one Alcyoniidae species, *H. sol*, was found in 2017 and all three of the *H. sol* colonies were found in one station in the Laurentian Channel.

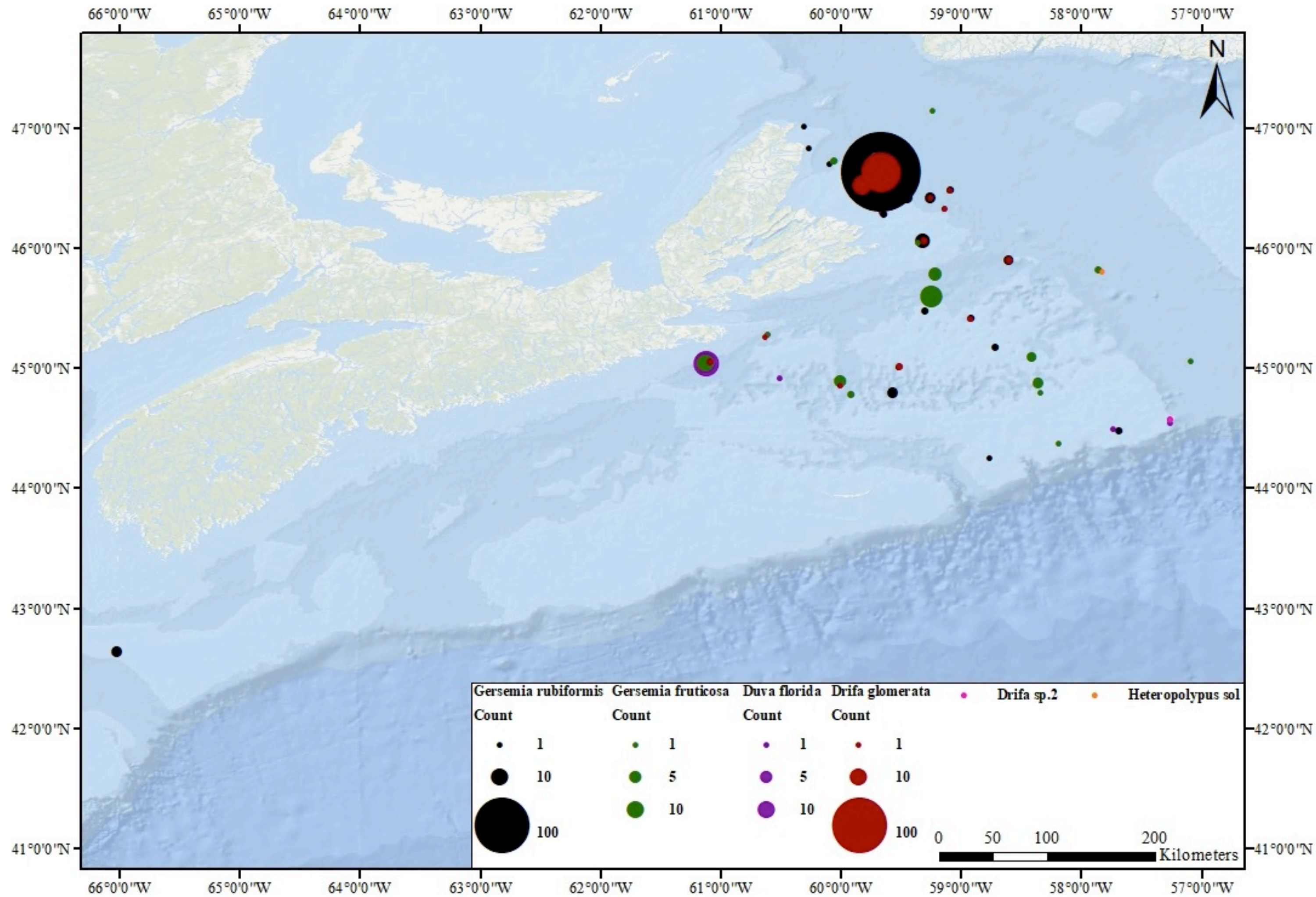

Figure 17 Proportional abundance of the soft coral based on colony counts. Map displays colony counts from the NED2017020 cruise.

4.4 Environmental conditions

4.4.1 Temperature and salinity

The interpolated average minimum and average maximum bottom temperature maps show that the northeastern portion of the Scotian Shelf is colder than the southwestern portion of the Scotian Shelf (Figure 18; Figure 20). The northeastern Scotian Shelf has a general temperature range of 1.8–4.3°C while the southwestern Scotian Shelf has a general temperature range of 5.8–10.4°C (Figure 18; Figure 20). In addition to a difference in bottom temperatures between the northeastern and southwestern portions of the Scotian Shelf, there is also a different in salinity (Figure 22; Figure 24). The northeastern Scotian Shelf exhibits lower salinity levels, 25.7-33‰, while the southwestern Scotian Shelf exhibits higher salinity levels, 29-35‰ (Figure 22; Figure 24). The majority of sampled colonies are found on the northeastern portion of the Scotian Shelf and shelf edge, suggesting that soft corals may have a preference for cold water and low salinity (Figure 15; Figures 18-24). Although all species appear most prevalently in the cooler and lower salinity areas of the Scotian Shelf, the Alcyoniidae species are located in areas with warmer waters and higher salinities compared to the Nephtheidae species. It is important to note that these ranges include averaged values from all seasons, thus temperatures and salinities within the study area may exceed or fall below the ranges given above.

4.4.1 Depth

Of all eight species, *A. grandiflorus* displayed the greatest depth range with a minimum observed depth of 46m and a maximum observed depth of 604m, and had an average range of 332-445m (Figures 26 & 27; Appendix E). In addition, the collected environmental data displays a difference in the depth that Nephtheidae species and Alcyoniidae species are found. The Nephtheidae species were found in shallower waters, 50-200m, than the Alcyoniidae species, 125-603m (Figures 26 & 27; Appendix E). However, the difference in depth between the two families could be regarded with some caution due to the small sample size of the Alcyoniidae species.

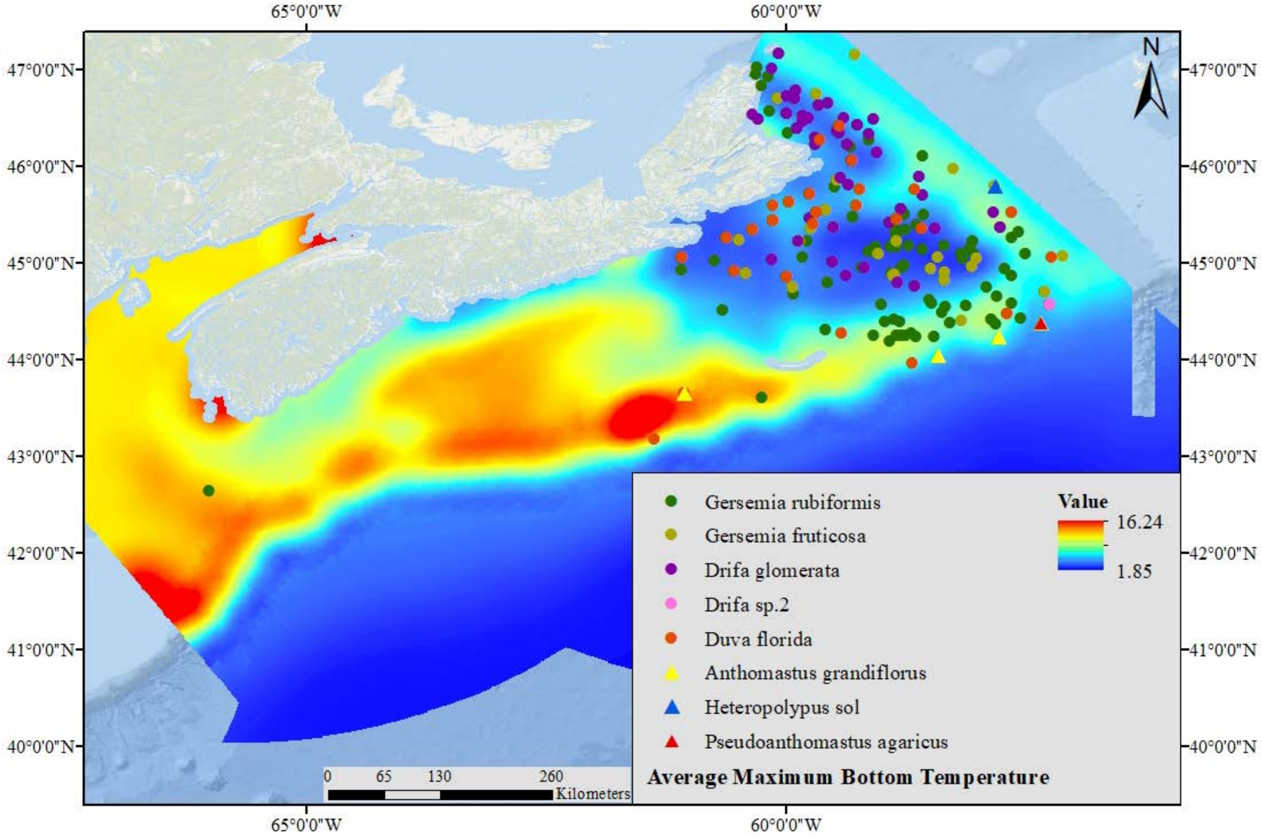

Figure 18 Multispecies distribution map displaying Average Maximum Bottom Temperature on the Scotian Shelf and Scotian Slope (Beazley et al. 2017).

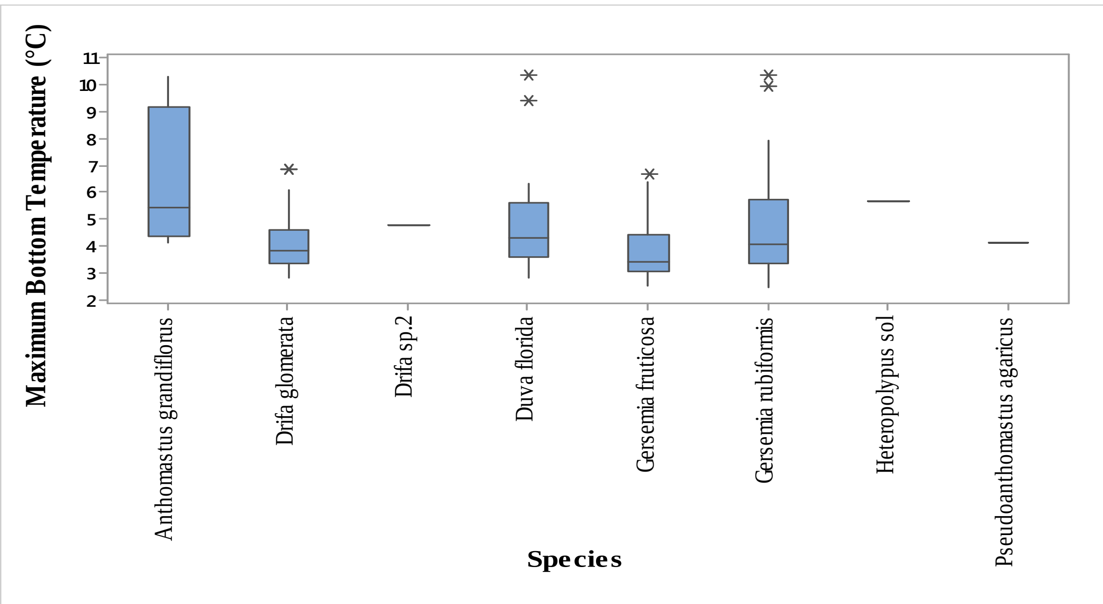

Figure 19 Average Maximum Bottom Temperature extracted from interpolated surface. The line in the blue boxes indicate the median values.

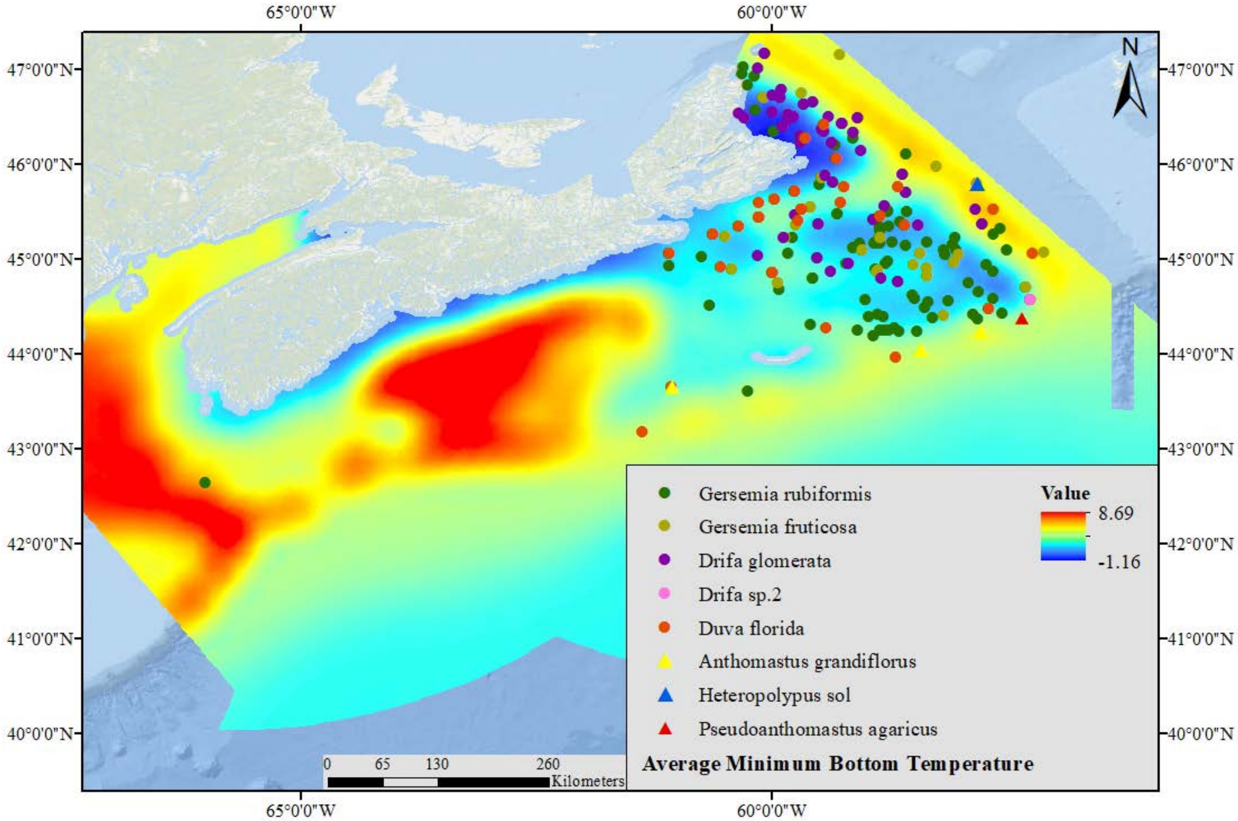

Figure 20 Multispecies distribution map displaying Average Minimum Bottom Temperature on the Scotian Shelf and Scotian Slope (Beazley et al. 2017).

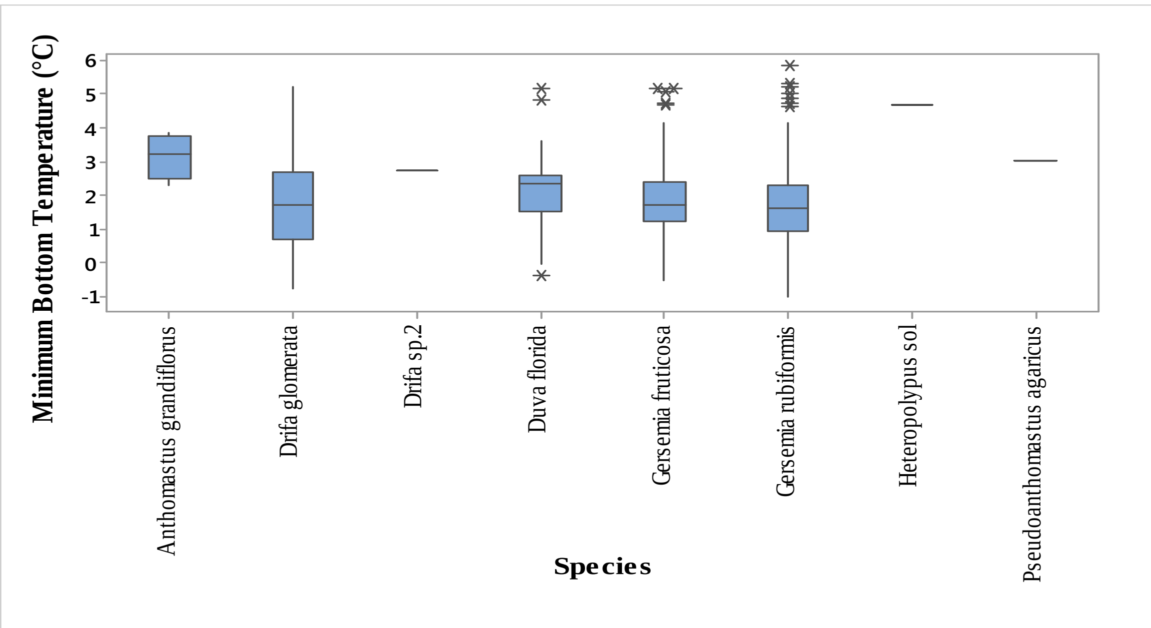

Figure 21 Average Minimum Bottom Temperature extracted from interpolated surface. The line in blue boxes indicate the median values.

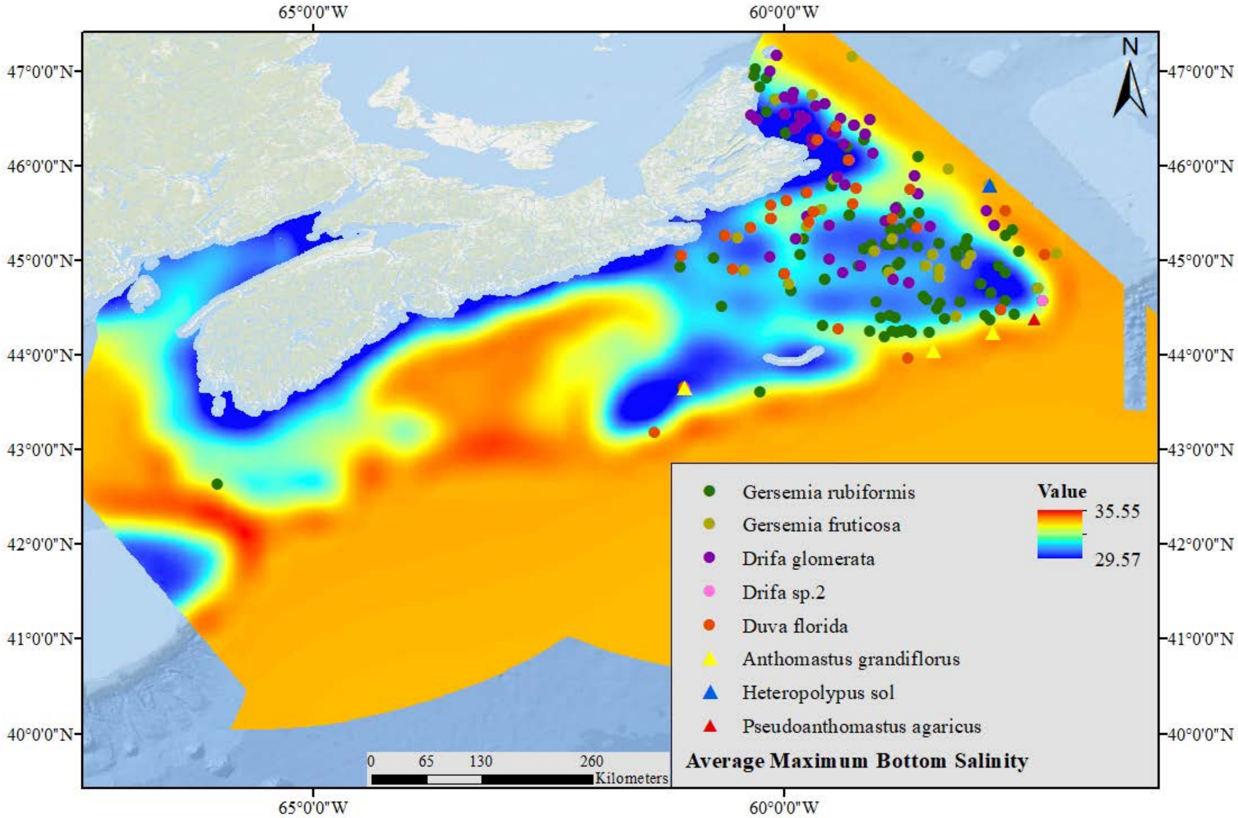

Figure 22 Multispecies distribution map displaying Average Maximum Bottom Salinity on the Scotian Shelf and Scotian Slope (Beazley et al. 2017).

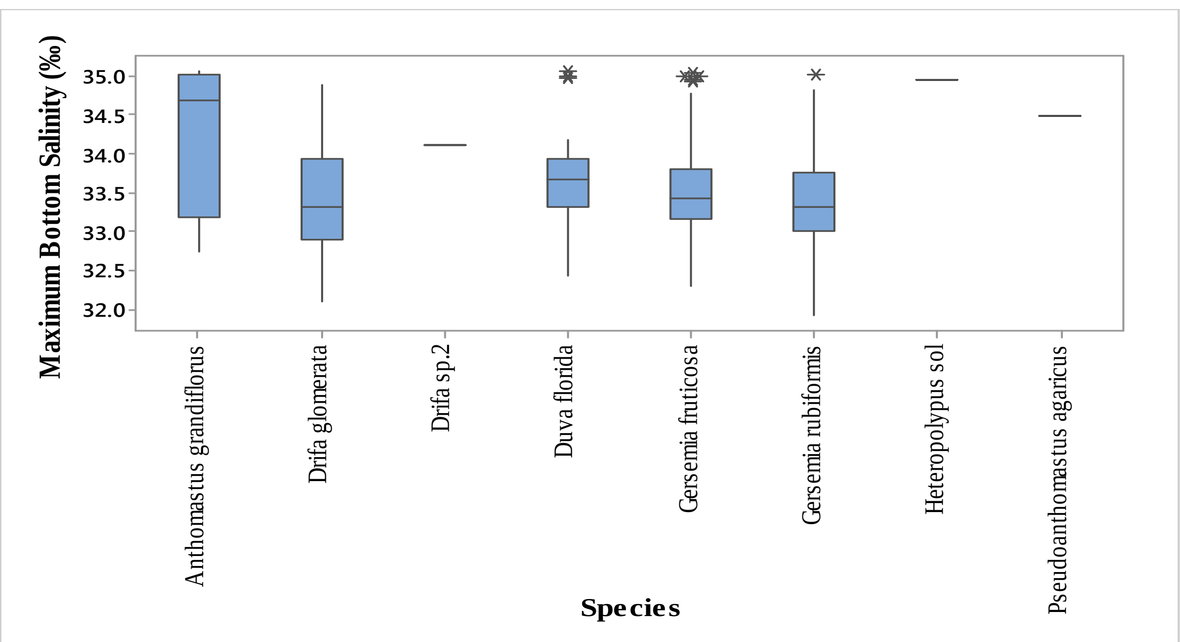

Figure 23 Average Maximum Bottom Salinity extracted from interpolated surface. The line in blue boxes indicate the median values.

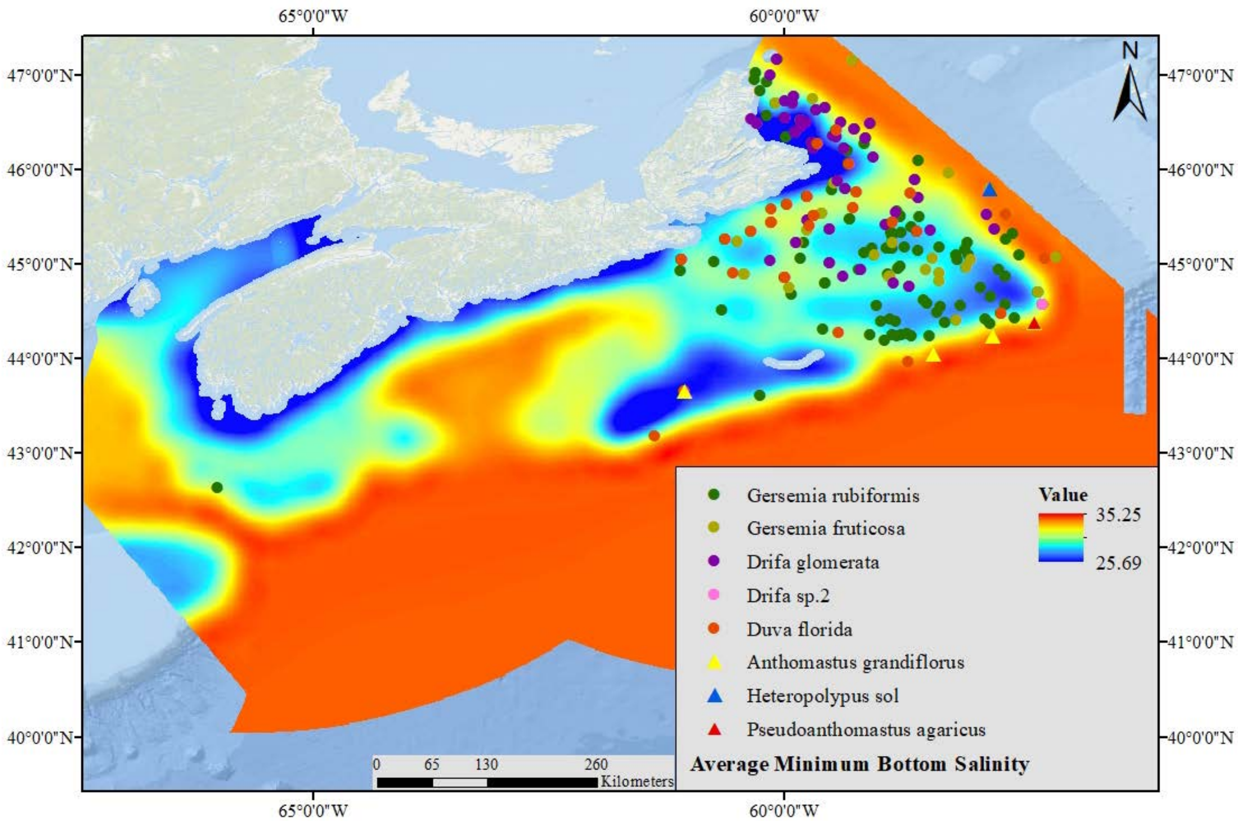

Figure 24 Multispecies distribution map displaying Average Minimum Bottom Salinity on the Scotian Shelf and Scotian Slope (Beazley et al. 2017).

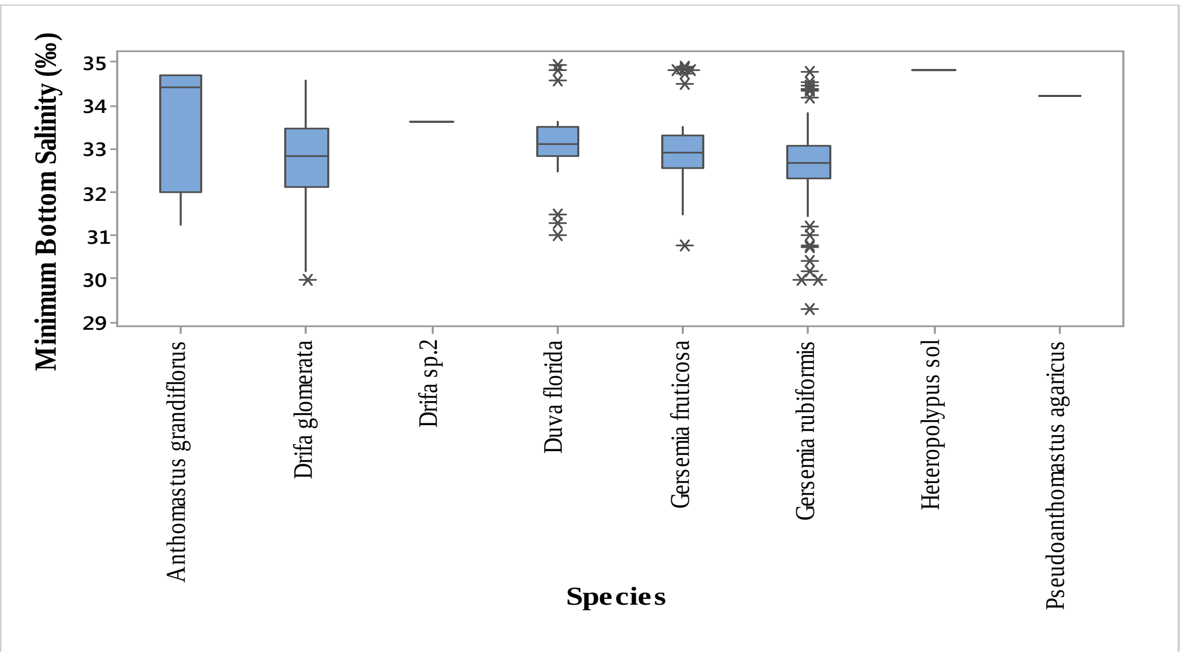

Figure 25 Average Minimum Bottom Salinity derived from interpolated surface. The line in blue boxes indicate the median values.

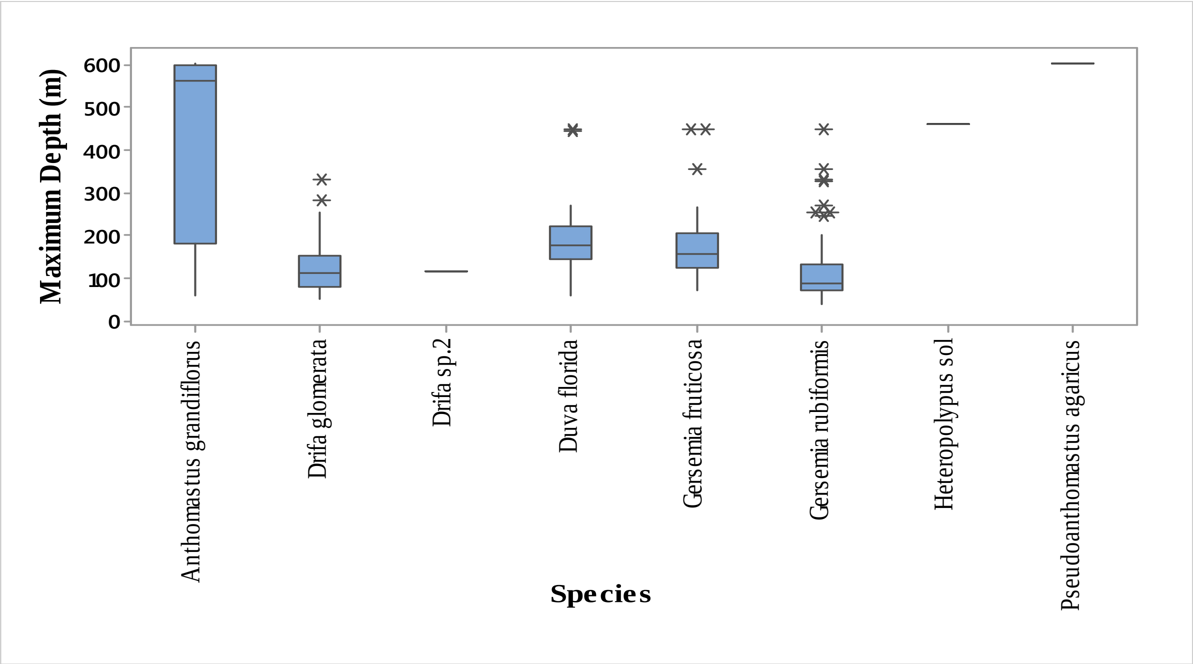

Figure 26 Maximum depth collected during 2001-2011 and 2017 RV surveys.

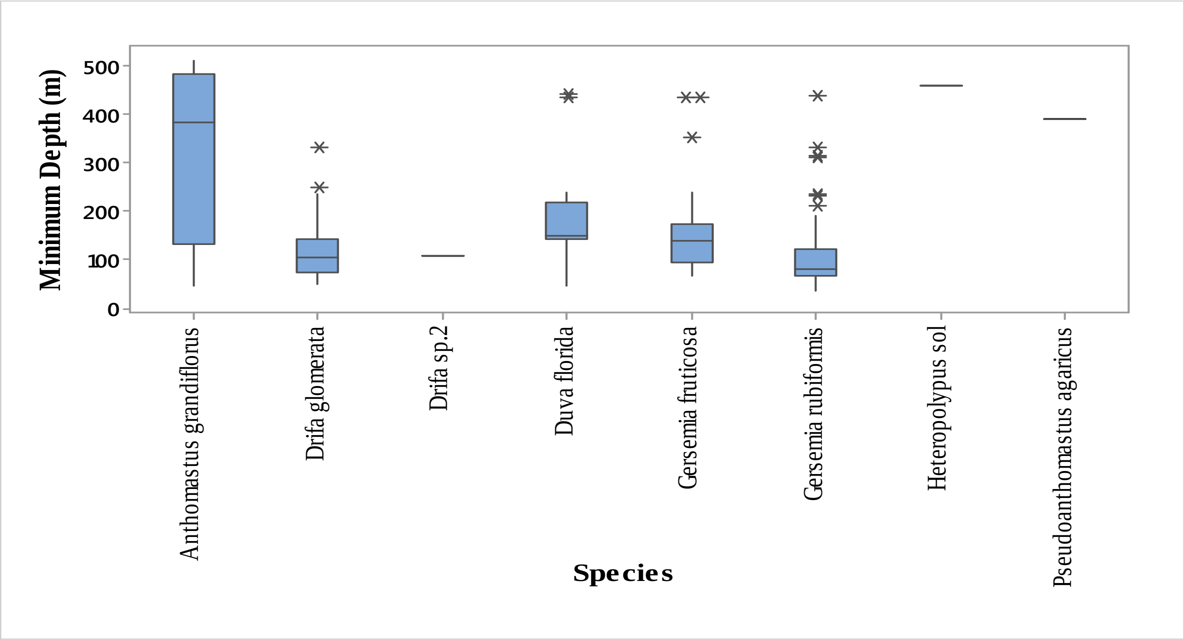

Figure 27 Minimum depth collected during 2001-2011 and 2017 RV surveys.

5.0 Discussion

This study is the first of its kind because it is the first to develop a species-specific distribution map, using updated taxonomy, of soft corals found offshore Nova Scotia since the soft coral distribution map made by Cogswell et al. (2009). Additionally, this is the first study to document and map the abundance based on colony counts and habitat preferences of soft corals found on the Scotian Shelf and slope and Bay of Fundy. Therefore, this study has provided important insight into the distribution, abundance, and habitat preferences of the alcyonacean subgroup, soft corals found offshore Nova Scotia. Eight species of soft corals, belonging to the Nephtheidae family and the Alcyoniidae family, were identified from the colonies collected during the 2001-2011 and in the 2017 DFO trawl surveys. All eight species had an affiliation for the northeastern portion of the Scotian Shelf and shelf edge. The northeastern portion of the shelf and shelf edge exhibit colder bottom temperatures and lower salinity levels compared to its southwestern counterparts. Although all species had a northeastern affiliation, the majority of the Nephtheidae species were found on the shelf while the majority of the Alcyoniidae species were found on the shelf edge, which experiences warmer and higher salinity levels than the northeastern shelf. In addition, the highest abundance of colonies was collected in the Sydney Bight area, and the most abundant species in that area and overall was *G. rubiformis*, as *G. rubiformis* made up 62% of all analyzed colonies. This section will discuss the key findings of this study and compare them to what is currently known about soft corals, and what the next steps are in terms of soft coral research in the Northwest Atlantic Ocean.

5.1 Coral Identification

The majority of the identified species from this study correspond with the species found in previous studies conducted in the Northwest Atlantic Ocean and adjacent waters (Breeze et al. 1997; Henry et al. 2003; Mortensen and Buhl-Mortensen 2004; Mortensen et al. 2006; Wareham and Edinger 2007; Cogswell et al. 2009; Wareham 2009; Murillo et al. 2011; Altuna et al. 2014). However, there is still debate regarding the taxonomy of some soft corals, especially in the Northwest Atlantic Ocean and adjacent waters, as they are easily misidentified and have been greatly ignored in the past (Jensen n.d; Sun et al. 2010; Altuna et al. 2014; 2017 personal communication with Dr. Murillo). Particularly, there is discussion on whether colonies collected and identified as *G. fruticosa*, in past studies, are in fact its own species of *Gersemia* or whether there are a variety of body plans for *G. rubiformis* (Sanmartín Payá 2004; Jensen n.d). Although there is debate surrounding *G. fruticosa*, this study separated the colonies into the two species of *Gersemia*, since there were some physical differences in the *Gersemia* colonies, and if future genetic research proves that there is no *G. fruticosa* offshore Nova Scotian than the colonies identified as *G. fruticosa* can easily be regrouped in with the *G. rubiformis* colonies.

The major physical differences observed between the *G. fruticosa* and the *G. rubiformis* colonies include polyp size, polyp retraction, capitulum shape, branch length, and sac shape. Firstly, the *G. fruticosa* colonies had long, non-retractile polyps located along and at the end of branches while *G. rubiformis* colonies exhibit small, retractile polyps at the end of branches. Secondly, the capitulum was larger and/or more prominent on *G. rubiformis* colonies than on *G. fruticosa* colonies. Thirdly, the branches were more visible and appeared longer on *G. fruticosa* than *G. rubiformis*, since the capitulums on

G. rubiformis were large, and thus reduced visibility of the branches and/or reduced the size of the branches. Finally, the sac of *G. fruticosa* colonies appeared thinner and larger, as multiple colonies used it to attach to or engulf rocks or sediment, than the discoidial sac of *G. rubiformis*. Although there were some physical differences between the two *Gersemia* species, there were some colonies that possessed characteristics of both species and minimal difference in sclerite size and shape. The most noticeable difference in sclerite shape occurred in the branches, in which *G. fruticosa* had only capstans in the branches while *G. rubiformis* branches contained both capstans and spindles, see section 3.4 (Altuna and Murillo 2014). It would be helpful, from a taxonomic standpoint, for future research to examine the genetics of the collected colonies. Genetic tests would determine whether *G. fruticosa* is present in the Northwest Atlantic, or if there are varying body plans of *G. rubiformis*.

5.2 Coral distribution

5.2.1 Environmental conditions

The results of this study displayed two distinct trends in soft coral distribution offshore Nova Scotia, 1) all species have an affiliation for the northeastern portion of the Scotian Shelf and shelf edge; 2) the majority of the Alcyoniidae species were found on the edge of the Scotian Shelf while the majority of the Nephtheidae species were found on the continental shelf. The distribution of other cold-water corals in this region has been attributed to several factors, mainly depth and environmental conditions, such as temperature and salinity (Breeze et al. 1997; Mortensen et al. 2006; Gilkinson and Edinger 2009; Sun et al. 2010; Murillo et al. 2011). From examining Figures 18, 20, 22, and 24 there is a difference in the environmental conditions on the northeastern portion of the Scotian Shelf and shelf edge compared to the southwestern portion of the Scotian

Shelf and shelf edge. The northeastern shelf and shelf edge have lower bottom temperatures and salinity levels than its southwestern counterparts. These differences are attributed to the direction of currents and their source water (Figure 28) (Wareham and Edinger 2007; Saba et al. 2016). The Labrador Current and the Gulf of St. Lawrence bring down colder, fresher water, making the northeastern portion of the Scotian Shelf and shelf edge colder and lower in salinity than the southwestern Scotian Shelf and shelf edge, which is influenced by the warmer, saltier Gulf Stream water (Figure 28) (Saba et al. 2016). The distinct distribution of all examined species to the northeastern Scotian

Figure 28 Major currents of the Northwest Atlantic Ocean and Labrador Sea. Black arrows indicate colder, fresher water from the Labrador Current, white arrows indicate warmer, higher salinity water from the Gulf Stream, and dashed arrows indicate mixing of waters. Image from: Saba et al. 2016.

Shelf and shelf edge, and the constant difference in environmental conditions between the northeastern and southwestern Scotian Shelf and shelf edge suggest a preference of soft corals to colder temperatures and lower salinities.

Few studies have examined both the distribution of soft corals and the environmental conditions in which they are found, making it difficult to draw conclusion on why soft corals inhabit certain areas and not others in Atlantic Canada. With that being said, Mortensen et al. (2006) found a similar pattern to the present study in that Nephtheids were found in shallower, colder water than the Alcyoniids offshore Nova Scotia and in the Gulf of St. Lawrence. Furthermore, Mortensen et al. (2006) and the present study show that *G. rubiformis* occupies the shallowest waters, on average, compared to other soft coral species. In addition to Mortensen et al. (2006), Wareham and Edinger (2007) examined the distribution of cold-water corals in the Newfoundland and Labrador region, and found that only Nephtheids were found on continental shelves. This phenomenon was attributed to the lack of hard substrata and cold temperatures in which other corals could not colonize (Wareham and Edinger 2007). In comparison, the one Alcyoniid species, *Anthomastus grandiflorus*, found in Warehman and Edinger's (2007) study were found on the shelf edge and slope of the Southern Labrador Shelf, Northeast Newfoundland Shelf, and the Grand Banks of Newfoundland. This general trend of Nephtheids inhabiting the colder shelf while Alcyoniids inhabit the warmer shelf edge and slope was also seen in the present study. These findings reinforce the theory that Nephtheids prefer colder, shallower areas than Alcyoniids.

5.2.2 Depth

The present study's results showed a clear difference in the depths that Nephtheids occupy compared to Alcyoniids. This general depth trend between the two Alcyonacea families was also displayed in the Mortensen et al. (2006) study in which the two examined Nephthidae species, *G. rubiformis* and *D. florida*, were found at shallower depths than the one examined Alcyoniid species, *Anthomastus* spp. In addition, like the findings of the present study, *G. rubiformis* was one of the shallowest species, on average (Mortensen et al. 2006; Wareham and Edinger 2007). Furthermore, the depth values for the Alcyoniids in the present study fall within the depth range given by Altuna et al. (2014), but the small sample size of Alcyoniids in the present study could reduce the accuracy of the present studies numbers (Figures 26 & 27; Appendix E). The small sample size of Alcyoniids in this study does not suggest that Alcyoniids are rare offshore Nova Scotia, but rather that this study did not target Alcyoniid habitat. Alcyoniids have been found in greater numbers offshore Nova Scotia, specifically in the Gully, the NECCCA, and the LCA, but these areas were not sampled from because they are protected and their biodiversity has already been examined (Cogswell et al. 2009). In addition, the listed protected areas exhibit greater depths compared to the areas sampled in the present study, further suggesting that Alcyoniids prefer deeper waters, and that their habitat was overlooked in this study (Cogswell et al. 2009). Thus, there is a need to further examine the Scotian Shelf edge and Scotian Slope in order to improve our understanding of Alcyoniid distribution, abundance, and depth ranges in offshore Nova Scotian waters.

5.4 Abundance based soft coral hotspot

The abundance maps based on colony counts highlighted a soft coral hotspot of abundance offshore Nova Scotia. The area with the highest soft coral abundance is on and around Sydney Bight, off northern Cape Breton. Four species, *G. rubiformis*, the most abundant, *G. fruticosa*, *D. glomerata*, and *D. florida*, were found in the Sydney

Bight area. This area does not experience as much fluctuation in temperature and salinity as other portions of the northeastern Scotian shelf, and cold-water corals prefer areas with stable environmental conditions, which may explain the high abundance around Sydney Bight (Figures 17-24) (Mortensen et al. 2006). However, further examination of this areas environment, such as substrate type and current speed, could provide a clearer idea of why soft corals prefer this part of the Scotian Shelf. Also, the suggested Sydney Bight hotspot is based off of data from only one cruise, NED2017020, which might understate the abundance of soft corals in the study area. In order to gain a better understanding of the abundance of soft corals offshore Nova Scotia, it would be useful to repeat this study with a dedicated taxonomist onboard the trawl survey vessel, as was done for the NED2017020 cruise.

5.5 Considerations for soft coral conservation

It was previously stated that soft corals are protected within Atlantic Canada's MPAs, such as the Gully, the NECCCA, the LCA, and St. Anns Bank, even though they were not the target organisms for these protected areas (Cogswell et al. 2009; DFO 2018). In particular, the proximity of the St. Anns Bank MPA to Sydney Bight has resulted in the protection of some of the soft coral aggregations found around the suggested hotspot (Figure 17; Appendix B) (DFO 2018). When comparing the St. Anns Bank MPA boundaries over the species-specific abundance maps (Appendix B), the St. Anns Bank MPA contains congregations of *G. rubiformis*, *G. fruticosa*, *D. glomerata*, and a few *D. florida* (DFO 2018). Although the St. Anns Bank MPA captures some of the soft coral aggregations found off northern Cape Breton, the highest abundance is found west of St. Anns Bank, and therefore the majority of the soft corals within this area are not protected (Appendix B) (DFO 2018). In addition, based on the distribution maps developed in the present study the majority of soft corals, especially Nephtheids, found offshore Nova Scotia do not reside within the boundaries of Atlantic Canada's MPAs (Figure 15) (Cogswell et al. 2009; DFO 2018).

The lack of soft coral protection offshore Nova Scotia in addition to the recognition of soft coral gardens as ecologically significant habitat may deem soft corals as organisms to consider in the decision making process for protected areas (Kenchington 2014; DFO 2015; DFO 2017a). When considering soft coral conservation, the two families, Nephtheidae and Alcyoniidae, should be considered separately, since this study has shown that the two families have different habitat requirements and are located in different areas of offshore Nova Scotia.

5.6 Implication of research and future work

The findings of this study has improved the baseline knowledge surrounding soft corals offshore Nova Scotia in terms of their distribution, abundance, and habitat preferences. This baseline knowledge on Atlantic Canada's soft corals is important because DFO has been tasked with protecting 10% of Canada's coastal and marine areas by 2020, and a Coral and Sponge Conservation Plan for Eastern Canada has been implemented, thus this research could be used for protecting ecologically and biologically significant areas and/or representative areas (DFO 2015; DFO 2017a). Now that this study has provided a more complete representation of soft coral distribution, abundance, and habitat preference offshore Nova Scotia, research surrounding their role in their ecosystem is needed. Currently, only soft coral gardens have been deemed an ecological and biologically significant area by DFO, as soft coral gardens have a significant association with snow crab and juvenile northern shrimp (Kenchington 2014). The distribution and abundance maps generated from this study could be used to identify aggregations of soft corals, and potentially soft coral gardens offshore Nova Scotia. In addition, the results of this study show that soft corals are abundant and widely distributed on the northeastern portion of the Scotian Shelf, potentially marking them as a representative part of offshore Nova Scotia habitat. Although this research has improved our knowledge of soft corals offshore Nova Scotia, there are still knowledge gaps pertaining to soft corals.

Firstly, there is need for further taxonomic work, especially in regards to *G. fruticosa* and *Drifa* sp.2. In order to determine whether there is a difference between *G. rubiformis* and *G. fruticosa*, in Atlantic Canada, genetic testing should be done. Also, there is need to further examine *Drifa* sp.2. The sclerites of *Drifa* sp.2 are similar to those of *Drifa flavescens* (Sanmartín Payá 2004; Jensen, n.d), but the smaller polyp size of *Drifa* sp.2 indicates that further examination is required before assigning it to a species. Secondly, with the improved baseline knowledge on soft coral distribution and habitat, there is a need to further our understanding of these benthic invertebrates by researching their role in the ecosystem. Such research could focus on associated fauna. Finally, one of the key findings of this study was the preference of Nephtheids to colder waters, and this characteristic could make Nephtheids a potential indicator species of climate change. The Scotian Shelf has experienced a general increase in bottom temperatures, especially since 2010, and this could be problematic for organisms that require stable, cold temperatures, such as Nephtheids (Hebert et al. 2016; Saba et al. 2016; Rheuban et al. 2017). Future research could examine to what degree Nephtheids will be affected by ocean warming and if they can be used as model organisms for other benthic organisms that rely on stable, cold environmental conditions. In addition, collecting bottom temperature data and modeling bottom temperatures is more difficult than collecting sea surface temperature data, therefore future research could look into using cold water organisms, like Nephtheids, as proxies that indicate the warming of benthic waters (Saba et al. 2016).

6.0 Conclusion

This research has furthered our understanding on the species distribution, abundance, and habitat preference of soft corals on the Scotia Shelf, Scotia Shelf edge, and Bay of Fundy. Specifically, this research showed that there are eight species, *G. rubiformis* being the most abundant, of soft corals offshore Nova Scotia, and all eight have an affiliation for the northeastern portion of the Scotian Shelf and shelf edge. This northeastern affiliation is most likely due to the colder, lower salinity waters found on the northeastern shelf and shelf edge compared to the southwestern shelf and shelf edge. In addition, the Nephthediae species were found in shallower, colder, and lower salinity waters than the Alcyoniidae species. This information can be used by DFO to locate representative areas and/or ecologically and biologically significant areas and species, such as soft coral gardens (Kenchington 2014). Future research should include genetic verification of *G. fruticosa* in the Northwest Atlantic Ocean, further examination of *Drifa* sp.2, and examination of associated fauna and sensitivity of soft corals to climate change.

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Appendix A. Sclerite Preparation and Mounting

The following section includes the exact procedure used for sclerite isolation and sclerite mounting, however it is only a portion of the original document and should not be confused with the full document (Janes and Wah 2007). In addition, it is not a copy of the original document, but rather a word for word replication of the procedure.

Sclerite Preparation

Fixed specimens are removed from storage and placed on a cutting surface. Sampling should be done from various parts of the colony as outlined in the manual under genera descriptions.

When sampling surface sclerites make a deep cut and remove a good amount of tissue. If the cut is made to shallow into the surface, then the surface sclerites may be broken off or some of them missed all together. Place cut pieces on a glass slide using a numbering sequence to identify different regions sampled (i.e. 1 polyp, 2, stalk, etc…). Two to three samples can comfortably fit on a glass microscope slide. Older slides work very well for wet mounts. Sometimes a little skin oil, such as that from the forehead rubbed onto the slide before use helps to hold the dissolving agent in place and keep the droplets from running.

Add 2 to 3 small drops of sodium hypochlorite (Clorox, Bleach) 5% solution onto the microscope slide. This is used to dissolve organics away from the sclerites. It will also remove epiphytes such as sponge and algae that are commonly found present on octocoral colonies. Some of this debris is seen as contaminants when viewing with a compound microscope and needs to be differentiated from “unusual” sclerites.

After about five minutes, the sample tissue will break down and form a layer of foam or bubbles on the top of the sodium hypochlorite droplet obscuring sclerites underneath. If a little bit of the tissue remains just gently agitate it.

Once all the tissue has dissolved away, a fine teasing needle is used to pull the top layer of foam off the droplet by moving it to the side. It can then be removed by blotting with a paper towel. A drop of distilled water can be added to “rinse” the sclerites and spread them out a little. The slide is ready to examine under a microscope designated for wet mounts as some labs keep them separated from dry use only microscopes.

Sclerite Mounting

Once sclerites have been removed from tissue they can both be observed and photographed in a temporary wet mount. Another option is to place them in a permanent mounting. Obviously, permanently mounted sclerites have the advantage of being available for future examination and they can be sent off to other researchers or institutions. The down side is that it take a little more time to prepare the mounting medium and make the slides.

To permanently mount sclerites, rinse and wash them with distilled water. For a large sample this can be done in a glass test tube. Smaller samples can be done on a standard microscope slide or well slide. Once the sclerites are washed thoroughly add a drop or tow of neutrally buffered hydrogen peroxide. Rinse and dry. Prepare a permanent mounting medium such as "Durcupane" or "Depex". The neutral medium should have a notably different refractive index than calcite (1.52); otherwise the sclerites are not visible in the mounting.

Place sclerites on a clean slide with distilled water. Move or position the sclerites to minimize overlapping or having too many clustered together. Dry the slides in a low temperature oven or on a slide warmer until the distilled water evaporates. Then add a drop of the viscous Durcupane or other mounting medium onto the slides. Add a cover slip with firm, even pressure. Press downwards until the medium reaches the edges of the cover slip. Label slides and return them to a low temperature oven (93^{O}C/200^{O}F) or slide warmer for 6 to 8 hours or until resin is hard and dry. Store in a dark environment for many years!

Durcupan ACM Fluka preparation
(on the basis of Araldite)

20 milliliters Single component A/M Epoxy Resin
20 milliliters Single component B hardener
0.8 milliliters Single component C accelerator

Mark a small glass jar with 20 and 40-milliliter levels using measured amounts of de-ionized water. Dry the jar thoroughly. Add reagent "A" and "B" to the marks on the jar. Add reagent "C" and mix gently but completely. Avoid adding any air bubbles. Cover and store in the freezer at 0 degrees C. (32 degrees F.). Prior to use remove the medium from the freezer and warm to room temperature. This may take a few hours. Durcupan has a syrupy texture that becomes more viscous as it ages. Older mixed Durcupan may require warming over a flame for it to be usable. A new mixture should be made when it becomes too thick to work with. Store the mixture frozen after each use.

Appendix B. Species-specific abundance maps based on colony counts

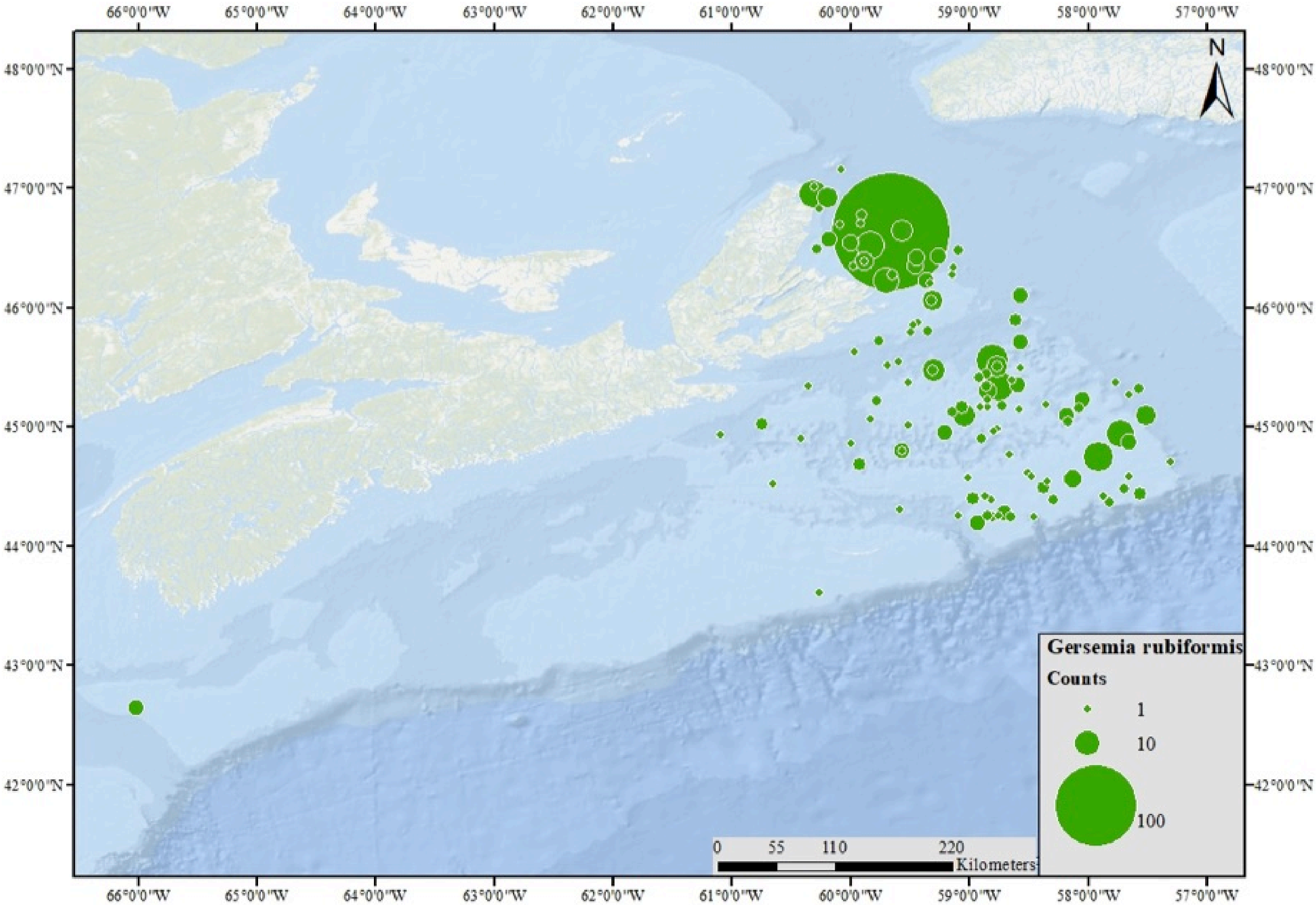

Figure 29 Proportional abundance map of *Gersemia rubiformis* based on colony counts. Data displays colony counts from all cruises during 2001-2011 and in 2017.

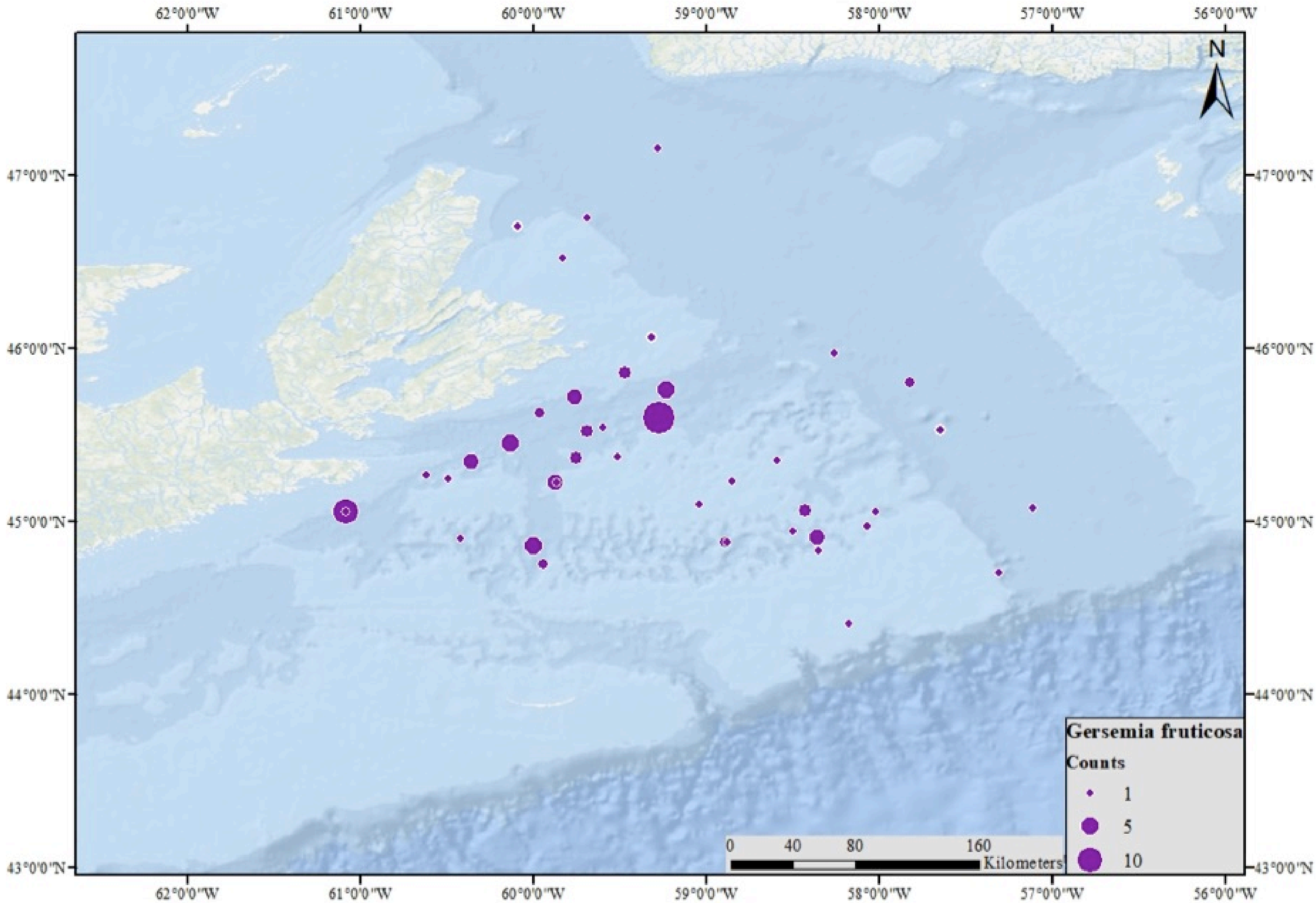

Figure 30 Proportional abundance map of *Gersemia fruticosa* based on colony counts. Data displays colony counts from all cruises during 2001-2011 and in 2017.

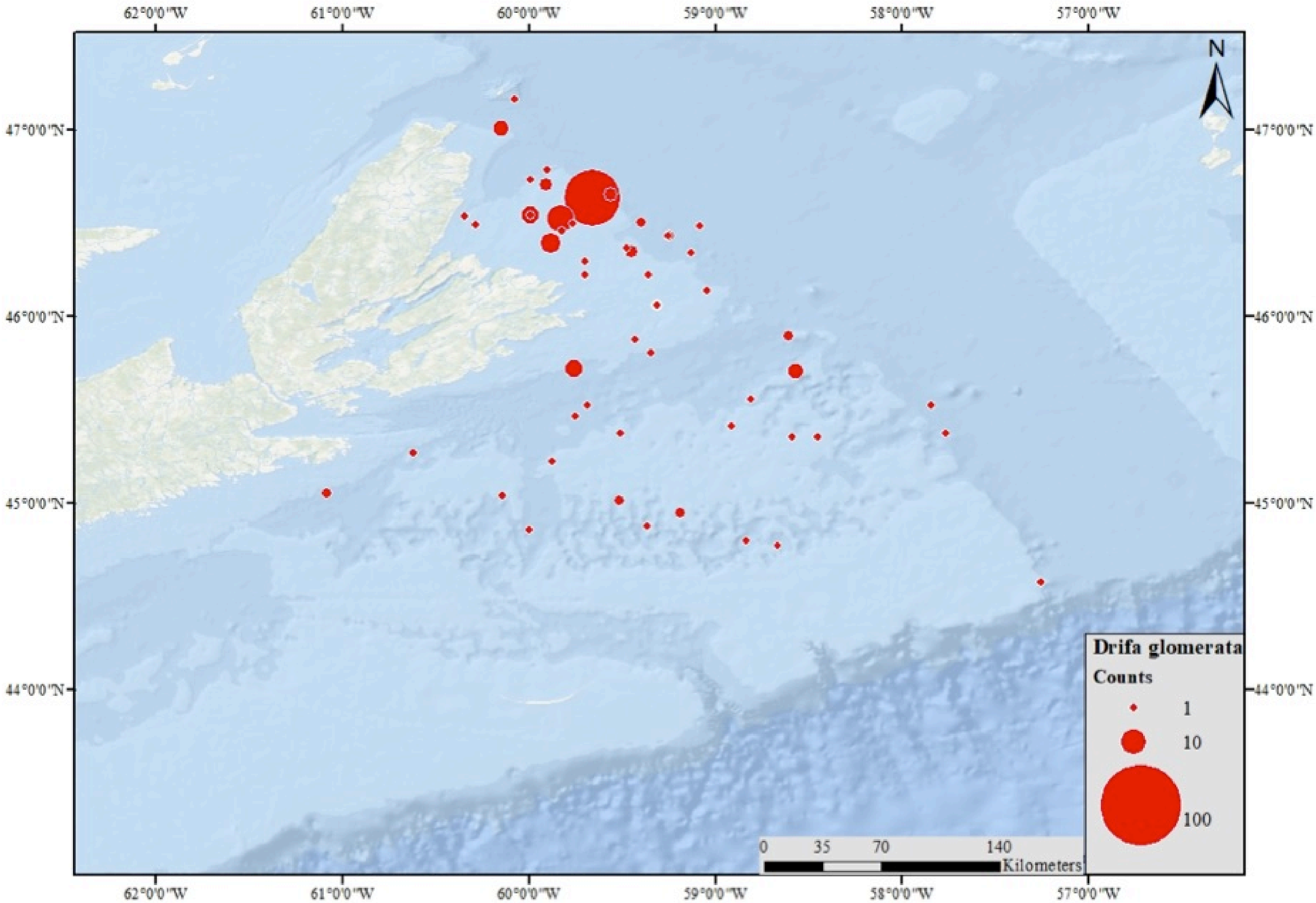

Figure 31 Proportional abundance map of *Drfia glomerata* based on colony counts. Data displays colony counts from all cruises during 2001-2011 and in 2017.

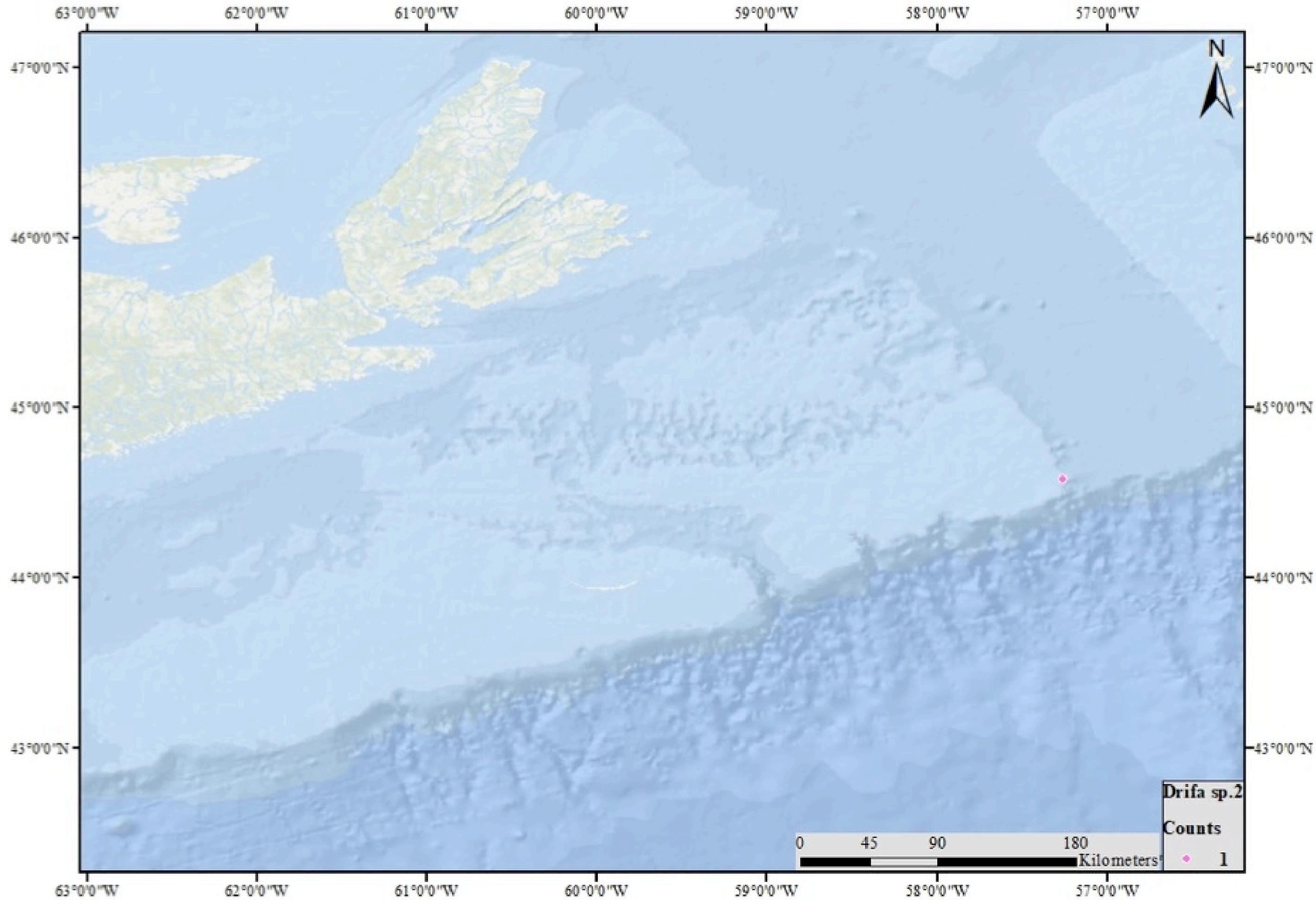

Figure 32 Proportional abundance map of *Drifa* sp.2 based on colony counts. Data displays colony counts from only the NED2017020 cruise.

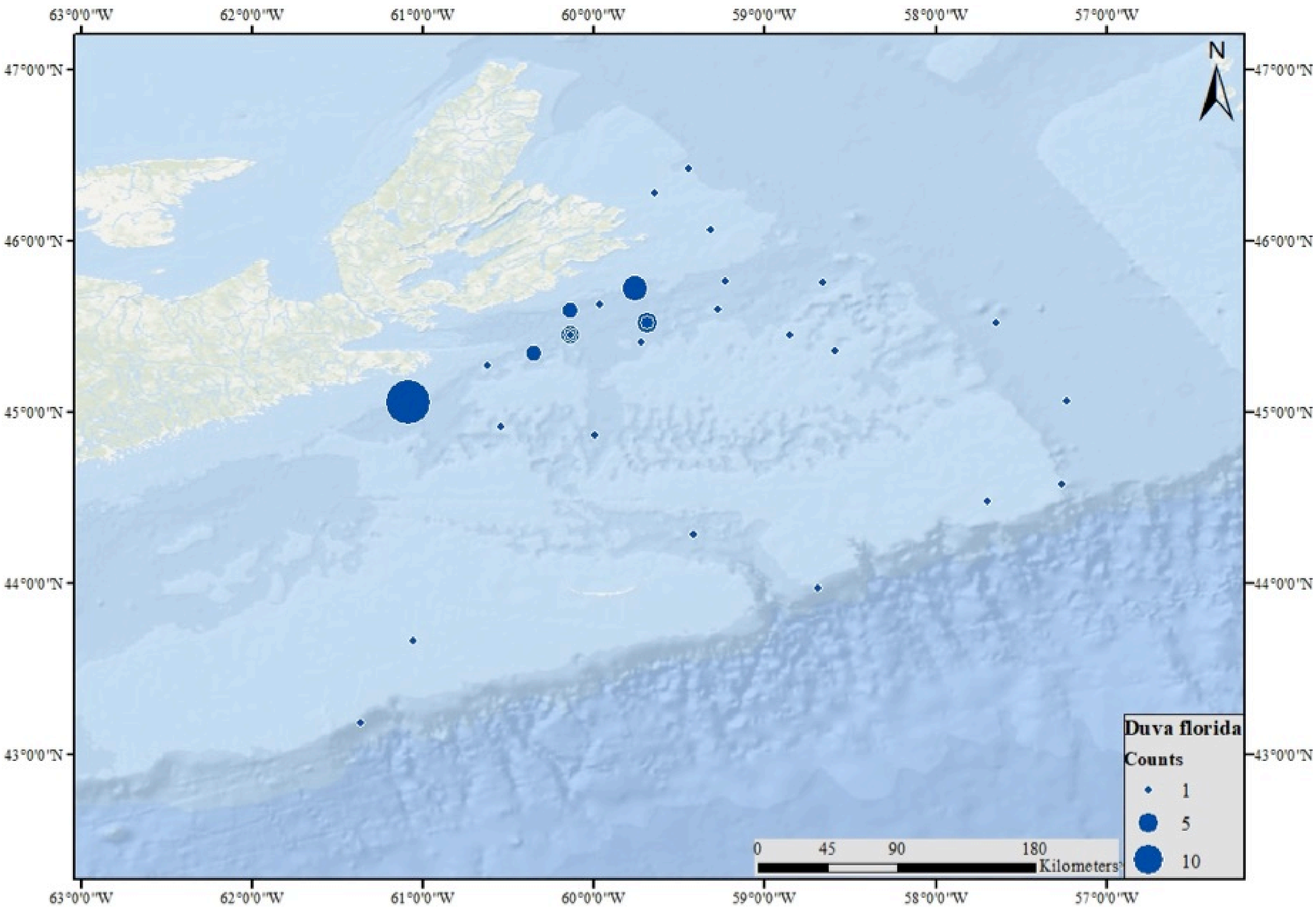

Figure 33 Proportional abundance map of *Duva florida* based on colony counts. Data displays colony counts from all cruises during 2001-2011 and in 2017.

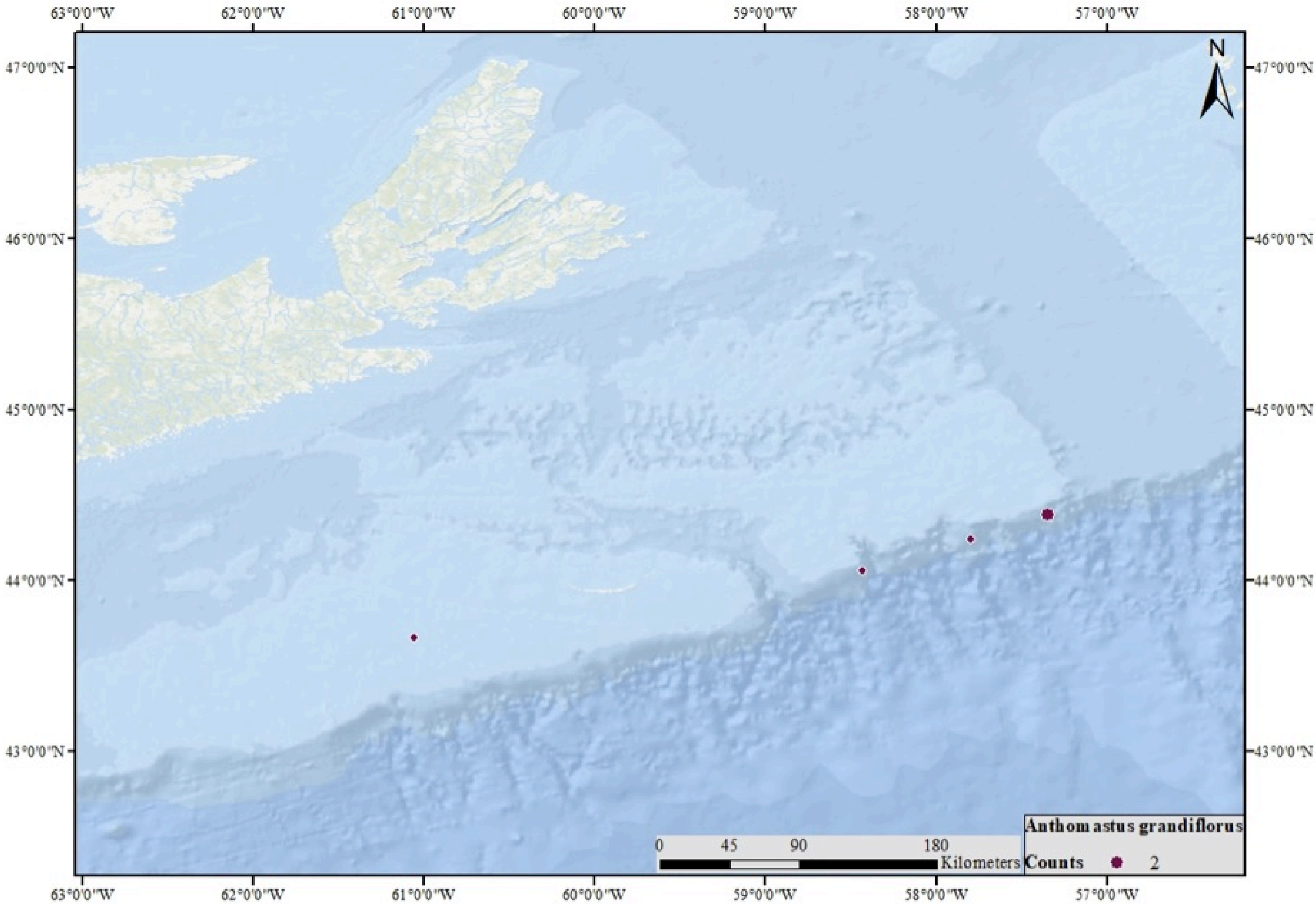

Figure 34 Proportional abundance map of *Anthomastus grandiflorus* based on colony counts. Data displays colony counts from the 2001, 2003, and 2006 cruises.

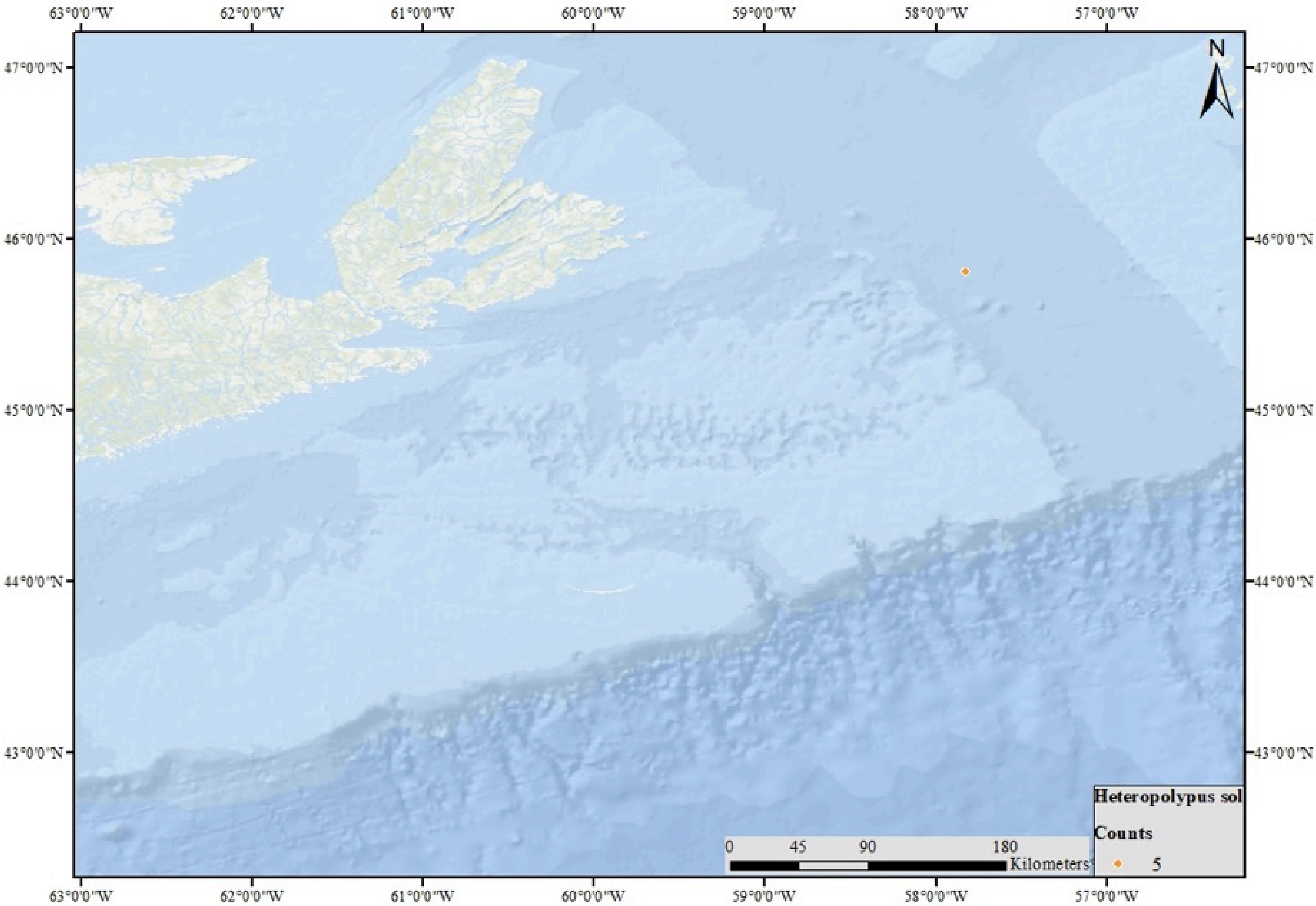

Figure 35 Proportional abundance map of *Heteropolypus sol* based on colony counts. Data displays colony counts from the NED2017020 cruise.

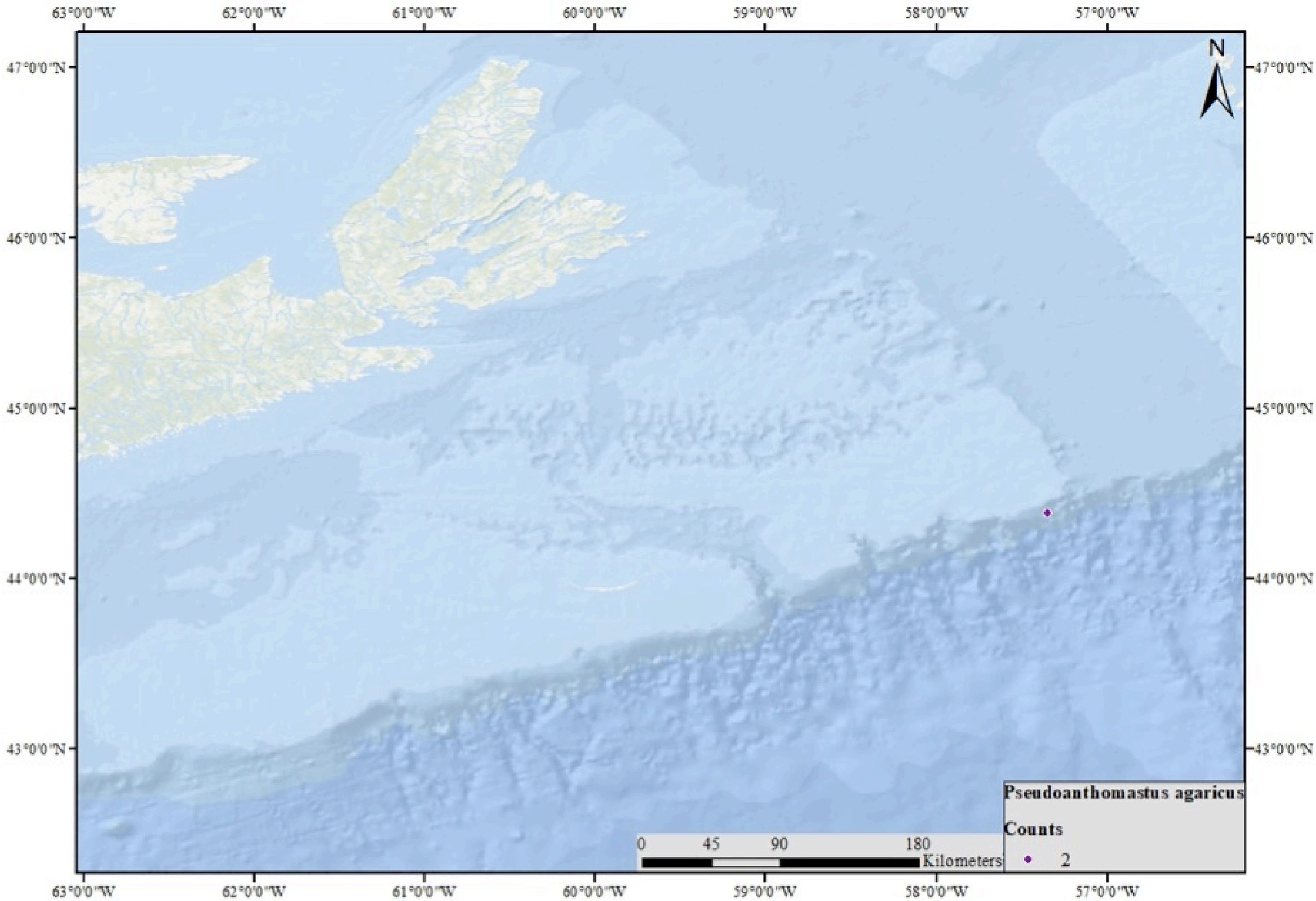

Figure 36 Proportional abundance map of *Pseudoanthomastus agaricus* based on colony counts. Data displays colony counts from the 2006 cruises.

Appendix C. Temperature range, salinity range, and depth range by species

Table 3 The temperature ranges, salinity ranges, and depth ranges of each species.

Species	**Temperature Range (°C)**	**Salinity Range (‰)**	**Depth Range (m)**
Anthomastus grandiflorus	2.3-4.1	31.24-35.06	46-604
Drifa glomerata	-0.8-6.8	29.91-34.88	48-329
Drifa sp.2	2.7-4.8	33.64-34.11	108-113
Duva florida	-0.4-10.3	30.97-35.06	46-446
Gersemia fruticosa	-0.5-6.6	30.72-35.03	66-446
Gersemia rubiformis	-1.1-10.3	29.25-35.02	35-446
Heteropolypus sol	2.9-4.1	34.82-34.95	461
Pseudoanthomastus agaricus	4.7-5.7	34.22-34.49	391-604