A description of the habitats and special natural features within the Scotian Slope Ecologically and Biologically Significant Area in the Maritimes Region

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2015

A DESCRIPTION OF THE HABITATS AND SPECIAL NATURAL FEATURES WITHIN THE SCOTIAN SLOPE ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREA IN THE MARITIMES REGION

by

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ABSTRACT

Stortini, C.H. 2015. A description of the habitats and special natural features within the Scotian Slope Ecologically and Biologically Significant Area in the Maritimes Region. Can. Tech. Rep. Fish. Aquat. Sci. 3136: iv + 53p.

Fisheries and Oceans Canada (DFO) Maritimes Region recently identified eighteen Ecologically and Biologically Significant Areas (EBSAs) within the offshore component of the Scotian Shelf Bioregion. These EBSAs were identified as areas that may require heightened management attention due to their biological or ecological importance. The Scotian Slope was identified as one broadly defined EBSA, because its steep slopes, unique geomorphology, and ocean current patterns support unique, diverse and productive ecosystems. The purpose of this report is to describe the variation in habitat types and ecosystems across the slope from east to west and with depth. This report adapts divisions of the Scotian Slope from a 2009 WWF-Canada report to describe the Scotian Slope and Rise in terms of geologically, oceanographically, and ecologically distinct “physiographic regions”. Furthermore, this report describes especially unique natural features within these physiographic regions and how they may fit DFO EBSA criteria. It is recommended that marine management programs that utilize EBSA delineation and definition take note of the variation among physiographic regions considered here, and that DFO Maritimes evaluate the potential of additional special features identified here to be considered EBSAs.

RÉSUMÉ

La Région des Maritimes de Pêches et Océans Canada (MPO) a récemment déterminé dix-huit zones d’importance écologique et biologique (ZIEB) dans la composante extracôtière de la biorégion du plateau néo-écossais. Ces ZIEB ont été désignées comme des zones pouvant nécessiter une attention accrue en matière de gestion en raison de leur importance écologique ou biologique. Le talus du plateau néo-écossais a été désigné comme une ZIEB définie d’une manière générale, car ses pentes abruptes, sa géomorphologie unique et ses régimes de courants océaniques favorisent des écosystèmes uniques, divers et productifs. Le présent rapport a pour but de décrire la variation des types d’habitats et d’écosystèmes sur l’ensemble de la pente d’est en ouest et en fonction de la profondeur. Le présent rapport adapte les divisions du talus du plateau néo-écossais tirées d’un rapport de WWF-Canada de 2009 pour décrire le talus et le glacis du plateau néo-écossais en termes de « régions physiographiques » distinctes sur les plans géologique, océanographique et écologique. En outre, le présent rapport décrit notamment les caractéristiques naturelles uniques dans ces régions physiographiques et la façon dont elles peuvent répondre aux critères des ZIEB du MPO. Il est recommandé que les programmes de gestion des ressources marines qui utilisent la délimitation et la définition des ZIEB prennent note de la variation entre les régions physiographiques prises en compte ici, et que la Région des Maritimes du MPO évalue la possibilité de caractéristiques spéciales supplémentaires déterminées ici et à considérer comme celles de ZIEB.

1.0. INTRODUCTION

Fisheries and Oceans Canada (DFO) Maritimes Region recently identified eighteen Ecologically and Biologically Significant Areas (EBSAs) within the offshore component of the Scotian Shelf Bioregion (Figure 1; DFO 2014a). These EBSAs were identified as areas that may require heightened management attention due to their biological or ecological importance (DFO 2014a). Their biological or ecological importance was determined by how well they met the following criteria: Uniqueness/Rarity, Aggregation, Fitness Consequences, Resilience and Naturalness. Appropriate literature and available regional-scale ecological data were considered in the identification of these eighteen EBSAs (DFO 2014a). Data layers considered include areas of high biological productivity or biomass, high fish and invertebrate species diversity, important habitat for fishes and invertebrates, coral and sponge occurrences, critical habitat for species at risk, important areas for seabird functional guilds, and distinct oceanographic and geomorphic conditions (DFO 2014a). Identification and description of EBSAs will inform a broad variety of ocean planning and management processes, and is particularly important given the intensity of existing uses and imminent expansion of industrial activities in the bioregion (e.g., LGL Limited 2014).

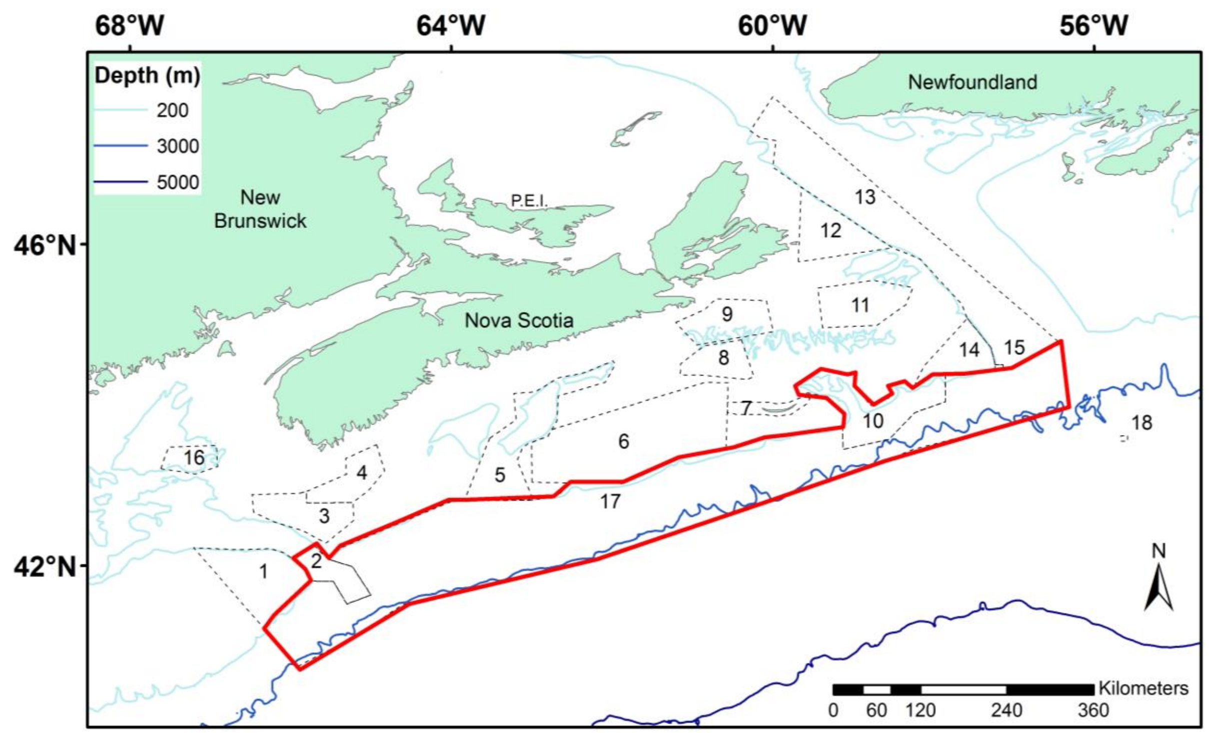

Figure 1. Offshore Ecologically and Biologically Significant Areas (EBSAs) in the Scotian Shelf Bioregion identified by Fisheries and Oceans Canada (DFO 2014a): 1) George's Bank, 2) Northeast Channel, 3) Browns Bank, 4) Roseway Basin, 5) Emerald Basin and the Scotian Gulf, 6) Emerald Western Sable Banks Complex, 7) Sable Island Shoals, 8) Middle Bank, 9) Canso Bank and Canso Basin, 10) Eastern Scotian Shelf Canyons, 11) Misaine Bank, 12) St. Anns Bank, 13) Laurentian Channel Slope, 14) Eastern Shoal, 15) Stone Fence and Laurentian Environs, 16) Jordan Basin and the Rock Garden, 17) Scotian Slope, and 18) Laurentian Channel Cold Seep. The Scotian Slope EBSA, over which smaller slope EBSAs overlap, is circled in red.

Of the EBSAs identified, the largest (72,800km^2) is the Scotian Slope EBSA (Figure 1). The Scotian Slope was identified as an EBSA because of the distinct habitat provided by its steep slopes, complex geomorphology, and unique ocean current patterns (DFO 2014a). These conditions promote high biological productivity and diversity, particularly in canyons and areas of intense upwelling or mixing (Freeland and Denman 1982; Hooker et al. 1999; De Leo et al. 2010; Moors-Murphy 2014). The slope is used as a migratory corridor and important habitat for many large pelagic fish, e.g., Swordfish (Tal Sperling et al. 2005) and Porbeagle Shark (Campana et al. 2002), cetaceans (Gomez-Salazar and Moors-Murphy 2014), and Leatherback Turtles (DFO 2011), provides a vertical migration route for mesopelagic species and larvae during diel feeding migrations, which can provide pulses of productivity to the rest of the slope ecosystem (Themelis 1996; Kenchington et al. 2014), and contains several sensitive ecosystems, such as coral communities and sponge aggregations (Breeze et al. 2002; Cogswell et al. 2009; Kenchington et al. 2010; Greenan et al. 2013; DFO 2014a). Certain ecologically significant and well-studied parts of the Scotian Slope EBSA have been identified as discrete EBSAs. These are the Eastern Scotian Shelf Canyons, the Northeast Channel, the Scotian Gulf Russian Hat sponge aggregation where it intersects with the upper slope, the Laurentian Channel Slope, and the Stone Fence and Laurentian Environs EBSAs (Figure 1). While some of these smaller slope-related EBSAs have been described in some detail, the larger Scotian Slope EBSA remains broadly defined (DFO 2014a). A comprehensive review of what is known about the habitats and special features of the Scotian Slope currently does not exist. The purpose of this report is to provide such a comprehensive review. The Scotian Rise is discussed as well, because the rise contains unique features such as cold seeps (e.g., the Laurentian Channel Cold Seep), and is also not well studied. The descriptions found within this report will thereby supplement the descriptions of the multiple slope EBSAs found within the offshore EBSA Science Advisory Report (DFO 2014a), and may aid in the identification of other discrete EBSAs along the slope, or in the refinement of the existing EBSAs. This report will also discuss areas where further research is required.

For the purpose of this report, the “Scotian Slope” is defined as the portion of sea floor and water column (from surface to bottom) found between the edge of the Scotian Shelf (200m) and the Scotian Rise (approximately 3000m; Han 2007; DFO 2014a), including the Eastern Scotian Shelf Canyons, Northeast Channel, Laurentian Channel Slope, and Stone Fence and Laurentian Environs EBSAs (Figure 2). The Scotian Rise meets the abyssal plains of the open ocean at approximately 5000m (Figure 2; Campbell et al. 2008; Campbell and Mosher 2014). The abyssal plains will not be described in this report. The western boundary of the Scotian Slope and Rise region, as discussed in this report, is marked by the Canada-U.S.A. border on George’s Bank, while the eastern boundary is marked by the eastern edge of the Laurentian Channel in order to encompass the Laurentian Channel and Fan (Figure 2).

Ecosystem structure is highly dependent on the physical and biological characteristics of the relevant landscape or seascape (Shmida and Wilson 1985; Kadmon and Allouche 2007; Wake et al. 2009; WWF-Canada 2009; Greenlaw et al. 2013; King et al. 2013). Therefore, where ecological data are limited, as for the majority of the Scotian Slope, descriptions of physiographic properties can help to further elucidate ecological significance. It is generally understood that certain characteristics (e.g., slope, sedimentary composition, ocean current patterns, biological habitat, productivity, geomorphological complexity) on the Scotian Slope vary from west to east and with depth, but this variation has not been explored or described in detail. Below 3000m, the Scotian Rise is more homogenous in terms of sedimentary composition and slope, but some unique features are present there as well that should be examined. In this report, available data, literature, expert knowledge, and ecological theory are used to offer a general description of the various habitats and ecosystems that occur, or may occur, within the Scotian Slope and Rise region. Here, the Scotian Slope and Rise is divided into discrete physiographic regions, based on earlier divisions proposed by the World Wildlife Fund – Canada (WWF-Canada 2009). Many of these physiographic regions are further subdivided into upper an lower portions based on changes in bathymetry, geomorphology, geology, oceanography, and ecology, and are described separately in Section 3. How and why these regions were identified is explained in Section 2. Special features within these physiographic regions are also described. Geological, oceanographic, and ecological information is considered in these descriptions. The final product, found in the Discussion section, is a set of two maps: 1) of the physiographic regions, and 2) of the special features within, which may fit the criteria for EBSA status. Whether or not these special features meet DFO EBSA criteria (found in DFO 2014a) is also discussed, as well as potential next steps towards continued refinement of the Scotian Slope EBSA. All figures were made using ArcMAP 10.1.

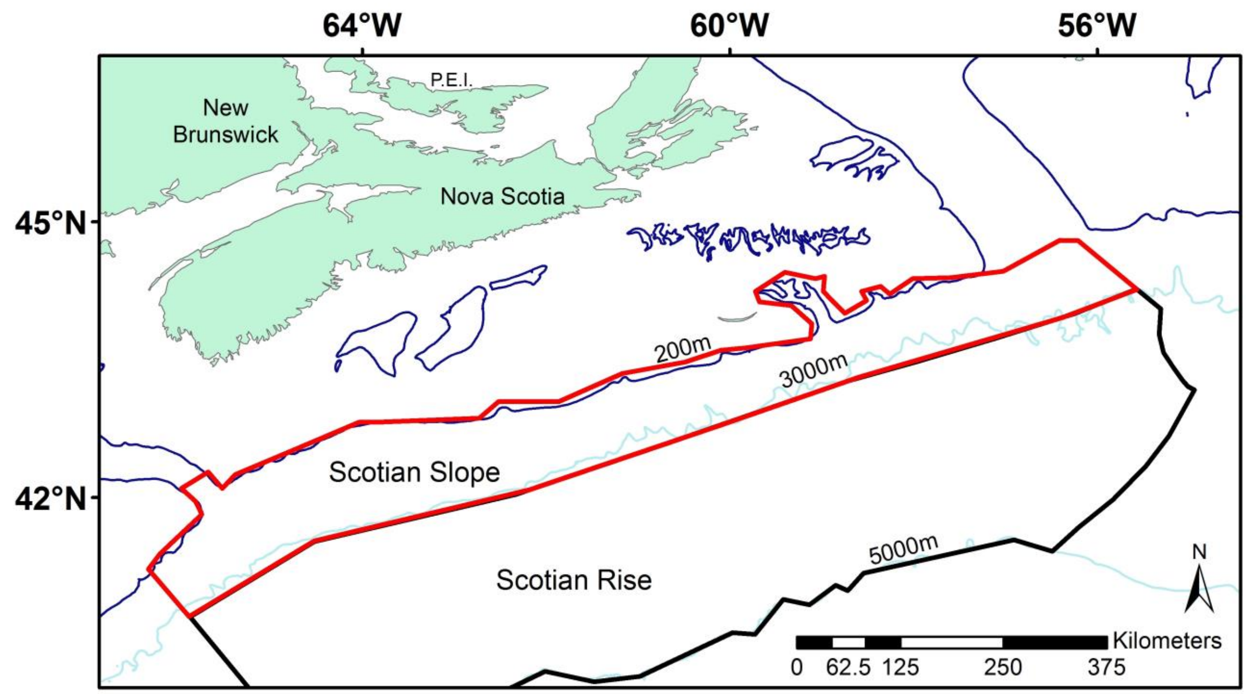

Figure 2. The Scotian Slope (200-3000m) and Rise (3000-5000m) region discussed in this report.

2.0. THE SCOTIAN SLOPE AND RISE

The Scotian Slope was strongly influenced by past glacial activity, which impacted the slope differentially from east to west. At times of ice sheet maxima, glacier ice was grounded on the upper slope to water depths of 600m (Piper and Campbell 2002). In the east, canyons were eroded by glacial meltwater, depositing thick sediments onto the lower slope (600-3000m), continental rise (3000-5000m), and abyssal plains (Campbell et al. 2008). Elsewhere, the slope experienced rapid sedimentation of mud (David Piper, NRCan, pers. comm.). Since ice retreat, some erosion has continued on the upper slope and in the submarine canyons, exposing glacially deposited bedrock (Edinger et al. 2011; David Piper, NRCan, pers. comm.). Sandy sediments from the shelf continue to be transported downslope via canyons and channels (Campbell et al. 2008). Where there are major channels or very large canyons (e.g., The Gully), transported sand and gravel dominate the landscape of the lower slope and rise over wide areas (Campbell and Mosher 2014).

Patterns of physical oceanography also differ from east to west and with depth along the slope. The upper slope is generally characterized by a strong southwest flow of a branch of the Labrador Current called the Shelf-Edge Current (Figure 3; Loder et al. 1998; Xue et al. 2000; Brickman and Drozdowski 2012; Wu et al. 2012; Brickman et al. in press). This water body is generally less saline and cooler than the water flowing over the lower portions of the slope. The lower slope experiences more mixing of the Shelf-Edge Current and Gulf Stream. The water body characterizing this portion of the slope is often referred to as “Warm Slope Water” (Themelis 1996; Kenchington et al. 2014) and harbours different mesopelagic communities than the cooler waters of the upper slope.

In the east and along the slope off George’s Bank, presence of canyons induces tidal currents and vertical mixing (Bell 1975; Baines 1982, 1983), and the transportation of wave energy from the open ocean onto the shelf (Gordon and Marshall 1976). In the west, deep basins on the shelf cause an influx of slope water onto the shelf and a reciprocal transport of shelf water onto the slope (Figure 3; Brickman et al. in press). The two major channels of the region, the Northeast Channel and the Laurentian Channel, as well as a feature called the Scotian Gulf, also foster major exchanges of shelf and slope waters (Figure 3; Brickman et al. in press). At the Northeast Channel, slope water is transported into the Gulf of Maine (creating highly energetic habitat, ideal for filter-feeding organisms), where it is mixed with shelf waters via highly energetic tidal currents (Loder et al. 1998). The warm, energetic nature of the waters in the Gulf of Maine (Loder et al. 1998), including over George’s Bank and Slope, creates different environmental conditions, including higher productivity (Fuentes-Yaco et al. 2015), when compared to the rest of the Scotian Slope. Current flow out of the Laurentian Channel creates a similar energetic environment to the Northeast Channel, though at cooler temperatures and lower salinity (Edinger et al. 2011).

Differences in geomorphology, surficial geology, and physical oceanography from east to west along the slope are examined here in terms of how they form very different habitat types. The various broad-scale habitat types of the Scotian Slope are hereafter referred to as physiographic regions. The heterogeneity of physiographic regions along the Scotian Slope fosters a wide diversity of organisms and ecosystems (concept of habitat heterogeneity fostering biodiversity reviewed in Tews et al. 2004). Due to the high cost of exploring deep waters, and the difficulty of trawling rocky, steep, complex bathymetry, the ecology of the Scotian Slope is not well studied. However, much can be inferred about the various ecosystems of the Scotian Slope from available data, expert knowledge, and knowledge of variation in geomorphology, surficial geology, and physical oceanography. This report will explain the logic behind the delineation of each physiographic region, and will describe the various ecosystems they support, including particularly special features (e.g., areas of especially high coral abundance or diversity, rare species aggregations, unique ecosystems, etc.). Geological, bathymetric, and oceanographic data used to delineate the physiographic regions were obtained from the Geological Survey of Canada, Canadian Hydrological Service (2004), and DFO respectively.

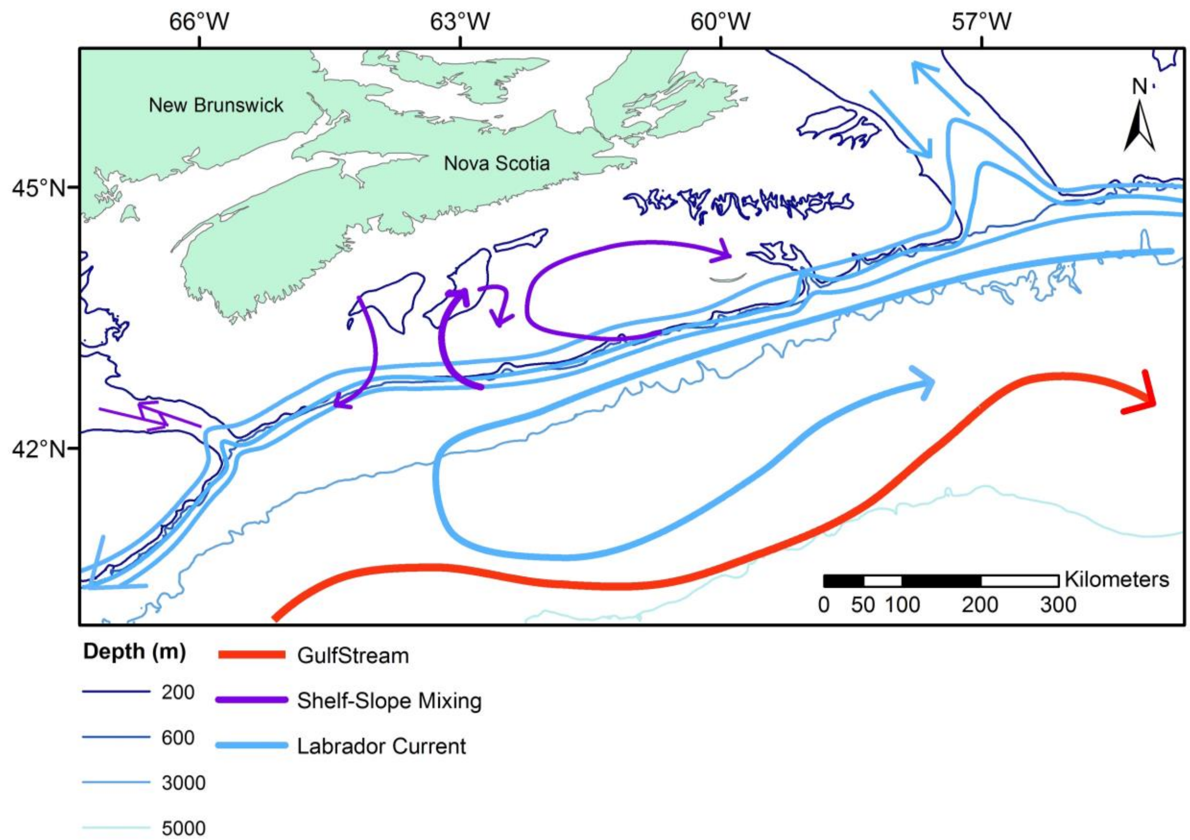

Figure 3. A simplified depiction of the direction and relative temperatures (blue is colder, red is warmer, purple is intermediate, i.e., a mixture of warm slope water and cold shelf water) of ocean currents impacting the Scotian Slope. The Gulf Stream carries warm water from the Gulf of Mexico, while the Shelf-Edge Current, a branch of the Labrador Current, carries cold water from the Labrador Sea. This figure is a modification of Figure 1 of Brickman et al. (in press), and Figure 2 of Brickman and Drozdowski (2012).

In response to a need for data to inform ecosystem-based management, efforts have been made to explore the Scotian Slope in recent decades. Some particularly unique portions of the slope have been described, although much is yet to be studied. One of these unique features is the The Gully, the largest submarine canyon off the east coast of North America. This feature has been studied extensively due to its significant diversity and abundance of deep-sea corals (Breeze et al. 1997; Hargrave et al. 2004; Cogswell et al. 2009; Kenchington et al. 2010; DFO 2014a), and its importance to an endangered population of Northern Bottlenose Whales (Moors-Murphy 2014). For these reasons, it was designated a marine protected area (MPA) in 2004 (DFO 2008).

Information about The Gully and surrounding canyons contributes to our understanding of canyon ecology on the Scotian Slope in general. Additional ecological surveys have been conducted in other submarine canyons and areas of known coral abundance (Cogswell et al. 2009), some of the findings of which will be discussed in following sections; other findings from exploratory dives and photos taken by industry are yet to be documented as data require further analysis (Anna Metaxas, Dalhousie University, pers. comm., and Ellen Kenchington, DFO, pers. comm., respectively). Other data sources will also be used to describe the ecology of the physiographic regions and special features. Some strata on the less steep western portion of the slope have been explored during the annual DFO Research Vessel Trawl Survey since 2010, and the shelf edge along the entire slope has been surveyed since 1970 (Clark and Emberley 2011). These data, and data from the DFO At Sea Observer program (DFO 2012), aid in the examination of ecological differences among physiographic regions. Furthermore, the DFO Maritimes Cetacean Sighting Database (DFO 2014b) and other observer data (OBIS 2015) provide useful distribution data for cetaceans. Published information of similar oceanographic regions, as well as expert knowledge, will further supplement the available data.

As previously mentioned, the physiographic regions delineated in this report (Figure 4) were modified from those proposed in an earlier report by the World Wildlife Fund – Canada (WWF-Canada 2009). These divisions were deemed appropriate given the current state of knowledge of the geology, geomorphology, and oceanography of the Scotian Slope. However, it should be noted that many of the delineated physiographic regions, particularly those found below 3000m, still require ground-truthing, i.e., exploration to determine whether these regions are in fact physiographically, and/or ecologically distinct from surrounding areas. Heeding expert advice (David Piper, NRCan, pers. comm.), some modifications were made to those WWF physiographic regions for which updated information exists. The physiographic regions as described in this report are: the Laurentian Channel and Fan, Upper Eastern Scotian Slope (UESS), Lower Eastern Scotian Slope (LESS), Upper Western Scotian Slope (UWSS), Lower Western Scotian Slope (LWSS), Northeast Channel and Fan, Upper George’s Slope (UGS), Lower George’s Slope (LGS), Scotian Rise, Scotian Rise Debris Flow, and Gully Fan (Figure 4).

Consideration of upper (200-600m) and lower (600-3000m) portions as separate physiographic regions is unique to this report and based on surficial geology (Piper and Campbell 2002; David

Piper, NRCan, pers. comm.). Generally, the upper slope is complex and sand-filled in the east, and relatively flat and sand and gravel-filled in the west, while the lower slope consists mainly of bioturbated mud and sand transported down-slope by canyons and channels (Piper and Campbell 2002). A further modification of the WWF-Canada (2009) divisions is that the division between eastern and western slope regions is defined by changes in surficial geology in addition to bathymetry (e.g., canyons vs no canyons). In the WWF report (WWF-Canada, 2009), this division was placed just west of Verrill Canyon (WWF-Canada 2009), likely based on bathymetry alone. Here, the division is placed along the western ridge of Mohican Channel. East of Mohican Channel, sediment cover on the upper slope is mostly sand, and sediment cover on the lower slope and rise is mostly mud. West of Mohican Channel, sediment cover on the upper slope has more gravel, and high backscatter in sidescan sonar data suggests the 1m thick surface layer of mud may be underlain by other glacially deposited sediments on the lower slope (David Piper, NRCan, pers. comm.). This could also indicate a higher occurrence of sand, likely transported via the Northeast Channel (David Piper, NRCan, pers. comm.). The channels are considered distinct physiographic regions, as in the WWF-Canada report (2009), because their physical oceanography and historical processes of sediment transport create habitats that are unique to the rest of the slope. For example, the Laurentian Fan consists of thick layers of deposited sand and gravel, which are scoured by channels, creating rough terrain, which is unique in relation to the rest of the Scotian Rise (Piper 2001). The slope off George's Bank, hereafter referred to as "George's Slope", is considered a discrete physiographic region, as in the WWF-Canada report (2009), because of the influence of highly energetic Gulf of Maine waters (Loder et al. 1998), high productivity (Fuentes-Yaco et al. 2015), and the Gulf Stream (Figure 3). Finally, the Scotian Rise is considered one physiographic region, as in the WWF-Canada report (2009), because sediment cover and bathymetry are generally homogeneous across the entire rise (David Piper, NRCan, pers. comm.). As data are limited, especially in deeper regions (lower slope and rise), other physiographic regions and special features could be identified with more research.

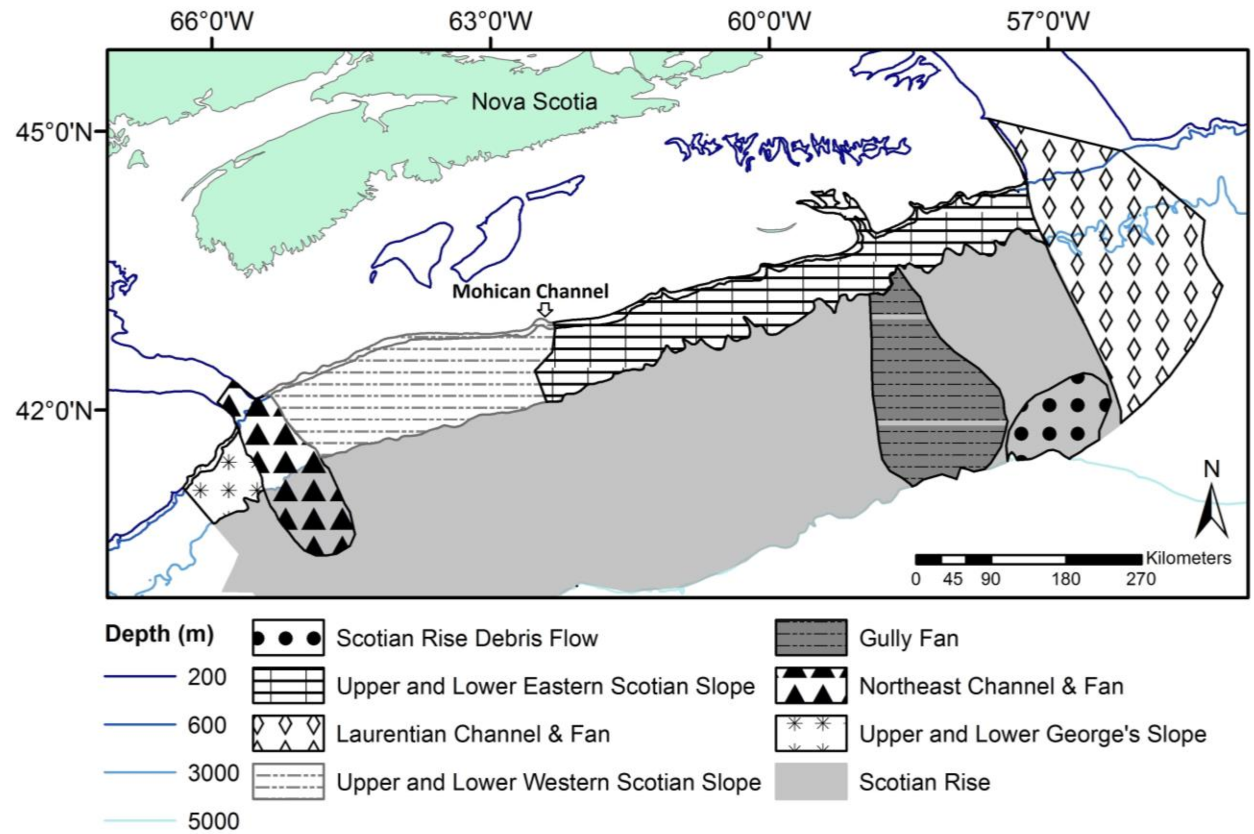

Figure 4. The physiographic regions of the Scotian Slope and Rise as delineated and discussed in this report: The Laurentian Channel and Fan, the Scotian Rise Debris Flow, the Gully Fan, the Upper (200-600m) and Lower (600-3000m) Eastern Scotian Slope, the Upper (200-600m) and Lower (600-3000m) Western Scotian Slope, the Northeast Channel and Fan, the Upper (200-600m) and Lower (600-3000m) George's Slope, and the Scotian Rise; adapted from WWF-Canada (2009).

3.0. PHYSIOGRAPHIC REGIONS AND SPECIAL FEATURES

Each physiographic region will be discussed below in terms of its physical oceanography, surficial geology and geomorphology, and ecology. Any special features within each region will also be described. Links among surficial geology and geomorphology, physical oceanography, and ecology are made evident, as these characteristics are strongly linked (Haffner 1952; Zelck and Klein 1995; Themelis 1996; Kostylev et al. 2001).

3.1. LAURENTIAN CHANNEL AND FAN

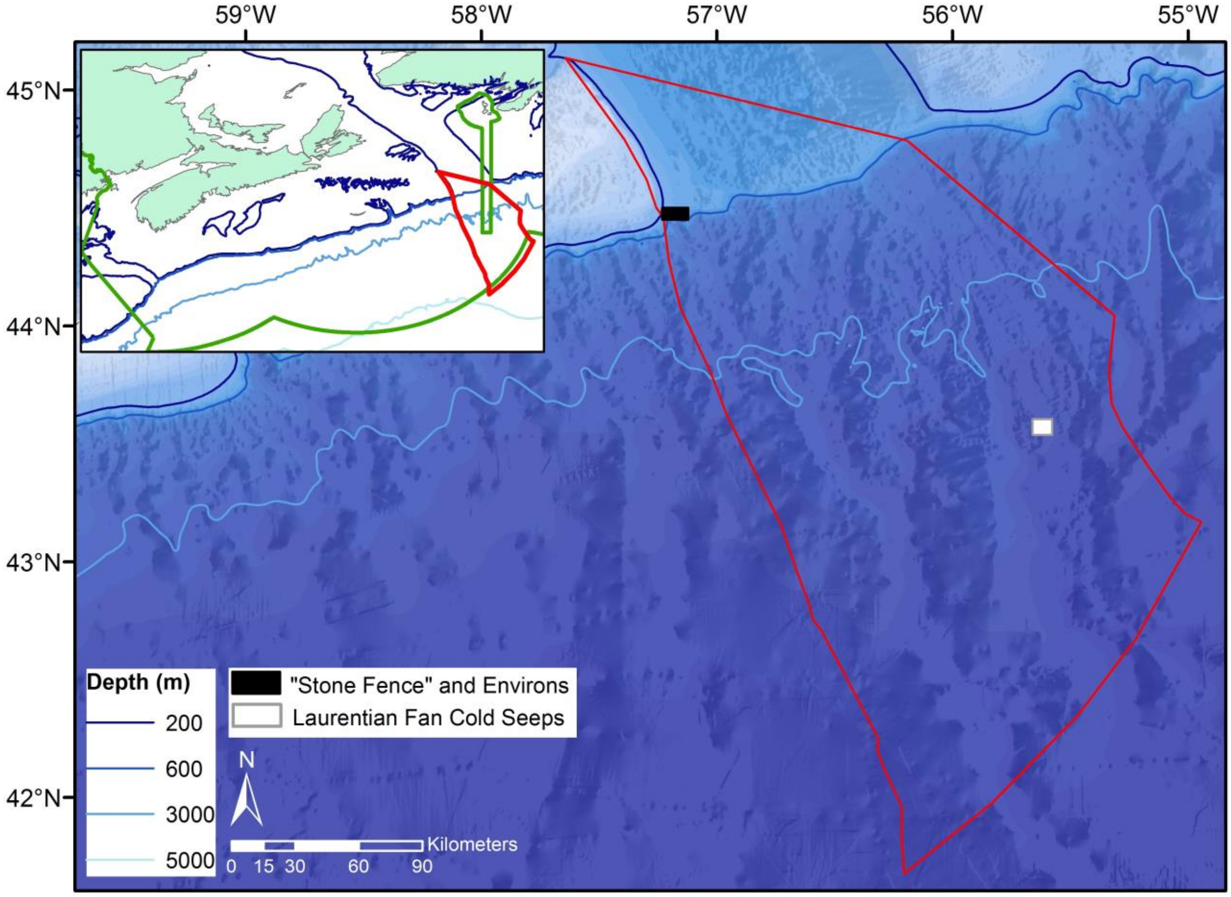

Figure 5. Bathymetry of the Laurentian Channel and Fan (Canadian Hydrographic Service 2004) and location of cold seep community and Stone Fence (DFO 2014b). Polygon of physiographic region modified from WWF-Canada (2009).

Physical oceanography

The Laurentian Channel and Fan physiographic region is located within and downslope of the Laurentian Channel (Figure 5). Branches of the Labrador Current flow out of, over, and into the Laurentian Channel, and so it is the main oceanographic influence in this physiographic region (Figure 3). The Shelf-Edge Current (a branch of the Labrador Current) flows into the Laurentian Channel along the eastern edge and flows back out along the western wall of the channel and then southwest along the shelf edge (Figure 3; see also Brickman and Drozdowski 2012; Brickman et al. in press). Outflow of the other branch of the Labrador Current from the Gulf of St. Lawrence impacts the deeper portions of the channel and fan in concert with the Gulf Stream (Figure 3).

Surficial Geology and Geomorphology

The walls of the Laurentian Channel at the shelf edge are steep, with cobbles and boulders exposed through past glacial erosion, and cemented glacial tills over bedrock (Edinger et al.

2011). This area is called the Stone Fence. High current flow here limits the accumulation of sand, which can smother corals (Ramp et al. 1985; Cogswell et al. 2009; Edinger et al. 2011). At around 1000m depth, the Stone Fence is high slope environment characterized by eroded bedrock (Edinger et al. 2011). From the mouth of the channel, past transportation of sediment formed a large submarine fan of mostly sand and gravel, which is laid over the entire slope and terminates at approximately 5200m (WWF-Canada 2009). The fan sediments were disrupted in 1929 by a large earthquake, which exposed quaternary mudstone, authigenic crust, and created cold seeps in some areas (Mayer at al. 1988; Edinger et al. 2011).

Ecology

The Laurentian Channel and Fan physiographic region contains important habitat for redfish species (COSEWIC 2010), and potentially White Hake, Greenland Halibut, Haddock, and Witch Flounder as well (Appendices 3.1 and 3.2). Tagging studies show that this physiographic region may be important summer feedings grounds for Leatherback Turtles in their annual migration north from their many southern breeding grounds (DFO 2011). This area is also frequented by Longfin Pilot Whales (Appendix 2; Jacques Whitford Environment Limited 2003), and is likely visted by Leach's Storm-Petrel (*Oceanodroma leucorhoa*), Black-legged Kittiwake (*Rissa tridactyla*), Northern Fulmar (*Fulmarus glacialis*), Cory's Shearwater (*Calonectris borealis*), other shearwaters, and Northern Gannett (*Sula bassana*), which tend to feed at the shelf edge, particularly in productive areas (Allard et al. 2014; Karel Allard, Environment Canada, pers. comm.). The rocky western wall supports an abundance of cold-water corals (Cogswell et al. 2009), which provide important habitat for some groundfish species (Husebo et al. 2002; Edinger et al. 2007). In much deeper waters (~3800-3900m), the exposure of bedrock via sediment failure, and the subsequent seepage of hydrogen sulphide, methane, and other hydrocarbon-rich fluids fuel a rare cold seep community on the Laurentian Fan (Mayer et al. 1988).

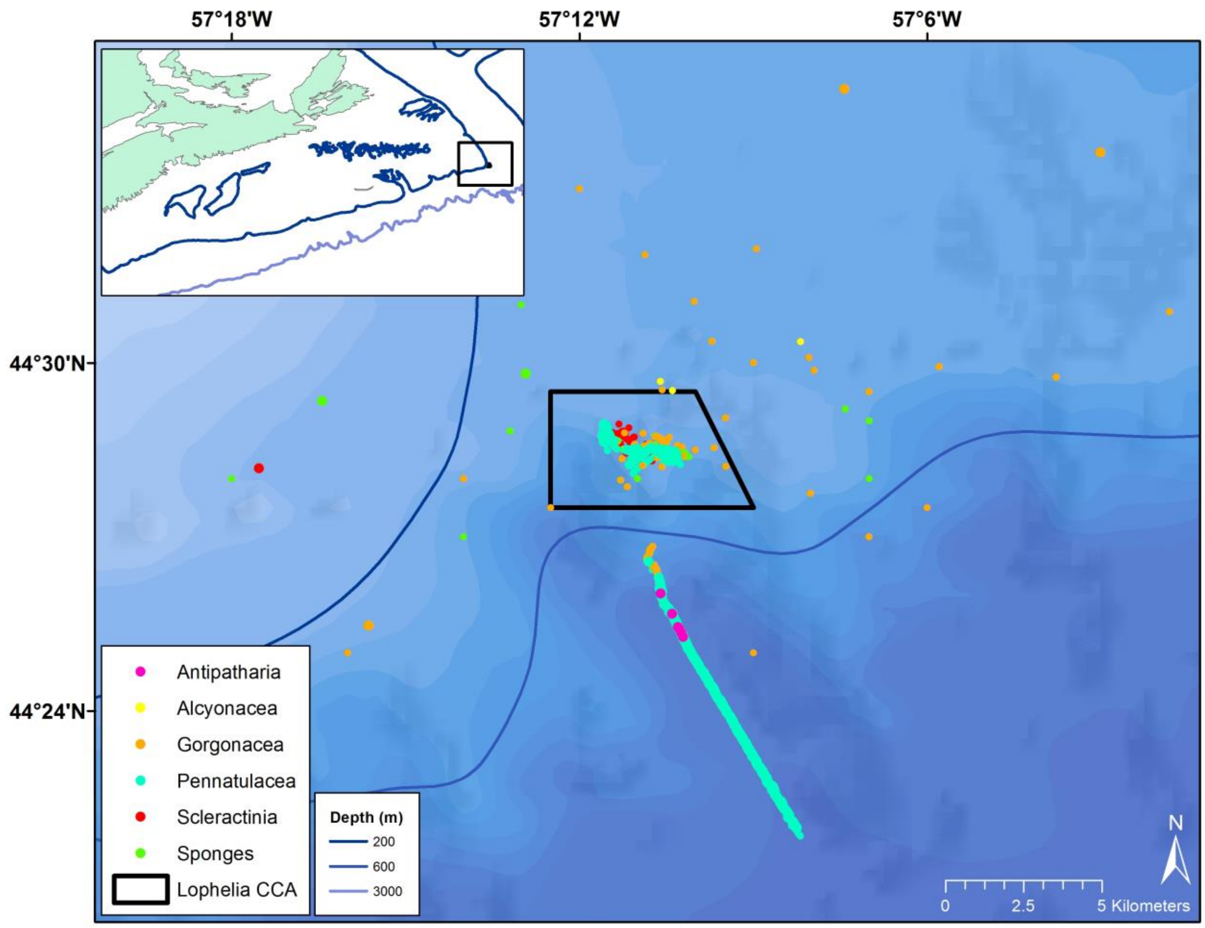

Figure 6. The current boundaries of the Lophelia Coral Conservation Area (Lophelia CCA) and Stone Fence EBSA (solid black outline), and observations of various coral species inside and outside those boundaries. Data obtained from DFO research vessel groundfish trawl survey data housed in DFO's Virtual Data Centre (VDC), DFO Science Survey Data, NRCan Science Survey Data, and Fisheries Observer Program data stored in DFO's Virtual Data Centre for the years 1965-2015. Note that effort is scattered in space and time.

Special feature: Stone Fence

As a result of the high and consistent current flow and transport of nutrients from the St. Lawrence River out to the open ocean, large Gorgonian, Scleractinian, and Antipatharian corals are abundant on the exposed cobble and bedrock of the western walls of the Laurentian Channel at the shelf edge (Appendix 1; Cogswell et al. 2009; Edinger et al. 2011). Sponges and seapens are also abundant here (Figure 6). This area contains the only known deep-sea coral reef of the stony coral, *Lophelia pertusa*, in the entire Northwest Atlantic Ocean (Cogswell et al. 2009); however, this reef has largely been reduced to rubble. The Lophelia reef suffered major damage by frequent trawl fishing activity in the past, mainly targeting redfish species, which tend to be associated with corals (Mortensen and Buhl-Mortensen 2005; Edinger et al. 2007; Henry and Roberts 2007). The Lophelia reef has been protected via the Stone Fence Lophelia Coral Conservation Area since 2004 in the hopes that it would recover from the damage caused by the trawling activity, however, there have been few signs of recovery. Due to the presence of a diversity of other coral species to the south of the currently delineated conservation area (Figure 6), it is suggested that the boundaries of this conservation area be expanded appropriately (Cogswell et al. 2009). It is also suggested here that a larger area than that considered in the Scotian Shelf EBSA report (Figure 5; DFO, 2014a) be considered as a special feature of the Laurentian Channel and Fan physiographic region in order to capture these additional observations below 600m (Figure 6). Given that only a small fraction of this region has been explored (Cogswell et al. 2009), and there is evidence of coral presence outside the Lophelia conservation area boundaries (Figure 6; Cogswell et al. 2009), further research should be done to describe the ecology of these surrounding areas. In fact, exploratory surveys have been conducted in these areas by the DFO Maritimes region Benthic Ecology group (led by Dr. Ellen Kenchington); however the video and photo data have not yet been analysed or published (Lindsay Beazley, pers. comm.). When available, data from these surveys will provide more information regarding the coral community composition surrounding the Lophelia Coral Conservation Area (Lophelia CCA in Figure 6).

Special feature: Laurentian Fan cold seeps

At around 3800-3900m on the Scotian Rise, the Laurentian Fan supports a unique community referred to as a “cold seep” (Figure 4; Mayer et al. 1988). The Laurentian Fan cold seep was identified as an EBSA because of its uniqueness to our region, biological diversity, and productivity (DFO 2014a); although biologists have yet to comprehensively describe the ecosystem (Petrecca and Grassle 1990). This cold seep is thought to have been established after the 1929 Grand Banks earthquake exposed underlying (historically deposited) hydrocarbon-rich matter, which fuels chemosynthesis (Mayer et al. 1988). Little is known about the structure and function of this ecosystem, but cold seep communities elsewhere are generally dominated by large bivalves related to the family *Mytilidae* (MacDonald et al. 1989; Jollivet et al. 1990; Van Dover et al. 2003). Given the paths of deep ocean currents, it is possible that the Laurentian Channel cold seep may act as an important stepping stone in the long-range dispersal of cold seep communities between the Blake Ridge cold seep in the western Atlantic, and the cold seeps of the western European and African continental margins (Van Dover et al. 2002; Van Dover et al. 2003).

Similar cold seep communities, likely formed through the exposure of historical sediments, have been observed to support coral growth over time (Edinger et al. 2011), and have a wide range of associated fauna, including cnidarians, annelids, arthropods, nemetodes, and echinoderms (Van Dover et al. 2003). The Laurentian Fan cold seeps, as well as other areas along the Scotian Slope where cold seeps could be found, should be explored to determine the ecological structure, diversity, and importance of these communities.

3.2. UPPER AND LOWER EASTERN SCOTIAN SLOPE (UESS AND LESS)

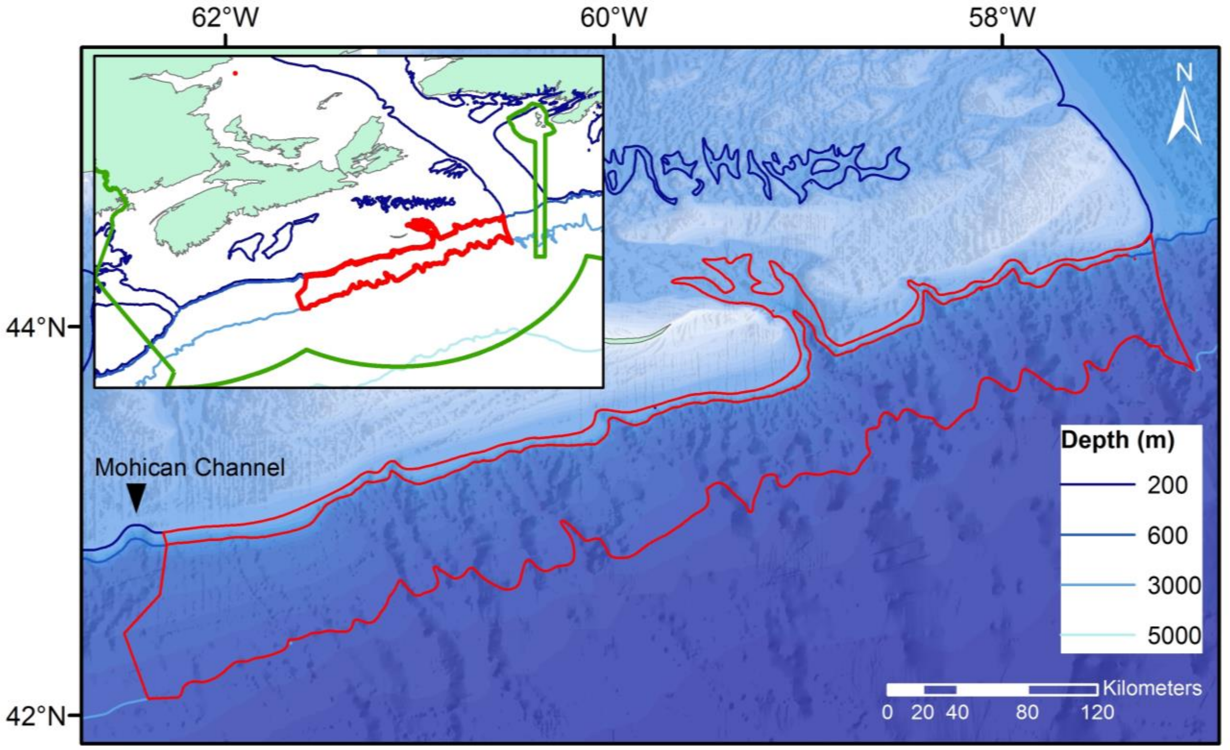

Figure 7. Bathymetry of the Upper and Lower Eastern Scotian Slope (UESS & LESS). Data were obtained from the Canadian Hydrographic Service (2004). The UESS ranges from 200-600m depth, while the LESS ranges from 600-3000m depth. Polygon modified from WWF-Canada (2009).

Physical Oceanography

The ESS, especially the UESS (Figure 7) is highly impacted by the strong southwestward flow of the cold Shelf-Edge Current (Brickman and Drozdowski 2012). The LESS is impacted by mixing of the Shelf-Edge Current and the Gulf Stream. The steep, deep, shelf-incising canyons create the perfect conditions for enhanced vertical mixing and internal waves (Klink 1988; Allen 1996; Chen and Allen 1996; Greenan et al. 2013). These canyons also act as conduits for transporting open ocean wave energy to the inner shelf (Gordon and Marshall 1976).

Surficial Geology and Geomorphology

The ESS is dominated by submarine canyons, rocky substrates (i.e., exposed bedrock from glacial erosion of the canyons), and steep slopes (Figure 7). In the UESS (200-600m), the shelf edge, floors of the canyons, and intercanyon areas are covered mostly in fine sand (Piper and Campbell 2002), underlain by sand and gravel deposits from the late Pleistocene and early Holocene (Campbell et al. 2008). The canyons form valleys and ridges in the LESS. The valleys of the LESS (600-3000m) are filled mostly with bioturbated mud and overlaying bedrock, while the ridges of the LESS are generally dusted with a layer of fine sand transported by the canyons (Piper and Campbell 2002). Sand and glacial till are transported from canyon heads downslope through the valleys and into submarine fans on the Scotian Rise, which can reach, at least in the case of The Gully, as far as 5000m.

The “eastern canyons”, which include The Gully, Shortland, and Haldimand Canyons (DFO 2014a) (Figure 8), are the largest (i.e., steepest, deepest, and widest) of the canyons in the ESS. The walls of these canyons are mainly sandstone, mudstone, and shale that were exposed by glacial melt-water erosion (Cameron and King 2008), with recently deposited sand intervening (Piper and Campbell 2002). Further west are the other canyons of the ESS, which include Logan, Bonnecamps, Dawson, and Verrill Canyons. These canyons are smaller, gentler in slope, and less-studied than the eastern canyons, but have more interconnected channels. All of the ESS canyons have generally the same geological makeup from 200-600m (UESS) where the canyon walls are made up of exposed sandstone and mudstone with some outcropping boulders and cobbles, and the heads and floors are covered in fine sand (Campbell et al. 2008). However, inter-canyon areas in the western part of the LESS are broader than the areas between the eastern canyons (Campbell et al. 2008; Campbell and Mosher 2014). Further, the slope-confined canyon, Bonnecamps, is filled with mud from its head to its terminal end (Piper 2001; Jenner et al. 2007).

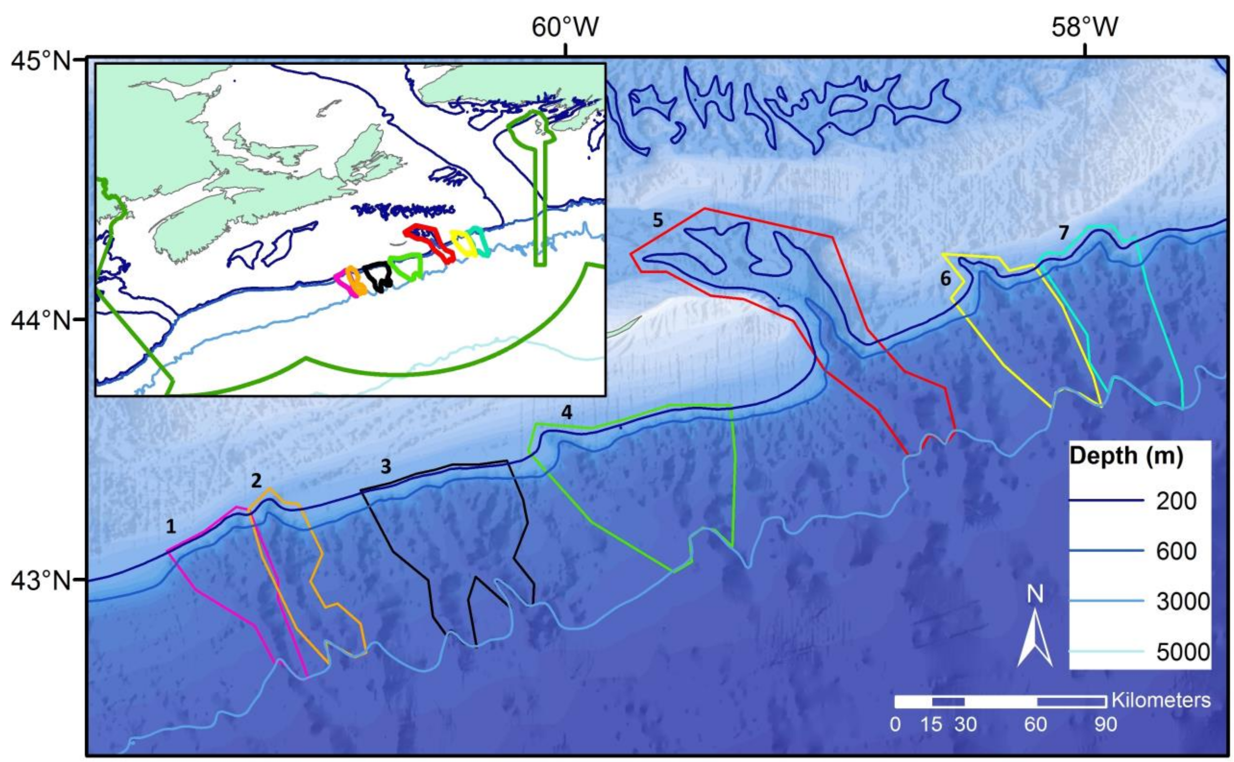

Figure 8. The submarine canyons of the ESS, from left to right: 1) Verrill, 2) Dawson, 3) Bonnecamps, 4) Logan, 5) The Gully, 6) Shortland, and 7) Haldimand. Canyons are only delineated to 3000m. Depth contours were obtained through the Canadian Hydrographic Service (Canadian Hydrographic Service 2004).

Ecology

Enhanced vertical mixing and internal waves within the ESS canyons (Klink 1988; Allen 1996; Chen and Allen 1996; Greenan et al. 2013), stimulates productivity, and limits sedimentation at the canyon heads and walls (Campbell et al. 2008). These conditions promote the abundance of vertically migrating zooplankton (Rutherford and Breeze 2002), and the attachment of sessile invertebrates to the rocky canyon walls and outcrops, which feed on the nutrients and living organisms floating in the water column (Edinger et al. 2011). Sessile invertebrates, such as corals and sea pens, enhance habitat complexity and provide shelter, feeding grounds, and nursery grounds for many other benthic creatures, including fish (Roberts et al. 2006; Henry and Roberts 2007; Baker et al. 2012). It has been found that there is a positive correlation between cold-water coral diversity and the diversity of benthic megafauna in this region as well as in similar habitats in the Northeast Atlantic (Mortensen and Buhl-Mortensen 2005; Henry and Roberts 2007).

The eastern canyons, especially The Gully, are considered important habitat for cold-water corals; these canyons contain a wide diversity and high abundance of these animals (Appendix 1) and their associated fauna (Breeze et al. 1997; Roberts et al. 2006; Edinger et al. 2007; DFO 2008; Cogswell et al. 2009), e.g., fish (Appendix 3). It appears that the existence of hard substrates and complex habitat are important determinants for occurrence of corals of the orders Gorgonacea (tree corals, bubblegum corals, sea whips, sea fans, etc.) and Scleractinia (stony corals) (Bryan and Metaxas 2007; Cogswell et al. 2009; White and Dorschel 2010; Edinger et al. 2011).

In addition to maintaining high coral diversity and abundance, the ESS is thought to contain the most important habitat for beaked whales in the entire Scotian Shelf and Slope region, likely because of the size and productivity of the eastern canyons (Moors-Murphy 2014). Sightings of Blue Whales (*Balaenoptera musculus*), Northern Bottlenose Whales (*Hyperoodon ampullatus*), and Longfin Pilot Whales (*Globicephala melas*) are abundant in and around these canyons (Appendix 2). Sowerby’s Beaked Whales (*Mesoplodon bidens*) are also known to occur here (Appendix 2). Sperm Whales (*Physeter macrocephalus*) may also benefit from the productive habitat provided by the eastern canyons, but are abundant across the entire Scotian Slope, not just in canyons (Appendix 2). The eastern canyons are now protected as Critical Habitat for the endangered Northern Bottlenose Whale (DFO 2009). The ESS Northern Bottlenose Whale population is genetically distinct from more northern populations of the species, and is at the southern-most limit of the species’ range (Dalebout et al. 2001). There are only 160 individuals in this population, which have all been sighted regularly in The Gully, Shortland, and Haldimand Canyons (Hooker et al. 1999; Wimmer and Whitehead 2004; DFO 2009; Moors-Murphy 2014). These characteristics make this population especially vulnerable to anthropogenic and climate change-related stressors. The population’s vulnerability contributed to the designation of The Gully as an MPA. The small inter-canyon areas are also productive, with whales, large pelagic fish, and the larvae of dispersing benthic fish and invertebrates found within these areas (Cogswell et al. 2009).

Less is known about the ecology of Logan, Bonnecamps, Dawson, and Verrill Canyons (compared to the eastern canyons), but they may also represent important habitat for beaked whales (Gomez-Salazar and Moors-Murphy 2014) and support soft corals (Anna Metaxas, Dalhousie University, pers. comm.).

Special feature: ESS canyons

There exist several suggestions on how to distinguish between submarine canyons (Harris and Whiteway 2011; Jobe et al. 2011; Huang et al. 2014). For the purpose of this report, the canyons of the Scotian Slope are characterized using the criteria suggested by Jobe et al. (2011). Jobe et al. (2011) describe two types of submarine canyons: 1) Type I, which incise the shelf edge, were eroded in the past by glacier melt water and turbidity currents, are filled with sand deposited in the Pleistocene and Holocene by sandy turbidity flows (erosional), and terminate in large submarine fans, and 2) Type II, which do not incise the shelf edge, are filled with mud-rich mass transport deposits from proglacial plumes and near-surface flows during the late Pleistocene (depositional), and do not terminate in submarine fans. Type I canyons may support higher biological productivity and diversity than Type II canyons because of their larger surface area, higher structural complexity (steeper, rocky walls, outcropping boulders, and sand fill, vs. shallower, with generally lower slopes and softer sediments, including mud fill) and increased vertical mixing (Greenan et al. 2013), which provides a constant supply of food. Due to these characteristics, Type I canyons often support abundant sessile organisms and generally higher biological diversity (concept reviewed in Tews et al. 2004). Further, Type I canyons tend to be closer to one another, allowing for greater habitat connectivity for mobile or dispersing organisms (Harris and Whiteway 2011). For example, the eastern canyons contained very similar coral communities and Northern Bottlenose Whales are known to travel among these canyons. Given the above descriptions, some of the ESS canyons (Figure 8) can be characterized as Type I canyons, and some can be characterized as Type II canyons (Table 1).

The deepest (to 3000m), steepest (>80° in the upper Gully), and most shelf-incising of the eastern canyons is The Gully (Figure 7; DFO 2007; Cameron and King 2008). This large canyon has many slope-confined feeder canyons to its west, but the main incising canyon is fed by a large sand-filled catchment from which sand, gravelly sand, and mud are transported downslope. The Gully was designated as an MPA under the *Oceans Act* in 2004 because of its ecological significance (Figure 6; DFO 2008). It is locally unique, and canyons of its size are globally rare.

Table 1. Characterizing the canyons of the ESS as either Type I or Type II according to the criteria of Jobe et al. (2011), and acknowledging the presence, or limitation of ecological knowledge to support their characterization as potential EBSAs. Where ecological knowledge is lacking (N), exploration of these canyons by biologists is suggested. Information on whether the canyons are sand- or mud-filled was obtained from the Campbell et al. (2008) series of maps of the surficial geology of the Scotian Slope. Whether the canyons were formed by erosional or depositional processes was then inferred given the surficial geology (rocky walls and sand fill = erosional, softer walls and mud fill = depositional). Whether or not the canyons were shelf-incising was determined by examining their bathymetry (i.e., whether the canyons heads extended onto the shelf past the 200m isobaths or not).

Canyon	**Shelf -ncising (Y/N)**	**Erosional/ Depositional**	**Sand-filled or Mud-filled**	**Type I OR Type II**	**Ecological knowledge (Y/N)**
The Gully	Y	Erosional	Sand	Type I	Y
Shortland	Y	Erosional	Sand	Type I	Y
Haldimand	Y	Erosional (likely)	Sand	Type I (likely)	Y
Logan	Y	Erosional	Sand	Type I	N
Bonnecamps	N	Depositional	Mud	Type II	N
Dawson	Y	Erosional	Sand	Type I	N
Verrill	Y (very little)	Depositional	Mud	Type II	Y (very little)

The oceanographic conditions within The Gully promote upwelling and therefore high productivity (Carter and Gregg 2002). The complexity of its walls promotes high biological diversity and its large surface area provides greater opportunities for settlement of a diversity of sessile invertebrates, which creates a range of habitat types that lead to high species richness (Hecker 1990; Hargrave et al. 2004). The Gully and the other eastern canyons, Shortland and Haldimand, are close in proximity to one another (Figure 8), and are all Type I canyons, and so have many ecological similarities. The eastern canyons host a diversity and abundance of cold water corals (Appendix 1), are important for commercially important groundfish (Appendix 3), host an abundance of Shortfin Squid, *Illex illecebrosus* (Appendix 3), an important prey species for the Northern Bottlenose Whale (DFO 2009; Gomez-Salazar and Moors-Murphy 2014), are listed as Critical Habitat for the endangered Northern Bottlenose Whale (Whitehead 2013), and are important feeding grounds for a wide diversity of seabirds, most notably Leach's Storm-Petrel, Black-legged Kittiwake, Northern Fulmar, Cory's Shearwater, and other shearwaters (Karel Allard, Environment Canada, pers. comm.). The productivity here may be a result of abundant vertically migrating mesopelagic fauna, which have been observed in The Gully, below 200m, as well as other areas along the shelf edge (Themelis 1996; Rutherford and Breeze 2002; Kenchington et al. 2014).

Currently, the eastern canyons (The Gully, Shortland, and Haldimand canyons), as a complex, are considered an EBSA (DFO 2014a), for the reasons given above. The other canyons of the ESS, especially the other Type I canyons, may also meet EBSA criteria, though supporting ecological data are limited. It has been suggested that because of their preference for canyon habitat (Figure 8) and squid (Appendix 3.4) as a food item, beaked whales, including Sowerby's Beaked Whales and Northern Bottlenose Whales, may find important habitat in Logan, Dawson, and Verrill Canyons as well (Gomez-Salazar and Moors-Murphy 2014). Indeed, there have been whale sightings in these canyons, particularly in Logan Canyon (Appendix 2). The southwestward flow of the Shelf-Edge Current is known to connect, and therefore foster biological similarities between, the eastern canyons. Since this current flows over the shelf edge and UESS in its entirety, it is likely that the other canyons are also connected, especially below 1000m where flow direction is more consistent (Brickman and Drozdowski 2012). Parts of Verrill and Dawson Canyons were explored in 2001 with a Remotely Operated Platform for Ocean Sciences (ROPOS) (Anna Metaxas, Dalhousie University, pers. comm.). They found that the bottoms of both canyons were covered in soft sediment, and the fauna consisted mostly of cup corals (order Scleractinia), soft corals (order Alcyonacea), sea pens (order Pennatulacea), anemones (order Actiniaria). However, they did not encounter a high abundance of corals as is present in the eastern canyons. The video data from this expedition is not yet analysed, but its analysis and subsequent publication would aid in further characterization of differences in ecosystem structure among the canyons of the ESS.

Some additional DFO Summer Research Vessel (RV) trawl survey strata have been explored from 750-1800m on the LESS in intercanyon areas below Verrill, Dawson, and Bonnecamps Canyons, though these strata have only been surveyed since 2010 (Clark and Emberley 2011). The shelf edge across the entire Scotian Slope has been surveyed in the summer since 1970, though effort is limited in the ESS due to the difficulty of trawling the rocky, complex habitat (Clark and Emberley 2011). RV Survey results show that, in the summer, the ESS is inhabited mostly by large-bodied fish and skates, as well as by jellyfish, sand dollars, red deep-sea crabs, and sea urchins (Clark and Emberley 2011). The most abundant fish on the shelf edge, especially in the UESS, were redfish (*Sebastes* spp.) (Appendix 3). The most abundant species in the LESS were Greenland Halibut (*Reinhardtius hippoglossoides*), and Roundnose Grenadier (*Coryphaenoides rupestris*) (Appendix 3). These results agree with earlier exploratory trawls conducted in the area in 1994 and 1995 (Halliday et al. 2012). Redfish are highly abundant around the ESS canyons, especially Logan, Dawson, Shortland, and Haldimand at the shelf edge (Appendix 3.4), possibly as a result of the presence of corals (redfish tend to associate with sea pens as well as corals; Mortensen and Buhl-Mortensen 2005; Roberts et al. 2006; Henry and Roberts 2007). Greenland Halibut, Atlantic Halibut, Thorny Skate, White Hake, and Witch Flounder have also been found around the ESS canyons at the shelf edge (Appendix 3).

3.3. UPPER AND LOWER WESTERN SCOTIAN SLOPE (UWSS AND LWSS)

The WSS (Figure 9) is the portion of the slope west of Mohican Channel and east of the Northeast Channel. This area differs in bathymetry, surficial geology, and physical oceanography from both the eastern slope (east of Mohican Channel) and the Northeast Channel and Fan.

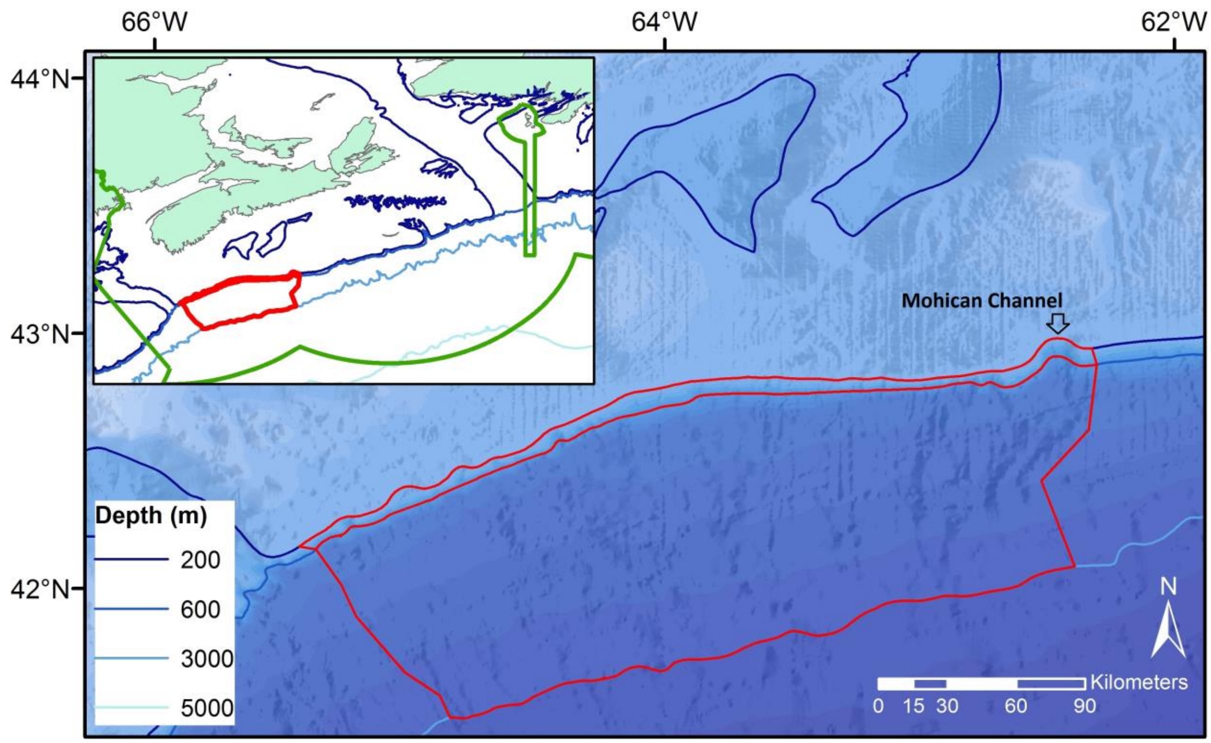

Figure 9. Bathymetry of the Upper and Lower Western Scotian Slope (UWSS & LWSS). Data were obtained from the Canadian Hydrographic Service (2004). The UWSS ranges from 200-600m depth, while the LWSS ranges from 600-3000m depth. Polygon modified from WWF-Canada (2009).

Physical Oceanography

The WSS is highly impacted by both the cold Shelf-Edge Current and the warm Gulf Stream as eddies called Warm Core Rings frequently mix the two in the deeper waters of this region (Han 2007). Incursions of warm, nutrient-rich slope water onto the shelf and flow of shelf water back down the slope occurs via a feature called the Scotian Gulf (Loder et al. 1998). This creates a unique, i.e., consistently warmer and more productive than surrounding waters (Johnson et al. 2012; Hebert et al. 2013), environment, and connects the WSS to the deep basins of the shelf.

Surficial Geology and Geomorphology

The WSS (both upper and lower portions) is the least steep and smoothest portion of the Scotian Slope. The UWSS consists mainly of sandy mud and gravel, while the LWSS consists mainly of bioturbated mud (Piper and Campbell 2002). The sediments of the UWSS and LWSS form shallow channels and ridges, and large depressions mark the occurrence of past mass sediment failures (Piper and Campbell 2002). The outflow from the Northeast Channel, also called the

Northeast Fan, deposits sandy sediments eastward onto the LWSS, and westward onto George's Slope (Campbell and Mosher 2014). The Northeast Fan and the Scotian Gulf, which is considered a debris-flow corridor transporting sediments from the deep basins of the shelf onto the slope, contribute to the homogeneous, flat nature of this region. The largely depositional landscape of the WSS could also indicate potential for cold seep communities. Indeed, using sidescan sonar, "pockmarks", which are seafloor craters formed by the venting of fluids and exposed by past sediment instability (cold seeps), are widespread throughout the LWSS (e.g., Piper 2001). These cold seeps have not yet been explored using video or photographing technology, so the ecological significance is yet to be determined. Further research is therefore required.

Ecology

Exploration of the deeper (750-1800m) strata by the annual RV trawl survey in 2010 showed that the most abundant species at these depths in summer on the LWSS is the Roundnose Grenadier (Clark and Emberley 2011). Shortfin Squid were abundant along the entire UWSS, especially near the Scotian Gulf. Redfish, Haddock, White Hake, Silver Hake, and Pollock have also been observed on the UWSS (Appendix 3). This area also hosts diverse, vertically migrating mesopelagic communities which differ between the upper slope to the lower slope (Themelis 1996), sponges (Appendix 1), including a dense aggregation of rare Russian Hat sponges (Figure 9), and fields of sea pens (Appendix 1). The productivity of this region, particularly around the Scotian Gulf, and particularly in terms of its harbouring of Russian Hat sponges, may be attributed to its warm, nutrient-rich water (Johnson et al. 2012; Hebert et al. 2013), and/or the dominance of glacial till in this area (David Piper, NRCan, pers. comm.).

Sea pens (of the order Pennatulacea) do not form reefs, and do not require hard substrate to colonize (Williams 2011; Kenchington 2014). However, they can occur in relatively high density fields on sandy or muddy bottoms anywhere between 30 and 2000m (Williams 2011) on the banks, inter-canyon ridges and channels on the LESS, and flatter portions of the slope, i.e., the WSS (Cogswell et al. 2009; Williams 2011; Appendix 3). The fact that they can occur in relatively high densities, and they increase habitat complexity in areas that would otherwise be sandy and flat, suggests that sea pens may play an important role in sandy/muddy benthic ecosystems that is not yet fully understood (Tissot et al. 2006). Sea pens can grow as tall as 1.5m and can live as long as 50 years (Kenchington 2014), meaning that sea pen fields can be highly vulnerable as a result of slow growth. Sea pens are abundant on the shelf edge and UWSS (Appendix 1). This could attract other benthic fauna, especially redfish species, which appear to coincide with the UWSS sea pen fields (Appendices 1 and 3), and are suggested to prefer sea pen and cold-water coral habitats (e.g., Roberts et al. 2006). Alcyonacean corals such as *Acanella arbuscula* and *Radicipes gracilis*, which have root-like holdfasts (Edinger et al. 2011), are also found in the soft sediments of the UWSS (Appendix 1).

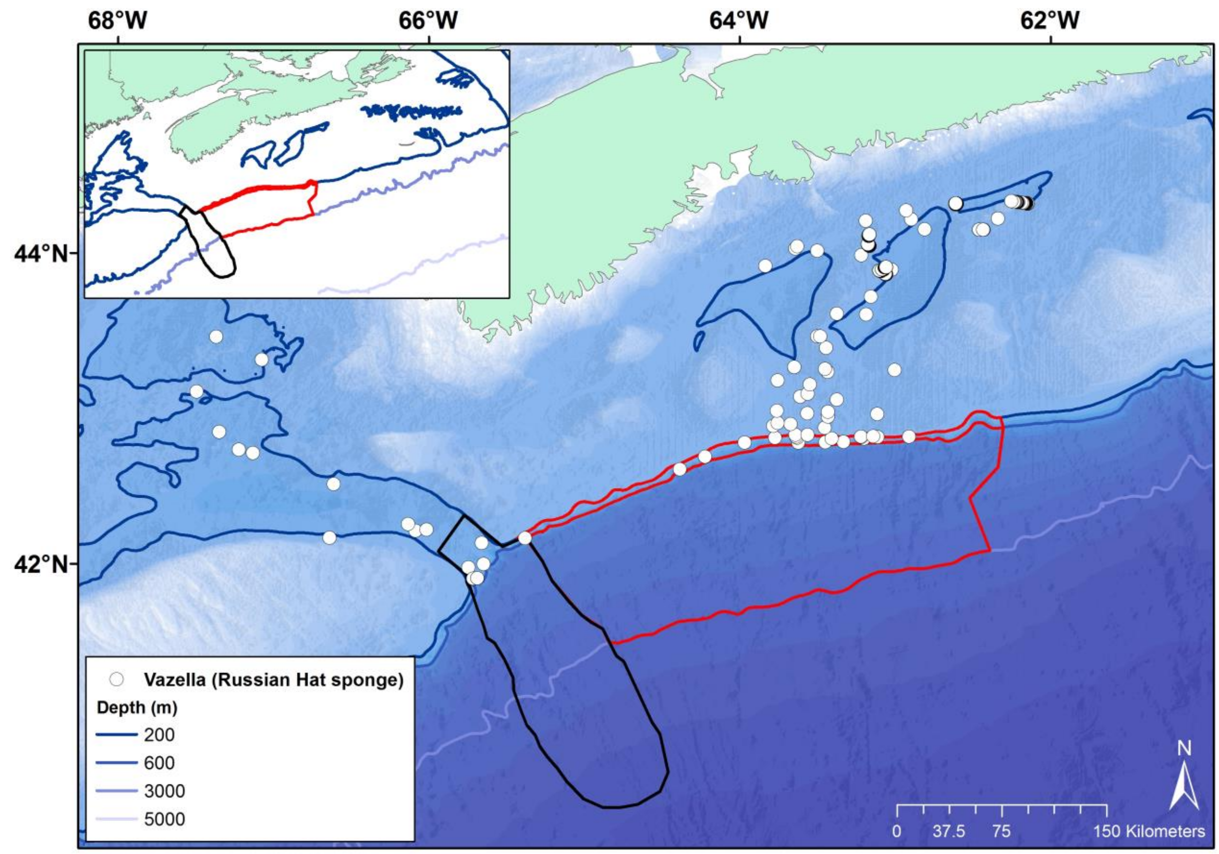

Figure 10. Russian Hat, *Vazella pouralesi*, sponge observation (presence only) obtained from DFO research vessel groundfish trawl survey data housed in DFO's Virtual Data Centre (VDC), DFO Science Survey Data, NRCan Science Survey Data, and Fisheries Observer Program data stored in DFO's Virtual Data Centre for the years 1965-2015. Note that effort is scattered in space and time. *Vazella* were known to be present along the shelf edge of the Western Scotian Slope (red), but new records indicate that this species is also present in the Northeast Channel (black).

Sponges are known to increase habitat complexity, and therefore productivity, similarly to cold-water corals (e.g., Beazley et al. 2013). Sponges have been observed on banks, in basins, in channels, and in submarine canyons (Appendix 1). A rare sponge species, *Vazella pourtalesi*, also called "Russian Hs", are abundant in the Scotian Gulf, including where the Scotian Gulf meets the UWSS at the shelf edge, and in Emerald Basin (Figure 10). The dense aggregations of this species in this area are considered globally unique (Kenchington et al. 2010, Kenchington 2014). As previously mentioned, these aggregations at the shelf edge could promote benthic productivity and attract a wide range of marine organisms. Indeed, it is widely suggested that sponge aggregations foster a higher abundance and diversity of epibenthic megafauna, similar to cold-water corals and sea pens (e.g., Beazley et al. 2013).

Special feature: Russian Hat sponges

The most notable special feature within in the WSS physiographic unit is the globally unique aggregations of Russian Hat (*Vazella pourtalesi*) sponges (Figure 10; Kenchington et al. 2010). These aggregations occur in parts of the Northeast Channel, Emerald Basin, the Scotian Gulf, and the shelf edge (Figure 10; Kenchington et al. 2010). *V. pourtalesi* has only been found in three places globally to date, and the Scotian Shelf Bioregion is the only place where this species occurs in such high densities (DFO 2013). Not only is this species of sponge rare, it is also highly vulnerable to human activities due to slow growth (DFO 2013). The Scotian Shelf *V. pourtalesi* sponge aggregation provides structural complexity to an otherwise homogenous landscape on the UWSS. These sponges may provide important shelter and habitat for other marine animals (Appendix 3), thereby promoting biological diversity and productivity (Fuller 2011; DFO 2013).

Special feature: Potential cold seeps

Given the presence of mass transport deposits, the history of sediment failure (Piper and Campbell 2002; Campbell et al. 2008), and the identification of "pockmarks" via sidescan sonar (Piper 2001), the potential existence of cold-seep communities between 500 and 1000m on the LWSS should be investigated (David Piper, NRCan, pers. comm.). More research should be done to identify cold seeps on the LWSS, and to explore the role of these communities in the larger marine ecosystem. Because the cold seeps of the Laurentian Fan are considered ecologically and biologically significant (DFO 2014a), cold seeps of the LWSS could be identified as discrete EBSAs as well.

3.4. NORTHEAST CHANNEL AND FAN

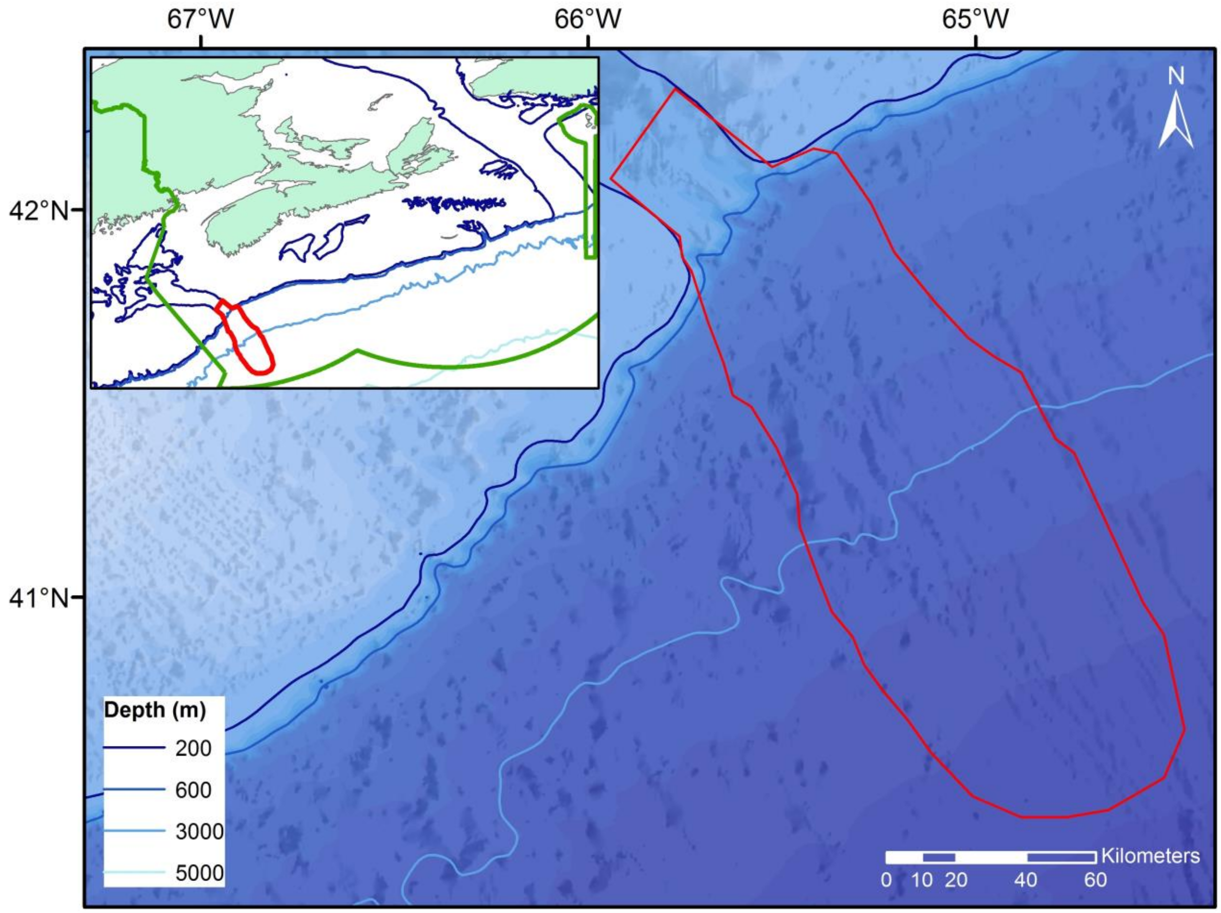

Figure 11. The Northeast Channel and Fan physiographic region (polygon obtained from WWF-Canada, 2009). Bathymetry data obtained from the Canadian Hydrographic Service (Canadian Hydrographic Service 2004).

Physical Oceanography

Strong tidal currents flow into and out of the Northeast Channel transporting water between the Gulf of Maine and the open ocean (Figure 3; Ramp et al. 1985). Warm Slope Water (highly influenced by the Gulf Stream) flows into the Northeast Channel, bringing warm, nutrient-rich water into the Gulf of Maine (Johnson et al. 2012; Hebert et al. 2013), which fosters high productivity (Figure 12; Fuentes-Yaco et al. 2015). The constant flow into and out of the channel creates constant turbulence against the channel's rocky walls, especially where the channel meets the shelf edge, and promotes mixing of nutrients, an important feature for filter-feeding organisms.

Surficial Geology and Geomorphology

The floor of the Northeast Channel consists of glacially-derived sandy and gravelly sediment, which was transported onto the slope and rise, forming a submarine fan (Edinger et al. 2011), similar to, but smaller and less rugged than the Laurentian Fan. Sand from the Northeast Fan is deposited on the slope both east and west of the Northeast Channel (Piper and Campbell, 2002). The walls of the Northeast Channel are composed of exposed bedrock, boulders and cobbles upon which a large aggregations of cold-water corals, mostly large Alcyonaceans (*Paragorgia arborea* and *Primnoa resedaeformis*), have formed (Edinger et al. 2011). Strong tidal flows supply food and prevent the settlement of sand over boulders and resident corals.

Ecology

The Northeast Channel was identified as an EBSA because it possesses high densities of large, sensitive coral species (Appendix 1), has persistently high phytoplankton biomass (Figure 12), and is an important area for Cusk, which is listed as a threatened fish species by COSEWIC (COSEWIC 2012; DFO 2014a). Indeed, it appears that the Northeast Channel and George's Slope have the highest annual mean contribution (%) of phytoplankton biomass of the entire Scotian Slope region (Figure 12). Further, Russian Hat sponges have been discovered here in recent years, leading to the suggestion that this area may also provide the unique habitat necessary for the growth of these rare sponges (Figure 10).

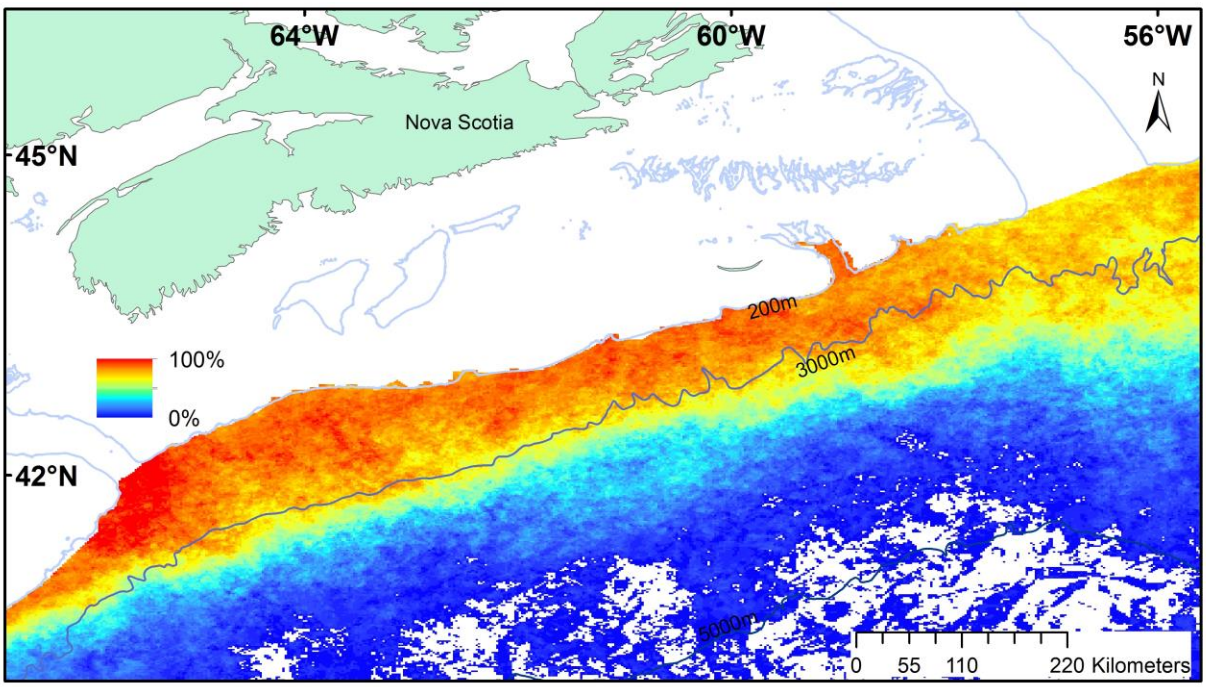

Figure 12. Relative contribution (%) to median annual phytoplankton biomass of the entire Scotian Slope (adapted from Figure 7d in Fuentes-Yaco et al. 2015), derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS_Aqua). Values of contribution are relative to the slope, not the shelf, as the slope is less productive than the shelf in absolute pigment concentrations. Phytoplankton contributions decrease from red (as high as 98%) to blue (close to 0%). Areas in white are either irrelevant to this report (shelf), or contribute 0% (some regions over the Scotian Rise, between 3000 to 5000m depth, and over the abyssal plains, deeper than 5000m).

3.5. UPPER AND LOWER GEORGE'S SLOPE (UGS AND LGS)

Physical Oceanography

The slope off the Canadian portion of George's Bank (Figure 13) is unique from the rest of the Scotian Slope. Waters in this region are derived from the Gulf of Maine, where slope and shelf waters mix and flow in and out of the Northeast Channel (Figure 3; Loder et al. 1998; Brickman and Drozdowski 2012; Brickman et al. in press). These waters are tidally energetic, and host the highest productivity of the entire slope (Figure 12; Clark and Emberley 2011; Fuentes-Yaco et al. 2015). Further, the presence of large submarine canyons likely promote vertical mixing, and transfer of wave energy onto George's Bank.

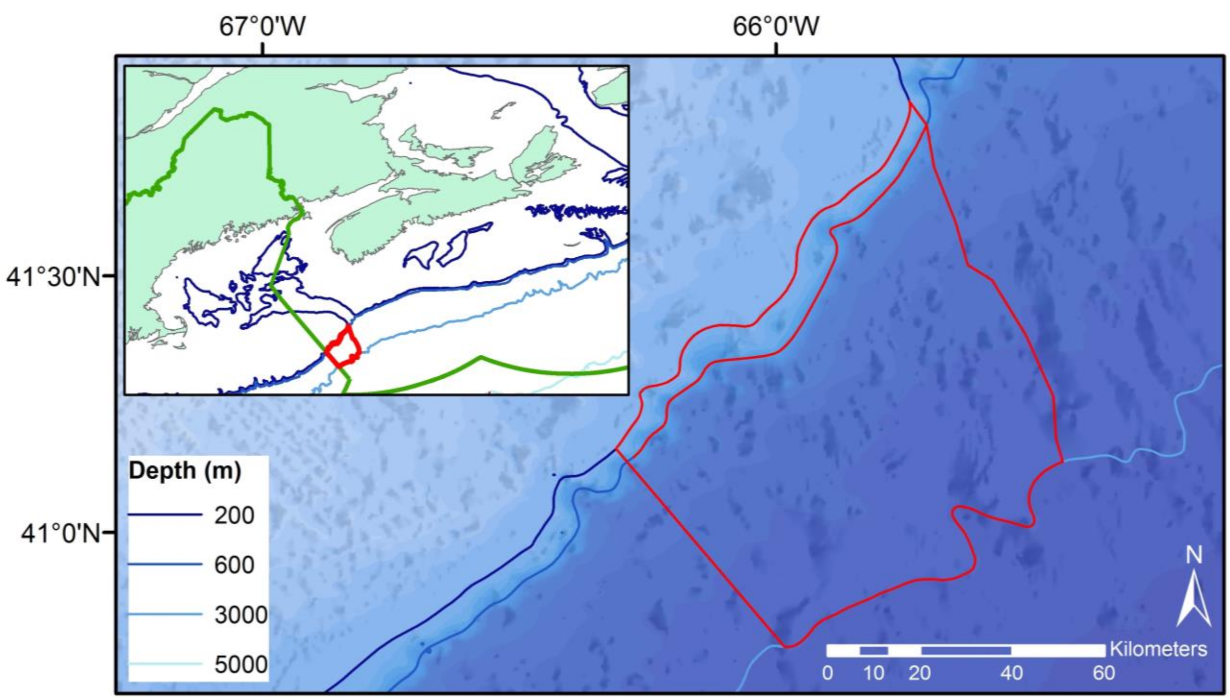

Figure 13. Bathymetry data for Upper and Lower George's Slope (UGS & LGS) obtained from the Canadian Hydrographic Service (2004) data. Higher resolution bathymetry data only exist for the upper 600m of this region (Figure 14). The UGS ranges from 200-600m depth, while the LGS ranges from 600-3000m depth. The Canada-U.S.A. boarder (green line) marks the western limit of this region.

Surficial Geology and Geomorphology

This region hosts two shelf-incising submarine canyons, Corsair Canyon and George's Canyon (Figure 14). Corsair and George's Canyons were formed via sediment collapse, and so may not be considered Type I canyons (which are formed via glacial scouring and melt-water erosion, although they both incise the shelf) (Table 2). The walls of these canyons are composed of ridges and gullies that have been formed as a result of slumping of glacially-derived mud (Valentine and Todd 2012). Although the walls of Corsair Canyon are steep and contain outcropping boulders upon which gorgonian corals have settled, the canyon floor has been found to be mostly sand/mud (Anna Metaxas, Dalhousie University, pers. comm.). Although only Corsair Canyon has been explored in this detail, proximity suggests George's Canyon is similar. While the floors of the canyons consist mainly of soft sediments, the intercanyon areas of the UGS are likely composed mostly of sand and gravel from George's Bank (Valentine and Todd 2012) and the Northeast Channel (Edinger et al. 2011). The LGS is likely composed of mostly bioturbated mud, similar to the rest of the slope, especially given the history of slumping in the region (Valentine and Todd 2012).

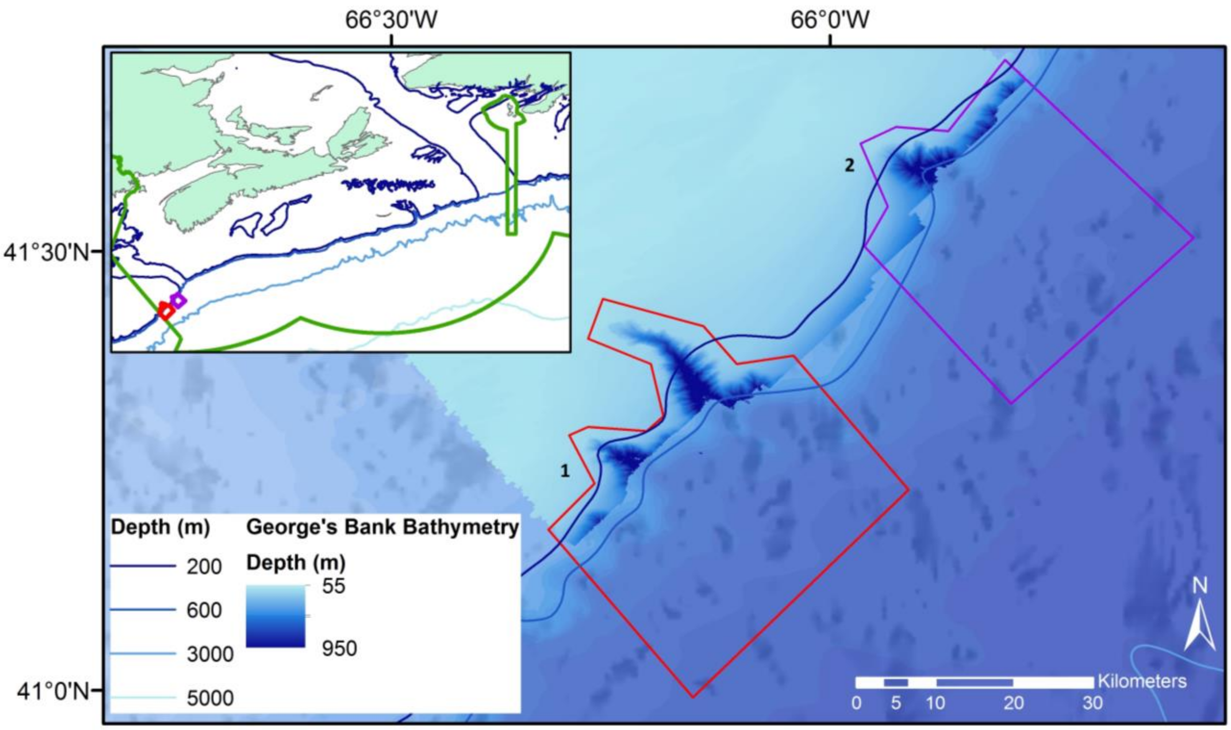

Figure 14. Multibeam data for the upper portions (200-600m) of the George's Slope canyons: 1) Corsair (red), and 2) George's (purple). Data were obtained from the Geological Survey of Canada (Valentine and Todd 2012). These data were unavailable below the 600m contour for this region; therefore these canyons could not be effectively delineated to 3000m.

Ecology

Little is known about the ecology of George's Slope. However, Sperm Whales, Longfin Pilot Whales, and Northern Bottlenose Whales have been sighted in this physiographic region, particularly in the canyons (Appendix 2). Further, recent exploration of Corsair Canyon indicates the area might host the highest abundance of bubblegum corals (*Paragorgia arborea*) of the entire Scotian Slope region (Anna Metaxas, Dalhousie University, pers. comm.).

Special features: George's Slope canyons

Dr. Anna Metaxas and her Canadian and American colleagues conducted two ROPOS dives in Corsair Canyon, in the summer of 2014. They found that the abundance of large bubblegum corals in Corsair Canyon may be significantly higher than in any of the other Scotian Slope canyons. These corals were found between 480-860m, i.e., the UGS (Anna Metaxas, Dalhousie

University, pers. comm.). The steep rocky walls, which promote primary productivity, and the high abundance of the sensitive, likely non-dispersing (Lacharité and Metaxas 2013) habitat engineer *P. arborea*, make Corsair Canyon a candidate for EBSA status. Given that George's Canyon is similar in geomorphology to Corsair Canyon, and that canyons close in proximity to one another tend to have similar ecological features (e.g., The Gully, Shortland, and Haldimand Canyons as discussed in Cogswell et al. 2009), it is likely that George's Canyon could be a candidate as well.

Table 2. Characterizing the GS canyons as either Type I or Type II according to the criteria of Jobe et al. (2011), and acknowledging the presence (Y), or limitation (N) of ecological knowledge to support their characterization as potential EBSAs.

Canyon	Shelf incising (Y/N)	Erosional/ Depositional	Sand-filled or Mud-filled	Type I OR Type II	Ecological knowledge (Y/N)
Corsair	Y	Depositional	Mud (likely)	Type II (likely)	Y
George's	Y	Depositional	Mud (likely)	Type II (likely)	N

3.6. SCOTIAN RISE

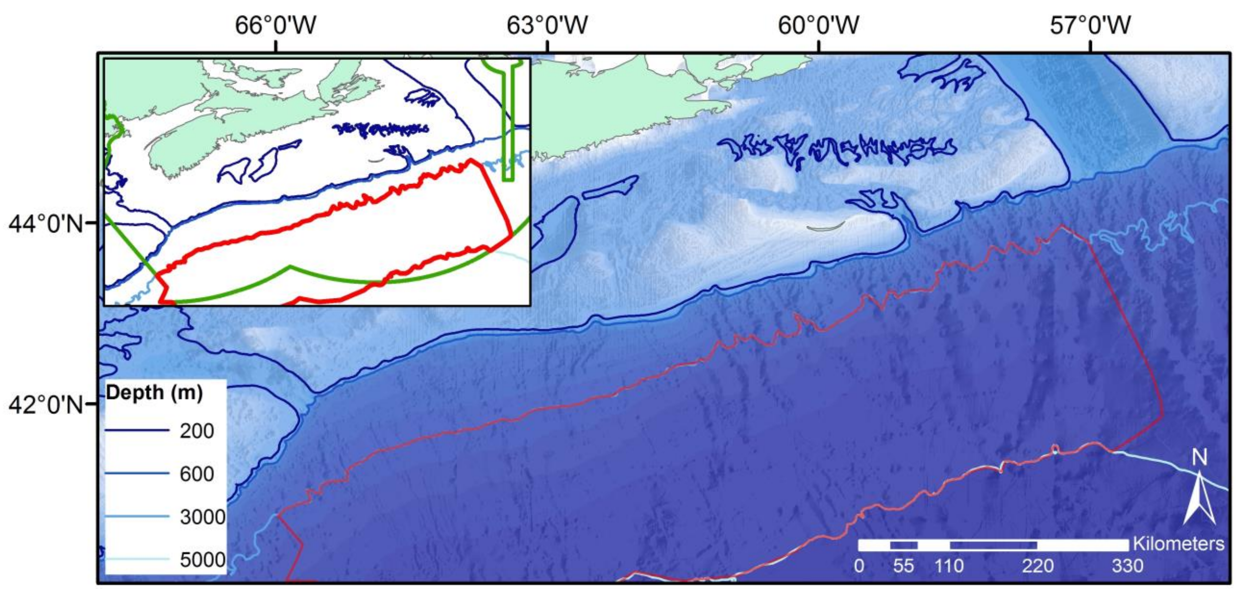

Figure 15. Bathymetry of the Scotian Rise physiographic region (Canadian Hydrographic Service 2004).

Above 3000m, the Scotian Slope can be described in terms of both physiographic regions and special features. Above 3000m, the Scotian Slope is highly heterogeneous in geomorphology, physical oceanography, and ecology, especially in the east. It is this heterogeneity that led to its identification as an EBSA. Below 3000m, slope decreases quickly, and sediment type, physical oceanography, and ecology become more homogeneous, except in The Gully submarine fan, and the Scotian Rise Debris Flow, which are considered discrete physiographic regions because of their [likely] unique geology. It should be noted that the Scotian Rise (Figure 15) has not been explored to the same extent as parts of the Scotian Slope; therefore much of the description of this and the following physiographic region(s) are inferences based upon sparsely available data. Exploration of these areas is necessary for ground-truthing, i.e., verifying whether there are in fact distinct physiographic regions below 3000m, and for the future provision of ecological descriptions.

Physical Oceanography

Above 1500m, the impacts of wind and tides on turbidity are more evident (Cogswell et al. 2009). Below 1500m, internal mixing is more limited, and water tends to move slower in the direction of the major ocean currents (i.e., the Shelf-Edge Current and the Gulf Stream) (Brickman and Drozdowski 2012). The lower slope and Scotian Rise are more impacted by the Gulf Stream than the upper slope (Figure 3). Generally, oceanographic influences do not differ greatly from east to west on the Scotian Rise.

Surficial Geology and Geomorphology

Below 3000m, slope is less steep, and the valleys and channels that dominate the lower slope gradually decrease in size and terminate. The Scotian Rise (3000-5000m) is dominated by mud and formaniniferal ooze, with foraminiferal ooze becoming more prevalent with depth (Barry and Piper 1993; Piper and Campbell 2002). This sediment cover is currently inferred to remain homogeneous from east to west, except for where there are sandy, gravelly, submarine fans (David Piper, NRCan, pers. comm.), which are considered discrete physiographic regions.

Ecology

Generally, the organisms found on the continental rise in any region are different from those found on the continental shelf and slope. These organisms are true deep-sea fauna. Given the deep-sea fish observed at shallower depths (750-1800m) along the LWSS during the 2010 Summer RV Survey (Clark and Emberley 2011), the most likely resident fish of the Scotian Rise are Hagfish and Dragonfish, which are known to live at depths beyond 3000m (Froese and Pauly 2015). Given what is known of continental rise ecosystems in general, the most abundant inhabitants of the Scotian Rise are likely benthic, sediment-dwelling organisms, such as tube worms, brittle stars, polychaetes, bivalves, and burrowing crustaceans (e.g., Thistle et al. 1985). If there are areas of seepage of deposited organic material, there may also be cold seeps and their related communities.

3.7. THE GULLY SUBMARINE FAN

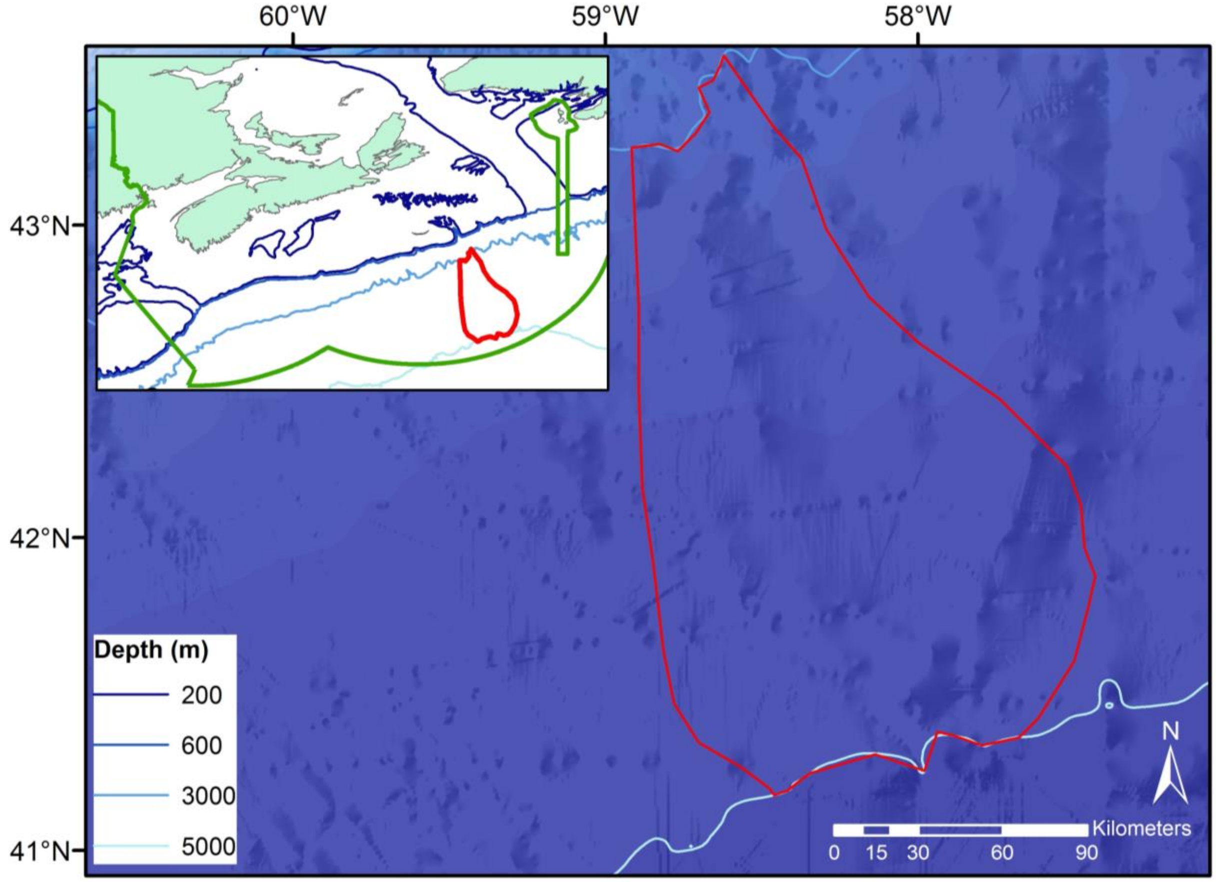

Figure 16. The Gully Fan physiographic region (Canadian Hydrographic Service, 2004). Polygon obtained from WWF-Canada (2009).

Physical Oceanography

Current data indicate that the physical influences of The Gully Fan (Figure 16) are likely not different from the rest of the Scotian Rise. However, the inferred rough geomorphology of this region could create slightly greater turbulence than surrounding, potentially smoother landscapes.

Geomorphology and Surficial Geology

The Gully Fan (Figure 16) consists of rough, gravelly sand transported through The Gully submarine canyon (David Piper, NRCan, pers. comm.). This makes this region unique from the rest of the Scotian Rise, and therefore it may support a different ecosystem.

Ecology

This region has not been studied by biologists, so little is known about its ecology; however, it can be inferred that, because of its distinct geology, it may host different organisms than what are present on the rest of the slope. Further research is required to determine the ecological characteristics of this region.

3.8. SCOTIAN RISE DEBRIS FLOW

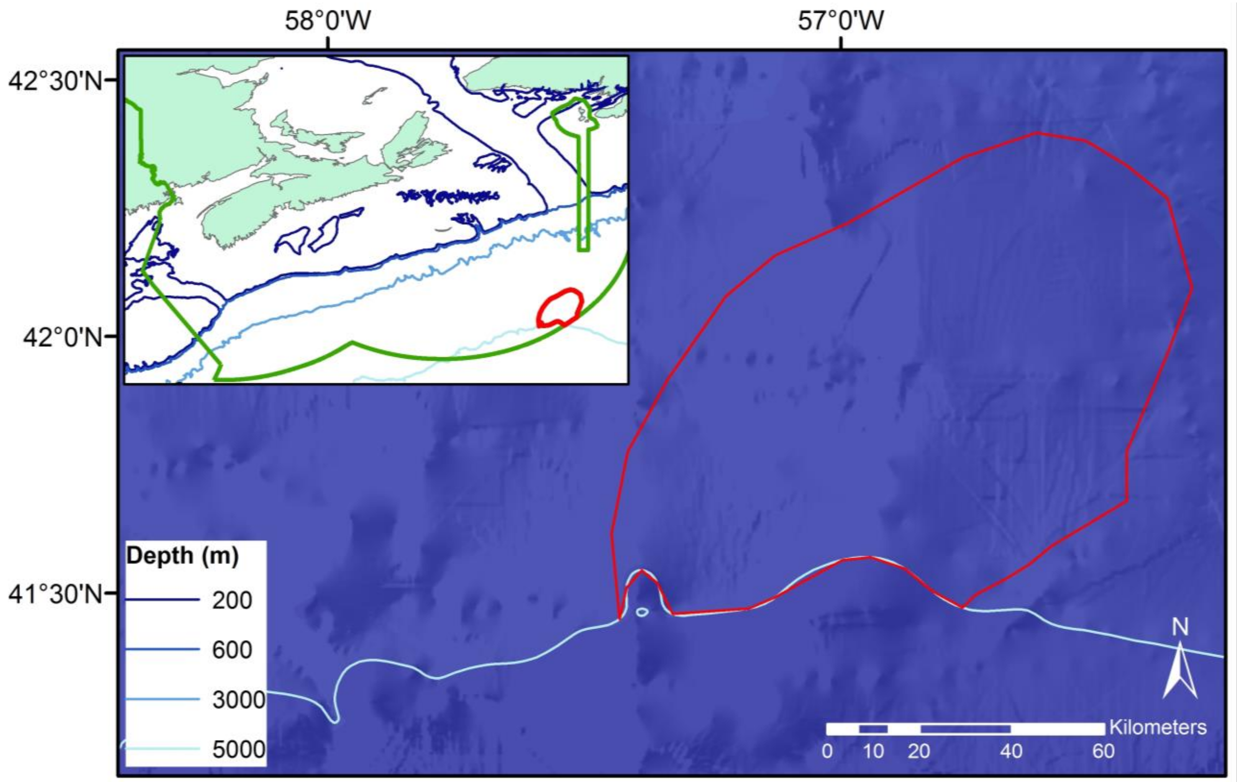

Figure 17. The Scotian Rise Debris Flow physiographic region (Canadian Hydrographic Service 2004). Polygon obtained from WWF-Canada (2009).

Physical Oceanography

Currently available data suggest that the physical influences of the Scotian Rise Debris Flow (Figure 17) are likely not different from the rest of the Scotian Rise.

Geomorphology and Surficial Geology

The Scotian Rise Debris Flow (Figure 17) was formed by a slump of sediments deposited by the Laurentian Channel (Piper et al. 1999). This physiographic region has high surface roughness, making it unique compared to the rest of the Scotian Rise (Piper et al. 1985; Piper et al. 1999).

Ecology

Because of its unique geology, this physiographic region may host different biological communities than the rest of the Scotian Rise. However, this region has not been explored; therefore data do not exist to provide evidence of any such differences. More research is required to evaluate the ecological structure of this physiographic region, as well as of the rest of the Scotian Rise, which may contain other physiographic regions or special features not yet discovered.

4.0. DISCUSSION

4.1. PHYSIOGRAPHIC REGIONS

The Scotian Slope and Rise is not a uniform, homogeneous physical feature. The physiographic regions described in this report (Figure 18) represent an attempt to subdivide the slope and rise based on its oceanographic, geological, geomorphological and ecological characteristics, so that subsequent management/ protection plans are made appropriately. Since ecological data are limited for the Scotian Slope and Rise, the physiographic regions were defined largely based on physical oceanography, surficial geology, and geomorphology, all of which help to determine ecosystem structure and the distribution of biodiversity type (Haffner 1952; Zelck and Klein 1995; Themelis 1996; Kostylev et al. 2001). Ecological data are limited, even for the best-studied physiographic regions; therefore it is suggested that further research be conducted to better describe the ecological significance of these physiographic regions (particularly those below 600m). It is important that inferred physiographic regions be ground-truthed, and that potentially ecologically significant areas be explored so that appropriate protection and management can proceed. That being said, the discussion of observed and inferred ecological differences among the physiographic regions of the Scotian Slope and Rise (Figure 4) provided in this report will have broad implications for various management activities. As more information becomes available, the boundaries and descriptions of the physiographic regions could be refined.

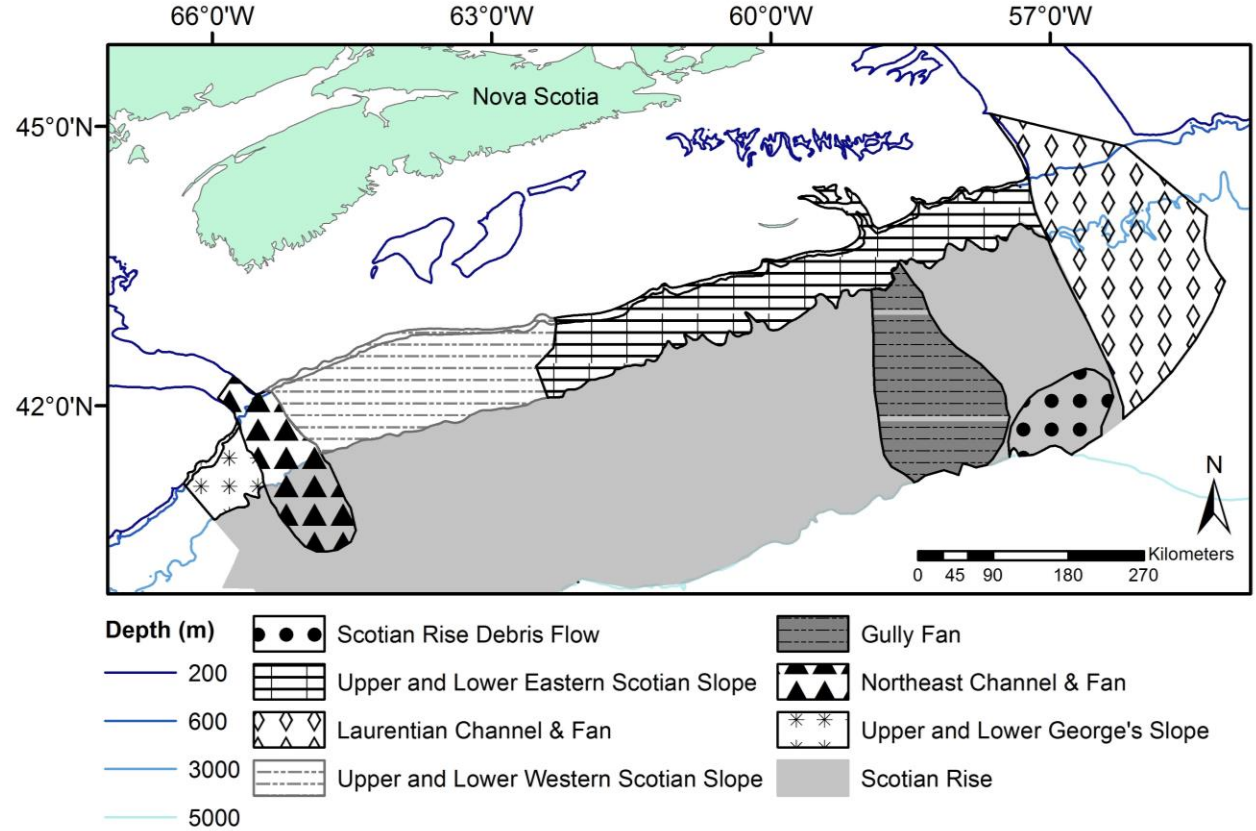

Figure 18. Physiographic regions of the Scotian Slope EBSA and Scotian Rise as defined in this report: The Laurentian Channel and Fan, the Scotian Rise Debris Flow, the Gully Fan, the Upper Eastern Scotian Slope (UESS), the Lower Eastern Scotian Slope (LESS), the Upper Western Scotian Slope (UWSS), the Lower Western Scotian Slope (LWSS), the Northeast Channel and Fan, the Upper George's Slope (UGS), the Lower George's Slope (LGS), and the Scotian Rise.

4.2. SPECIAL FEATURES

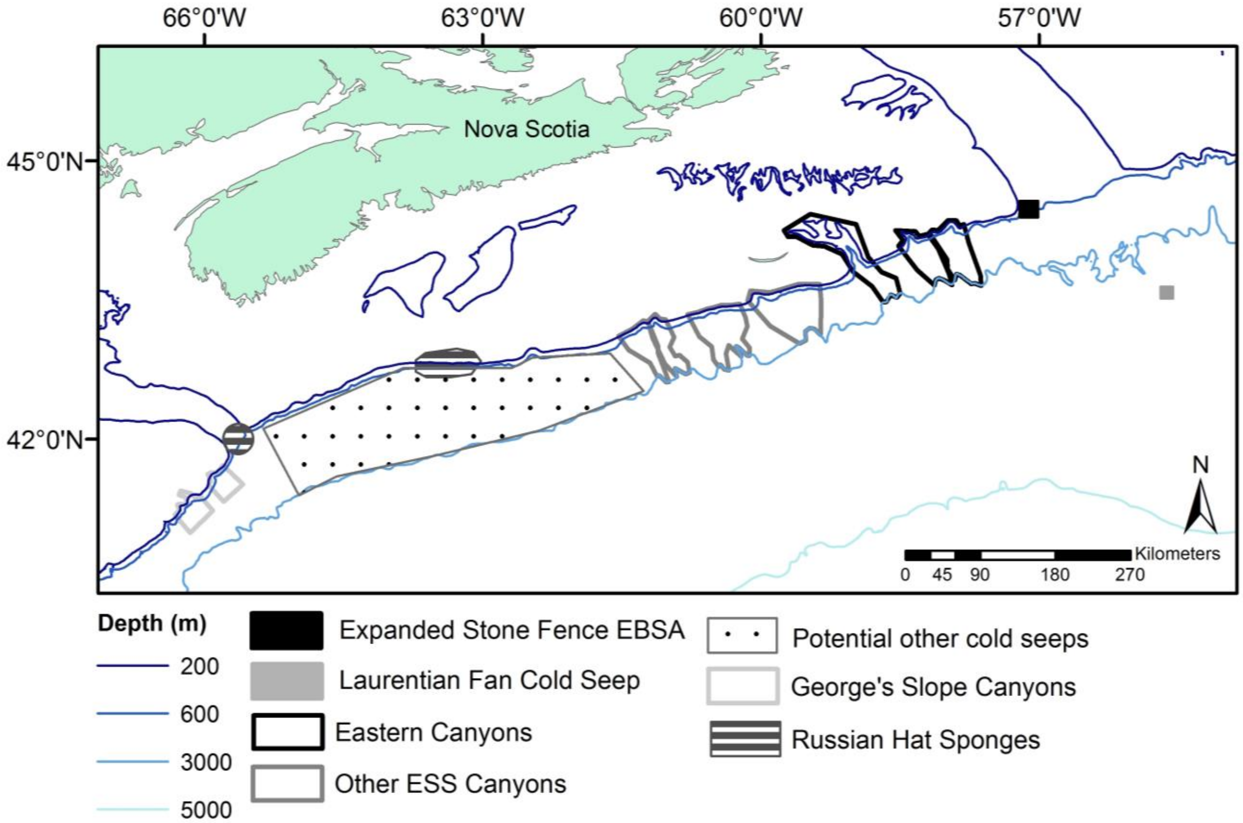

Figure 19. Special features of the Scotian Slope and Rise as reviewed in this report.

Most of the special features identified within the physiographic regions (Figure 19) have already been identified as EBSAs by Fisheries and Oceans Canada, Maritimes Region (DFO 2014a): The Laurentian Fan cold seeps, Stone Fence, the Scotian Gulf Russian Hat sponge aggregations, and the eastern canyons. However, there are some other special features described in this report that may meet DFO EBSA criteria, but have not yet been identified as such, and require further investigation (Table 3). The DFO EBSA criteria, which were determined in 2004 (summarized in DFO 2014a), are:

• *Uniqueness:* Areas that contain unique, rare, or distinct features in a regional, national or global context.

• *Aggregation:* Areas where significant numbers of a species or a wide variety of species are found during some period of the year, or areas where a structural feature or ecological process is observed in exceptionally high density.

• *Fitness Consequences:* Areas where important life-history activities (e.g., reproduction) that strongly affect the fitness of a species or population take place.

• *Resilience:* Areas that include habitat structures or species that are highly sensitive, easily perturbed, and/or slow to recover.

• *Naturalness:* Relatively pristine areas with little to no evidence of human influence.

Table 3. Special features within physiographic regions of the Scotian Slope, and whether they meet DFO EBSA criteria (X), or not (-). Abbreviations for DFO EBSA criteria are: U = Uniqueness, A = Aggregation, FC = Fitness Consequences, R = Resilience, N = Naturalness.

Special feature	**Characteristics**	**DFO Criteria**				
		U	**A**	**FC**	**R**	**N**
Corsair and Georges Canyons	As suggested by patterns observed in other canyons, the bathymetry of these canyons may enhance vertical mixing, resulting in high primary productivity (Breeze et al. 2002), especially since the region contains the highest annual contribution of phytoplankton of the entire slope (Fuentes-Yaco et al. 2015). These canyons contain unique habitat because they have higher geomorphic complexity than the surrounding slope, but softer sediments than ESS canyons (depositional, Type II). The abundance of a sensitive (slow-growing, and limited dispersal) coral species (potentially largest and most densely populated *Paragorgia arborea* community of the entire Scotian Slope), which may spend all life stages in this area (Lacharité and Metaxas 2013), suggests fitness consequences and resilience issues for the features. These coral communities may also host important life stages for other benthic organisms. Additionally, the lower portions of these canyons are relatively untouched by human activities. More research is required to fully describe the ecology of these canyons.	X	X	X	X	X
Stone Fence and surrounding area	The Stone Fence EBSA, is unique because of its high density of rare, sensitive corals, its unique geomorphology (mainly its steep rocky walls), and its unique oceanographic features (mainly the strong currents flowing out of the Laurentian Channel). As it is currently delineated, the Stone Fence EBSA may be too small to capture the full diversity of corals that have been observed in this area (Figure 6; Cogswell et al. 2009). The EBSA could be made larger to include portions of important feeding grounds for Leatherback Turtles (DFO 2012), other coral communities along the shelf edge and lower slope (Figure 6; Cogswell et al. 2009), concentrations of whale sightings (Appendix 2), and overwintering grounds for groundfish. More research is required to fully characterize the coral communities surrounding the current delineations of the Lophelia Coral Conservation Area (Stone Fence); however, currently available observations should be used as a guideline for expansion. Additionally, this area should be recognized as important to various life history stages of commercial fish species (FC); for example, it is suggested that corals provide important habitat for all life stages redfish species	X	X*	X*	X	-

Special feature	Characteristics	DFO Criteria				
		U	**A**	**FC**	**R**	**N**
	(*Sebastes mentella* and *Sebastes fasciatus*), as these fish are often found in conjunction with corals (Mortensen & Buhl-Mortensen, 2005).					
LWSS cold seeps	If the cold seeps of the Laurentian Channel are considered an EBSA due to uniqueness, diversity, and high productivity (DFO 2014a), and there is evidence (e.g., pock marks from side-scan sonar) to suggest cold seeps may be present on the LWSS, this should be investigated.	X**	X**	-	X**	-
Logan, Bonnecamps, Dawson, and Verrill Canyons	These canyons contain unique habitat because they have higher geomorphic complexity than the surrounding slope and likely contain different biological communities from other canyons. Bathymetry of canyons enhances vertical mixing, which results in high primary productivity (Klink 1988; Allen 1996; Chen and Allen 1996). Since this is the case in other canyons, it may be the case here as well. These canyons are also suspected to be important habitat for Northern Bottlenose Whales (Wimmer and Whitehead 2004; Moors 2012). This group of canyons likely has similarities in biology to the eastern canyons because of the flow of the Shelf-Edge Current, but may contain more soft corals than hard corals (as suggested by Anna Metaxas et al.'s observations), possibly due to differences in geology (more soft sediment than vertical rock faces; Campbell et al. 2008), and possibly lower abundance due to smaller surface areas. The ecology of these canyons should be further investigated. If there are abundant coral communities in these canyons, it may be expected that these coral communities support important life stages of other organisms, particularly fish. And if there are abundant coral communities, they are most likely sensitive to disturbance due to slow growth and limited dispersal.	X	X**	X**	X**	-

* Original delineation of the EBSA (DFO 2014a) did not meet this criterion.
** Likely, but supporting data are limited. Further research is required.

5.0. KNOWLEDGE GAPS

The provided delineations and descriptions of physiographic regions can be used to refine the definition, and supplement the current state of knowledge of the Scotian Slope EBSA and Scotian Rise. Consideration of the physiographic regions and special features described in this report may improve oceans planning and management activities related to the Scotian Slope and Rise.

The ecological significance of some of the identified special features, such as known and potential cold seeps, and less-studied ESS and George's Slope canyons, is a recognized knowledge gap and requires further evaluation. In particular, more investigation is needed to determine whether Logan, Dawson, Verrill, Corsair, and George's Canyons are important habitat for cetaceans. More exploratory dives using remotely operated cameras in these canyons would help further our understanding of their importance to cold-water corals and other sessile, structure-providing invertebrates. More investigation into the "pockmarks" on the lower WSS would be useful to determine if they are indeed cold seeps, and if so, whether those cold seeps host unique biological communities. There is also a gap in available data concerning the teleost and coral communities of deeper portions of the slope. Further investigation is required for a better understanding of coral distribution, abundance, and diversity around the Lophelia Coral Conservation Area (in progress – Lindsay Beazley, pers. comm.).

The quantity and quality of bathymetric, geological, and ecological data for several key areas of the Scotian Slope and Rise are relatively low. Further exploration of areas such as upper and lower George's Slope, The Gully Fan, Scotian Rise Debris Flow, lower WSS, lower ESS, and the Laurentian Fan would be beneficial. Further exploration of the slope and rise in general below 600m may lead to improved refinement of physiographic region boundaries and descriptions, and could also lead to the identification of additional special features.

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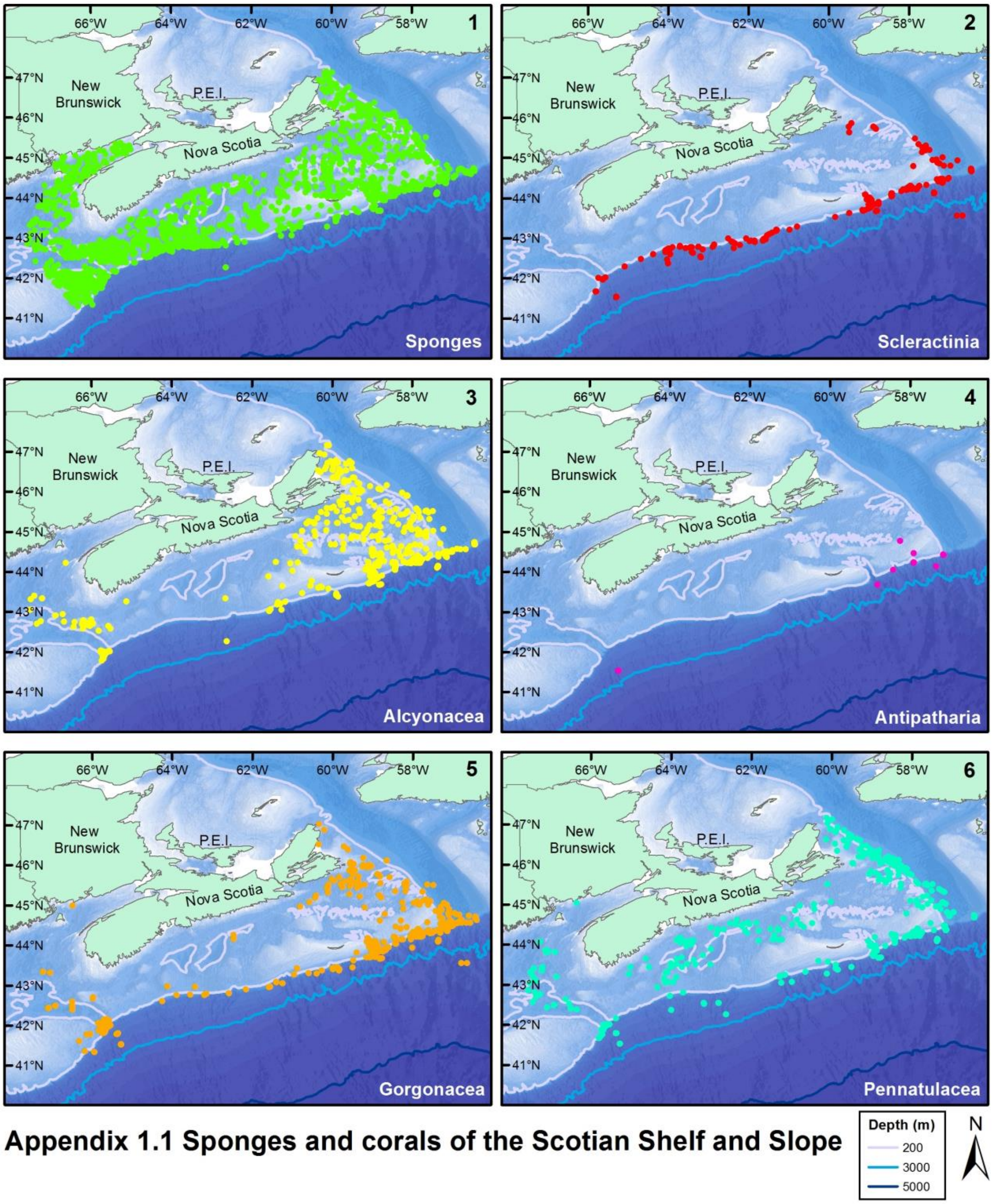
APPENDICES

Summary of available information on the distribution of corals, sea pens, and sponges (Appendix 1), cetaceans (Appendix 2), and fish and squid (Appendix 3) on the Scotian Shelf and Slope.

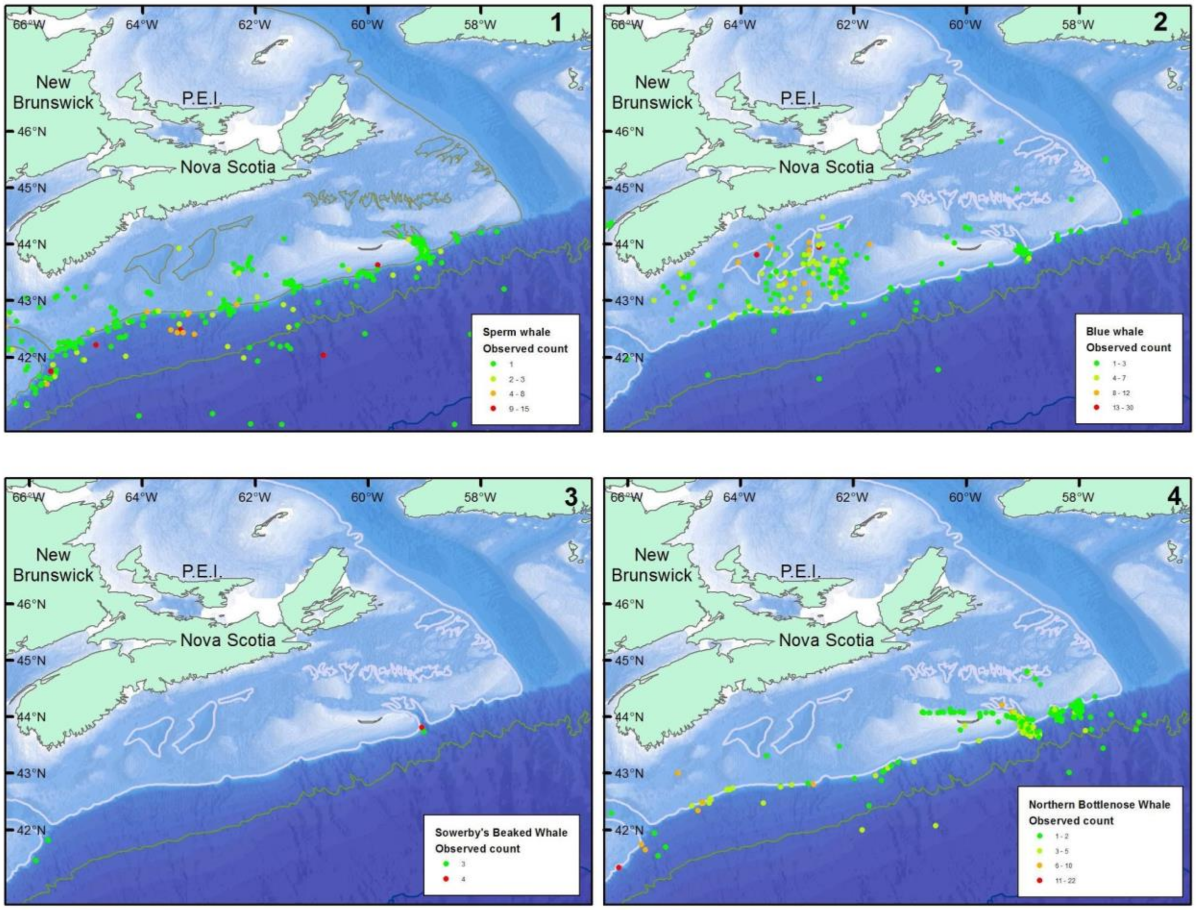
APPENDIX 1: PRESENCE OF CORALS, SEA PENS, AND SPONGES

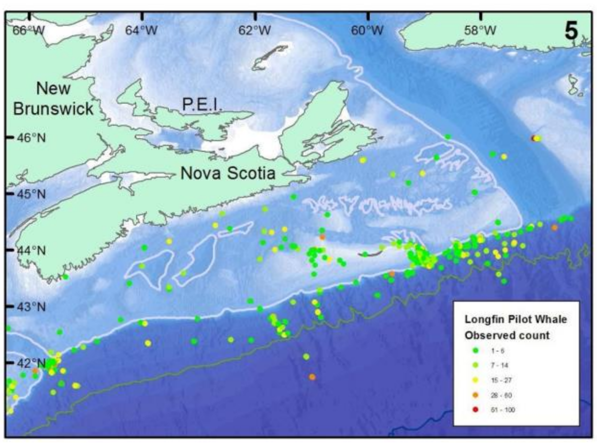


Appendix 1.1 Sponges and corals of the Scotian Shelf and Slope

Data from: DFO VDC groundfish survey and observer data and DFO/NRCan scientific survey data

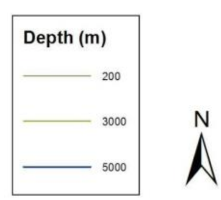
APPENDIX 2: WHALE OBSERVATIONS





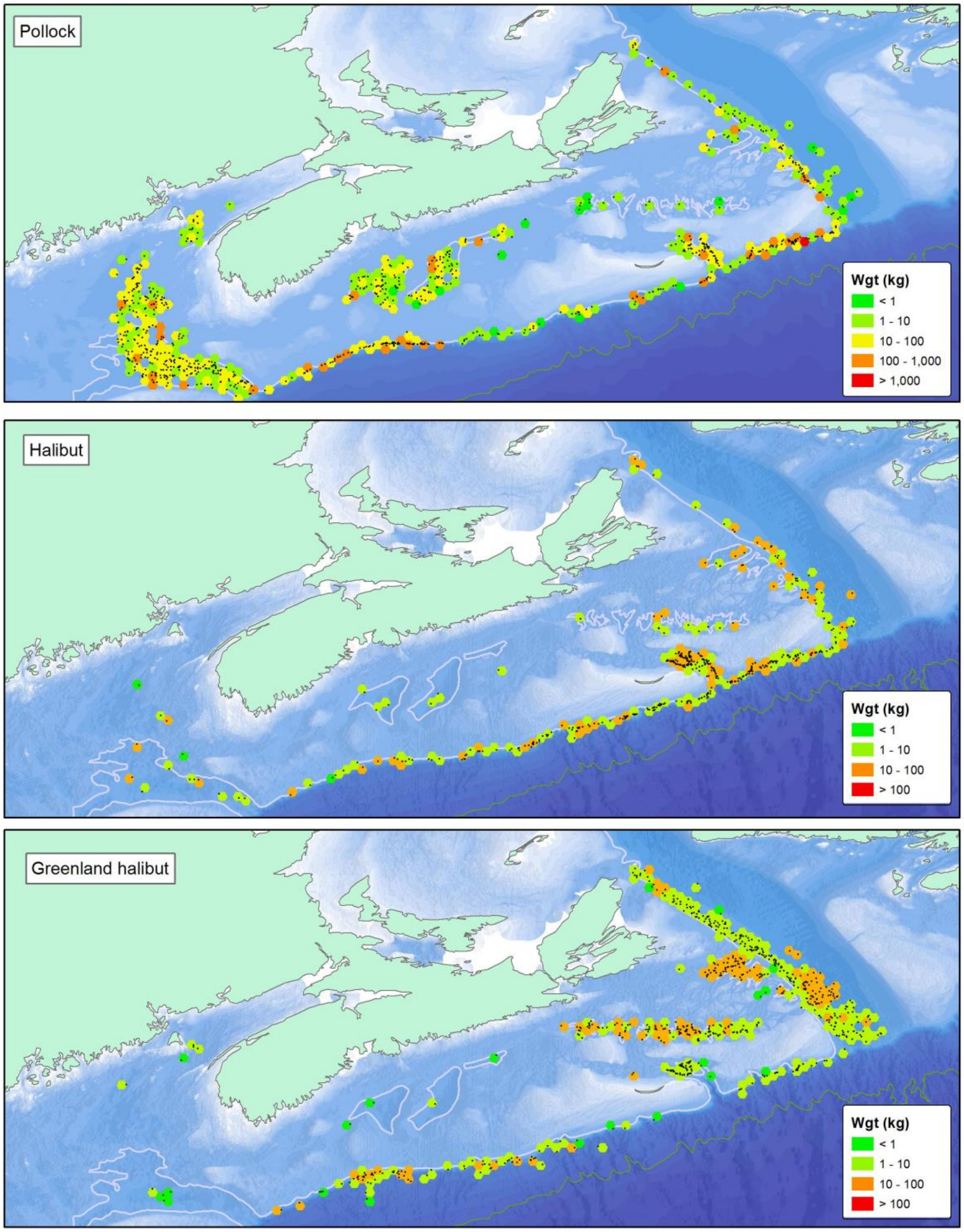
Data from: Ocean Biogeographic Information System (iobis.org)

(compilation of data from various sources, including the DFO Cetacean Sightings database (DFO, 2014a)



Appendix 2. Whales common to the Scotian Slope

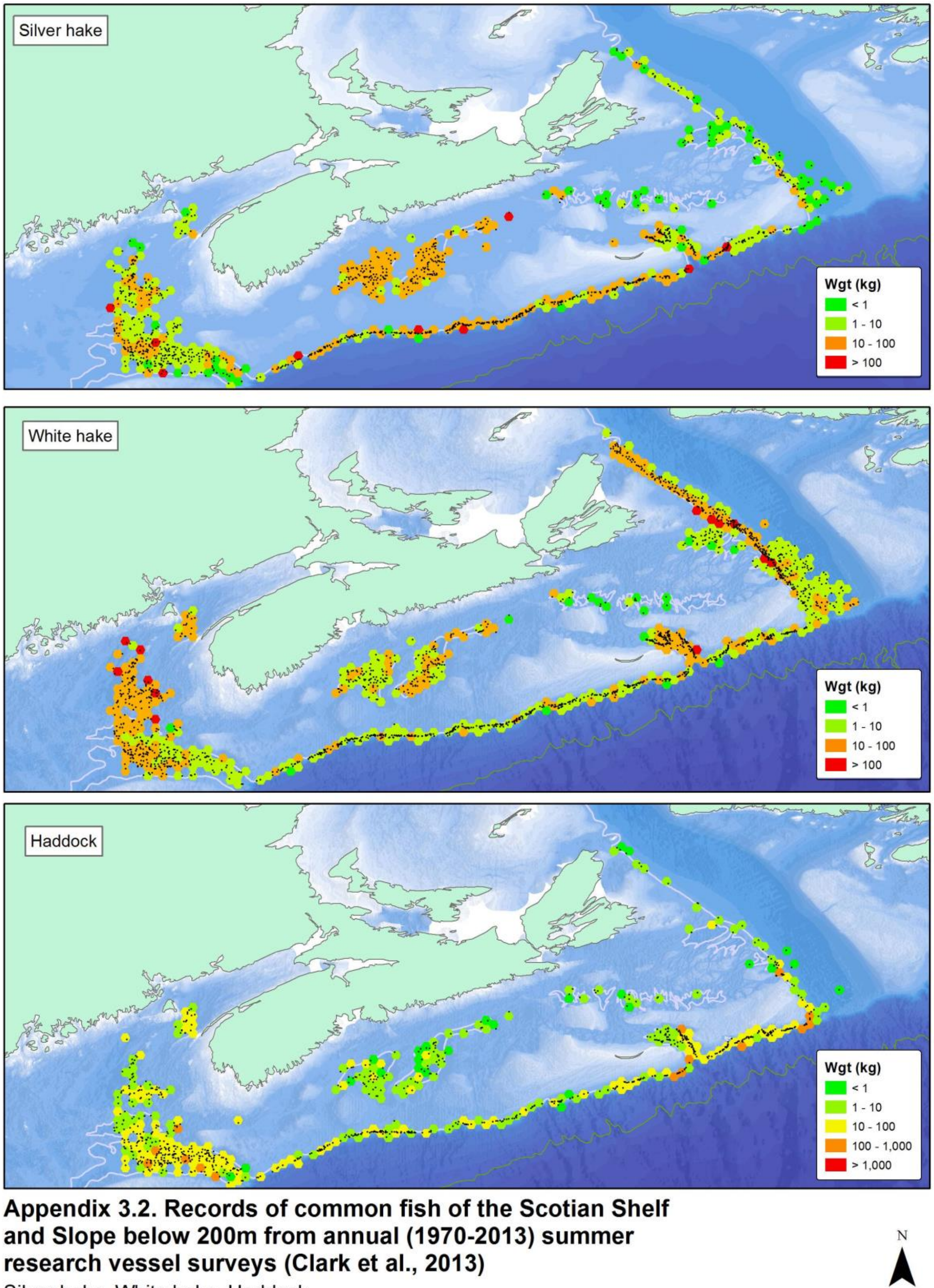
APPENDIX 3: FISHES AND SQUID BIOMASS



Appendix 3.1. Records of common fish of the Scotian Shelf and Slope below 200m from annual (1970-2013) summer research vessel surveys (Clark et al., 2013)

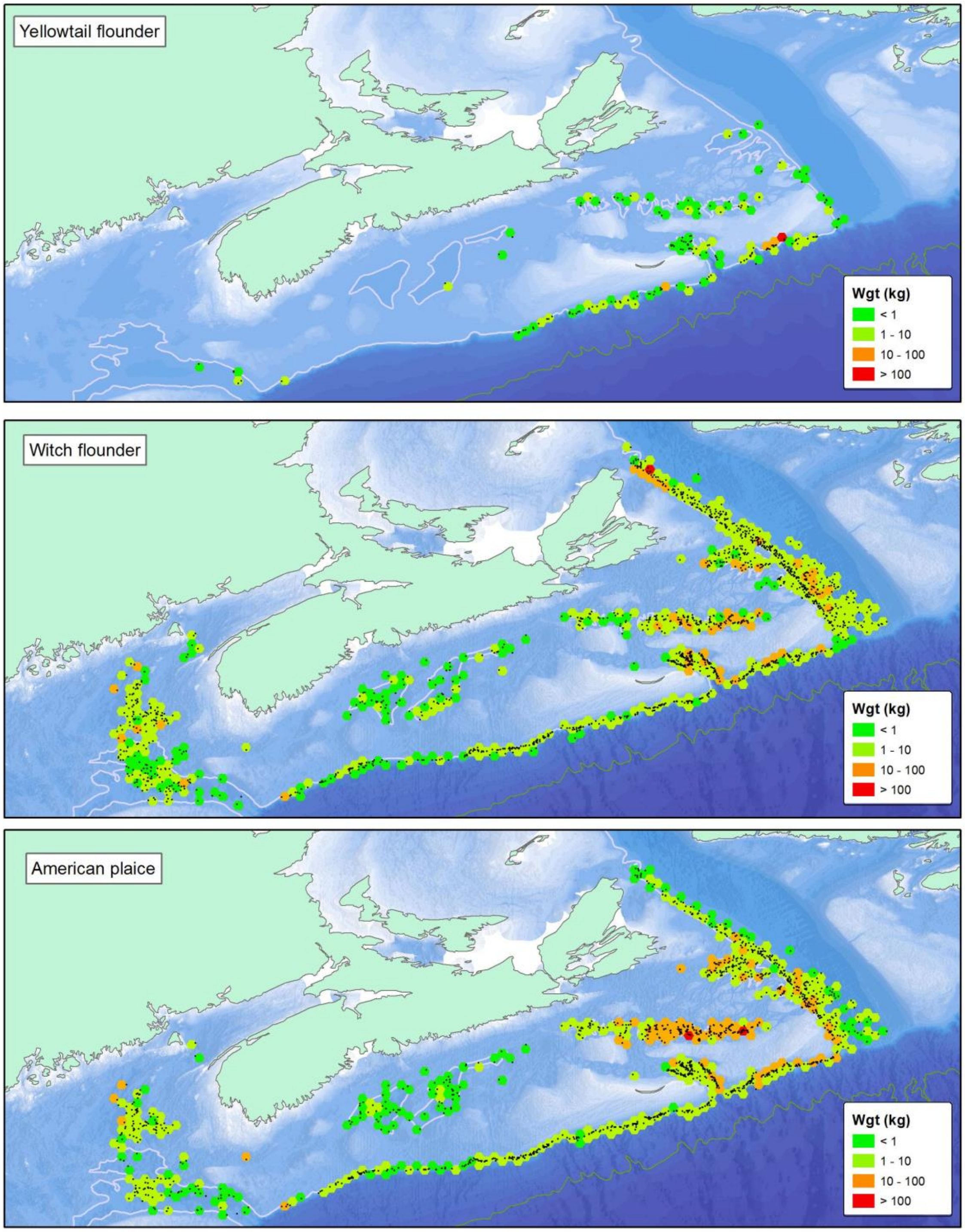
Pollock, Halibut, Greenland halibut

N



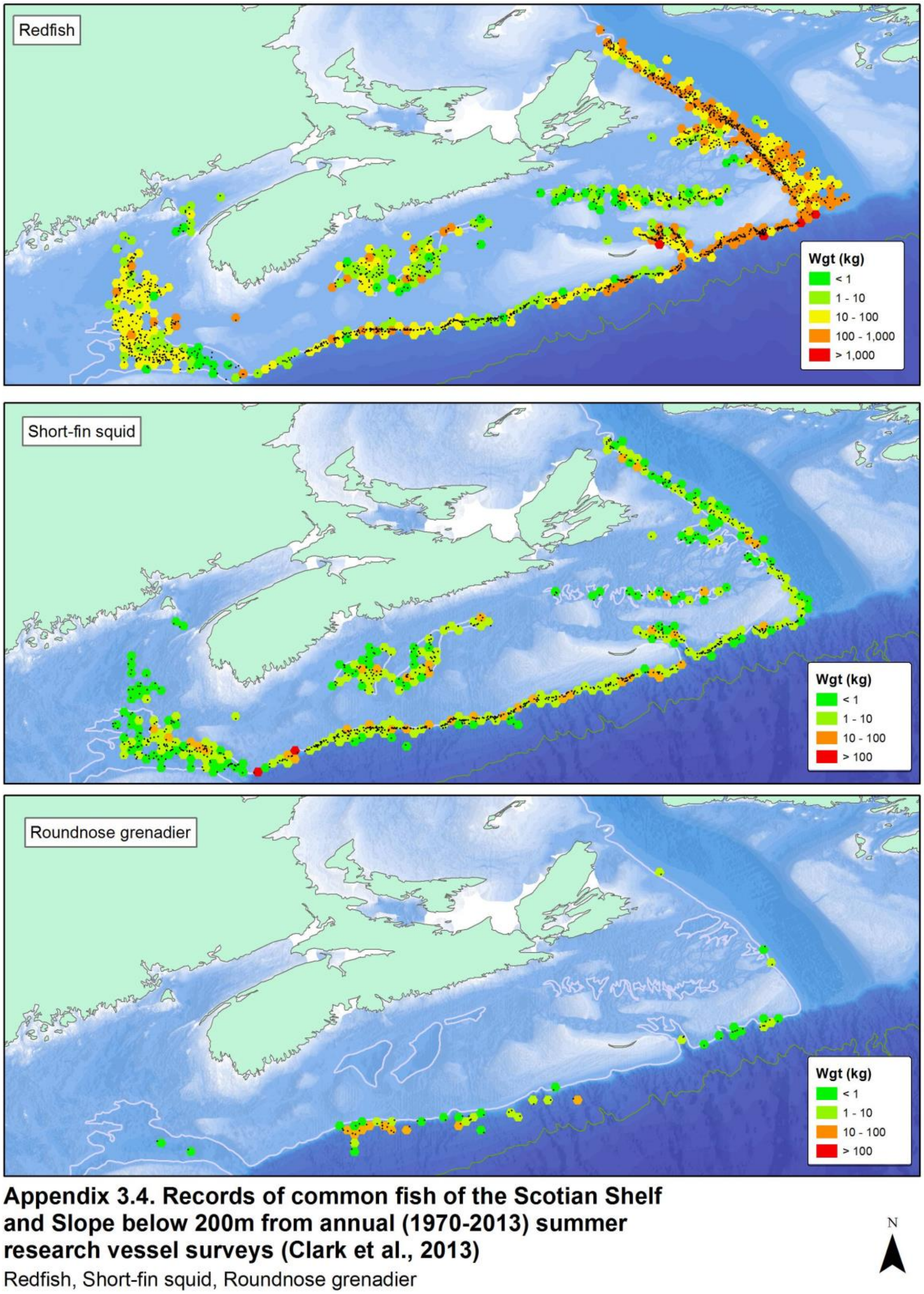
Appendix 3.2. Records of common fish of the Scotian Shelf and Slope below 200m from annual (1970-2013) summer research vessel surveys (Clark et al., 2013)

Silver hake, White hake, Haddock



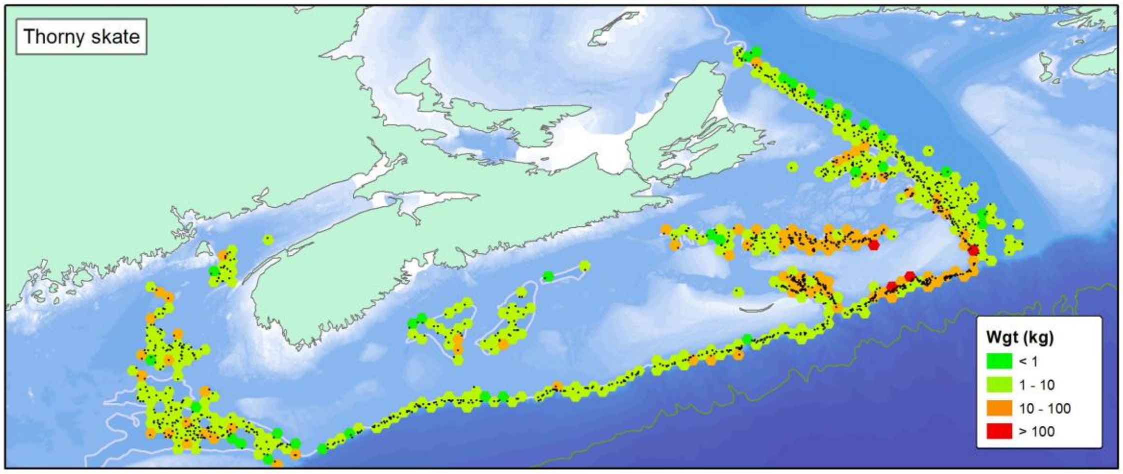
Appendix 3.3. Records of common fish of the Scotian Shelf and Slope below 200m from annual (1970-2013) summer research vessel surveys (Clark et al., 2013)

Yellowtail flounder, Witch flounder, American plaice



Appendix 3.4. Records of common fish of the Scotian Shelf and Slope below 200m from annual (1970-2013) summer research vessel surveys (Clark et al., 2013)

Redfish, Short-fin squid, Roundnose grenadier



Appendix 3.5. Records of common fish of the Scotian Shelf and Slope below 200m from annual (1970-2013) summer research vessel surveys (Clark et al., 2013)
Thorny skate