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**Newfoundland and Labrador Region**

### **Overview of the biophysical and ecological components of the Labrador Sea Frontier Area**

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## Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## ABSTRACT

A targeted research program, Integrated Studies and Ecosystem Characterization of the Labrador Sea Deep Ocean (ISECOLD), was initiated to support the biophysical and ecological characterization of the Labrador Sea Frontier Area (LSFA). The available knowledge indicates that the LSFA is characterized by important physical and ecological components and processes that are of global significance (e.g., oxygenation of deep-water environments and carbon capture). The LSFA's ecosystem is connected to important adjacent ecosystems (e.g., slope and shelf EBSAs, *Fisheries Act* closure areas) by ocean currents and the migration of organisms (ranging from zooplankton to large marine mammals) that use the area. Such migrations also bring LSFA biota to coastal peoples of Labrador, who have depended on these species as a food source for generations.

The Labrador Sea contains a gyre that likely collects and retains passively-transported nutrients and organisms, which in turn has the potential to attract species at higher trophic levels. Existing ecological data confirm that the LSFA supports year round use by migratory marine mammals, seabirds, and fish; several species of which migrate from beyond the region (temperate and tropical latitudes, the Northeast Atlantic and Hudson Bay). Several LSFA inhabitants (e.g., seabirds and marine mammals) are species of conservation concern and many others (e.g., deep-sea fish) have life history characteristics that make them sensitive to anthropogenic disturbance. Nevertheless, many aspects of the LSFA's ecosystem remain poorly understood and important ecosystem characterization must occur prior to recommending conservation objectives.

Data gaps are most prominent for some ecological processes (productivity, connectivity, temporal variability) and broad taxa groups (benthos and fish), where the most basic information (community composition, life history information and trophic relationships) is unavailable. Such a broad array of data gaps will require a prioritized research plan. It is suggested that in the short-term, Science initiatives focus on better characterization of the following three ecosystem elements:

- Mesopelagic fish,
- Demersal fish, and
- Benthic communities (particularly echinoderms, corals, sponges and infauna).

General areas of research beyond characterizing community composition should focus on processes of connectivity (drift models, genetics), productivity, trophic links (fatty acids, stable isotopes, stomach contents) and habitat-faunal relationships (e.g., currents, sea bottom).

A better ecological understanding of the LSFA will facilitate stakeholder engagement during the MPA establishment process, enable optimized placement of MPA boundaries and more informed management upon MPA establishment. Research initiatives will also provide an opportunity to contribute to a better understanding of a globally significant region and can enhance collaborations with indigenous communities and researchers.

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## INTRODUCTION

The Government of Canada has committed to protecting 10% of Canada's marine and coastal areas by 2020 as part of its commitment to achieve international (the Convention on Biological Diversity 2011-20 Strategic Plan for Biodiversity's Aichi Targets) and domestic (2020 Biodiversity Goals and Targets for Canada) biodiversity conservation goals and targets. Accordingly, a Five Point Action Plan (Fisheries and Oceans Canada [DFO] 2016) has been implemented that includes *Oceans Act* Marine Protected Areas (MPAs) in large offshore ocean areas as options towards meeting Canada's marine conservation targets.

An offshore portion of the Labrador Sea (~150,000 km<sup>2</sup>) is being investigated as a potential candidate large offshore ocean area. This study area, hereafter referred to as the Labrador Sea Frontier Area (LSFA; Figure 1), sits within the Polar Biome (Longhurst 1998) and extends from water depths of 2,000 m (beyond the continental shelf and slope) to the Canadian Exclusive Economic Zone (EEZ; max depth = 3,800 m) within Northwest Atlantic Fisheries Organization (NAFO) Divisions 2G and 2H.

The scientific knowledge regarding this area's ecosystem is limited, particularly for biological components, as the depths extend well beyond the range typically monitored by DFO and NAFO during stock assessment surveys and there is currently little resource development. Consequently, a targeted research program, Integrated Studies and Ecosystem Characterization of the Labrador Sea Deep Ocean (ISECOLD), was initiated to support the biophysical and ecological characterization of the LSFA.

This Research Document provides an overview of available scientific information and principal knowledge gaps of the LSFA for the following:

- Protected Areas and Closures
- Underwater Features
- Oceanography
- Plankton
- Benthic Communities
- Corals and Sponges
- Fish
- Seabirds
- Marine Mammals

While it is recognized that the LSFA includes ecological elements that have been relied upon by coastal indigenous groups of Labrador for generations, indigenous knowledge systems are not addressed in this document.

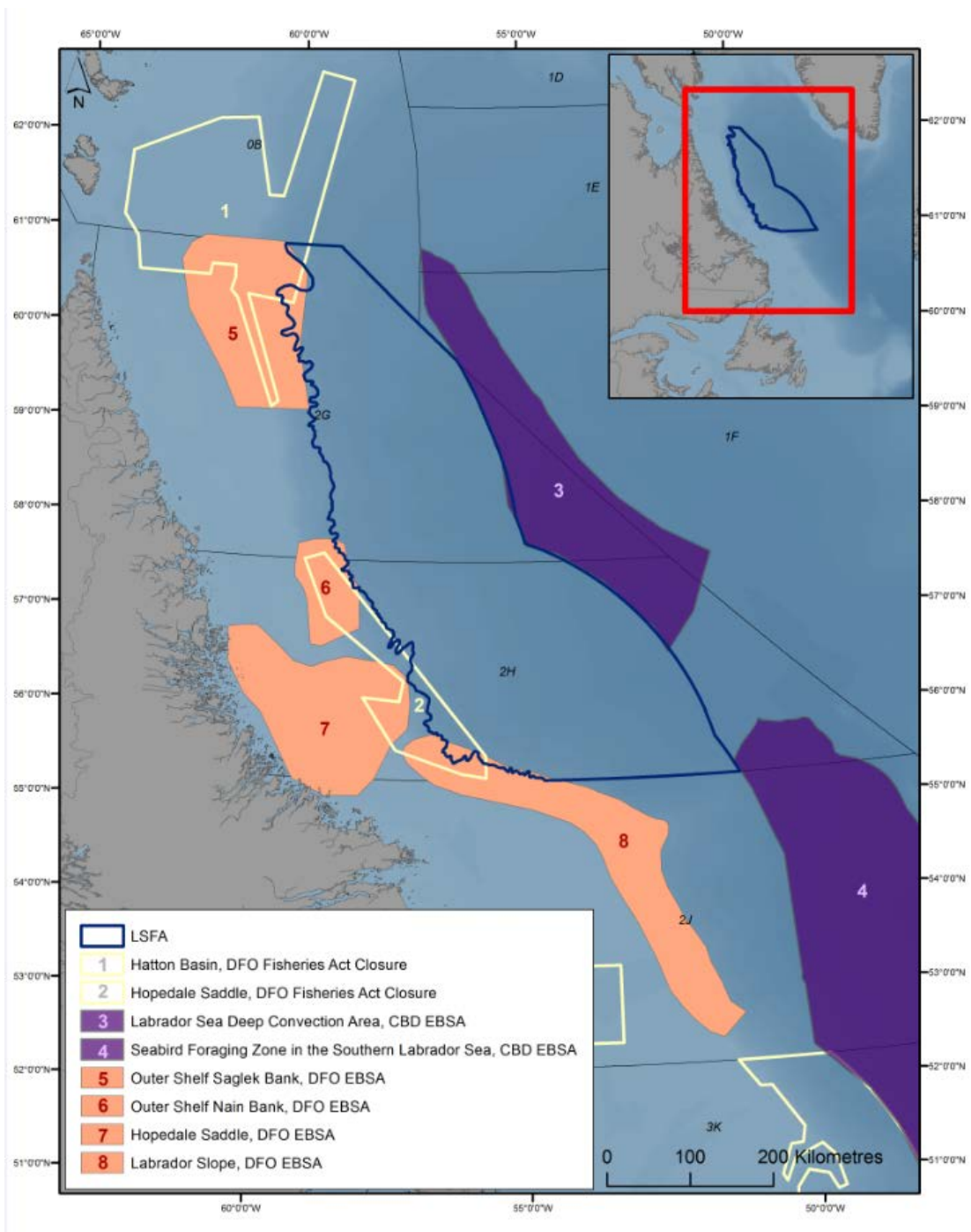


Figure 1: The Labrador Sea Frontier Area (LSFA) in relation to NAFO zones, Ecologically and Biologically Significant Areas (EBSAs), and Fisheries Act closures.

## PROTECTED AREAS AND CLOSURES

The LSFA contains fractions of two Ecologically or Biologically Significant Areas (EBSAs; Outer Shelf Saglek Bank and Labrador Slope) and two Fisheries Closure zones (Hatton Basin and Hopedale Saddle; Figure 1; Table 2). Other nearby EBSAs include Outer Shelf Nain Bank, Hopedale Saddle (geographically distinct from the similarly named Fishery Closure), the Southern Labrador Sea Seabird Foraging Zone, and the Labrador Sea Deep Convection Area EBSAs (Figure 1; Table 1). Canadian EBSAs and Fishery Closures have been designated primarily for features that occur at shallower depths than the LSFA. The absence of deep water (>2,000 m) representation is likely a result of lack of information on which to base these designations. In contrast, the Convention of Biological Diversity has identified two adjacent EBSAs over deeper waters that recognize important pelagic habitats (Southern Labrador Sea Seabird Foraging Zone) and ecosystem processes (Labrador Sea Deep Convection Area; Table 1). Collectively, these EBSAs and Fishery Closures recognize and/or protect a variety of ecological features ranging from oceanographic processes to zooplankton reservoirs, seabirds, marine mammals, corals, sponges and fish.

Table 1: Key ecological features of EBSAs and Fisheries Closures adjacent to the LSFA (adapted from DFO 2013).

EBSA/ Closure Area	Habitat Features	Key Ecological Features	Other Ecological Features
Outer Shelf Saglek Bank EBSA <sup>1</sup>	Outer shelf of Saglek Bank, Labrador Slope	<ul style="list-style-type: none"> <li>• Important coral and sponge concentrations</li> <li>• Feeding and migration area for several marine mammal species (whales and seals)</li> <li>• Important aggregation area for several seabird species, including Ivory Gull (<i>Pagophila eburnean</i>; endangered under Species at Risk Public Registry [SARA] )</li> </ul>	<ul style="list-style-type: none"> <li>• High densities of roundnose grenadier (<i>Coryphaenoides rupestris</i>)</li> </ul>
Outer Shelf Nain Bank EBSA <sup>1</sup>	Outer shelf of Nain Bank, Labrador Slope	<ul style="list-style-type: none"> <li>• High diversity of species</li> <li>• High concentrations of several coral species</li> <li>• Aggregations of several fish functional groups</li> <li>• Juvenile and female hooded seal (<i>Cystophora cristata</i>) aggregation area; pilot whale (<i>Globicephala melas</i> ) feeding area</li> <li>• Aggregations of several seabird species, including Ivory Gull (endangered under SARA)</li> </ul>	<ul style="list-style-type: none"> <li>• High densities of juvenile American plaice (<i>Hippoglossoides platessoides</i>)</li> <li>• Harp seal (<i>Pagophilus groenlandicus</i>) summer feeding area</li> </ul>



EBSA/ Closure Area	Habitat Features	Key Ecological Features	Other Ecological Features
Hopedale Saddle EBSA <sup>1</sup>	Hopedale Saddle, Labrador Marginal Trough, Nain Bank High Point	<ul style="list-style-type: none"> <li>• Unique Eastern Hudson Bay beluga (<i>Delphinapterus leucas</i>) overwintering area</li> </ul>	<ul style="list-style-type: none"> <li>• High concentrations of several coral species</li> <li>• Aggregations of several fish functional groups, core species and rare or endangered species</li> <li>• Aggregations of several seabird species, including Ivory Gull (endangered under SARA)</li> <li>• Harp seal summer feeding area</li> <li>• Juvenile and female hooded seal aggregation area</li> </ul>
Hopedale Saddle Fisheries Closure <sup>2</sup>	-	<ul style="list-style-type: none"> <li>• Cold-water corals and sponges</li> </ul>	-
Labrador Slope EBSA <sup>1</sup>	Labrador Slope, outer shelf, Hamilton Spur	<ul style="list-style-type: none"> <li>• High diversity of species</li> <li>• High concentrations of several coral and sponge species</li> <li>• Aggregations of all fish functional groups, several core species and several rare or endangered species</li> </ul>	<ul style="list-style-type: none"> <li>• Aggregations of several seabird species, including Ivory Gull (endangered under SARA)</li> <li>• Female and juvenile hooded seal aggregation area</li> </ul>
Southern Labrador Sea Foraging Zone EBSA <sup>3</sup>	-	<ul style="list-style-type: none"> <li>• Important foraging area for seabirds such as black-legged kittiwakes (<i>Rissa tridactyla</i>), thick-billed murre (<i>Uria lomvia</i>), and storm petrels (family: Hydrobatidae).</li> </ul>	-
Labrador Sea Deep Convection Area EBSA <sup>4</sup>	-	<ul style="list-style-type: none"> <li>• Winter waters that almost always mix to depths greater than 200m, and in some years, to 1600m</li> </ul>	<ul style="list-style-type: none"> <li>• Reservoir of copepod <i>Calanus finmarchicus</i>, which repopulates the adjacent shelves on an annual basis, and downstream regions (e.g., Scotian Shelf, Gulf of Maine, Georges Bank) over longer time scales</li> </ul>

EBSA/ Closure Area	Habitat Features	Key Ecological Features	Other Ecological Features
Hatton Basin Fisheries Closure <sup>5</sup>	-	<ul style="list-style-type: none"> <li>Significant concentrations of small and large gorgonian corals (order: Alcyonacea), and sponges.</li> </ul>	<ul style="list-style-type: none"> <li>Only known overwintering area for northern Hudson Bay Narwhal (<i>Monodon monoceros</i>)</li> <li>Supports important habitat for other marine mammals, seals, and high densities of sea birds (including depleted species, such as the <a href="#">endangered ivory gull</a>).</li> </ul>

<sup>1</sup>[DFO \(2013\) Science Advisory Report 2013/048](#)

<sup>2</sup>[DFO: Hopedale Saddle closure](#)

<sup>3</sup>[CHM: Ecologically or Biologically Significant Areas \(EBSAs\) Seabird Foraging Zone in the Southern Labrador Sea](#)

<sup>4</sup>[CHM: Ecologically or Biologically Significant Areas \(EBSAs\) Labrador Sea Deep Convection Area](#)

<sup>5</sup>[DFO: Hatton Basin Conservation Area](#)

## UNDERWATER FEATURES

Hydrographic and habitat characterization surveys are lacking for the vast majority of the LSFA with the exception of remotely measured bathymetric data, e.g., General Bathymetric Chart of the Oceans (GEBCO) and coarse level (1 km grid size) interpretation of geomorphic seabed features (Harris et al. 2014; Figure 2). While finer scale data would be valuable for guiding future research and management, comprehensive maps are unlikely to be available in the near future due to the size of the area and the requirement for specialized, large, deep-sea-capable survey equipment. Such surveys would be further complicated by the challenges of ground-truthing acoustically-derived habitat maps with *in-situ* sampling at great depths.

The analyses conducted by Harris et al. (2014) indicate that the LSFA is characterized by slope and abyssal habitats incised with submarine canyons that run from the continental shelf into the LSFA (Figure 2). While most of the abyssal zone is characterized as Abyssal Plain, some patches of Abyssal Hills also occur in the LSFA. A single, large fan deposit, than runs from the slope to the abyssal region, also occurs in the northern portion of the LSFA (Figure 2).

What is known is suggestive of connectivity between adjacent shelf and slope habitats and the deeper waters of the LSFA. Geological studies on the Northwest Atlantic Mid-Ocean Channel (NAMOC) of the Labrador Sea (summarized by Piper 2005) indicate that the geology of the Canadian deep-water margin is driven by historical erosional processes resulting from major ice streams discharging subglacial meltwater and sediment plumes, and the transfer of sediment through submarine canyons (Piper 2005). For example, the fan in the northern part of the LSFA (Figure 2) was likely sourced from the Hudson Strait ice stream; the largest ice stream draining the Canadian Arctic to the Atlantic. Similarly, the numerous canyons and gullies along the Labrador continental slope are suggestive of subglacial meltwater discharged seaward of the shelf break (Piper 2005). In contrast, the distribution of sediments on the seafloor is shaped largely by the modern current regime. In the shallower parts of the continental slope plume deposits are reworked by currents, icebergs and storm waves. At greater depths (i.e. >1,300 m), there is a greater importance of turbidity current deposits resulting in a more muddy substrates (Piper 2005).

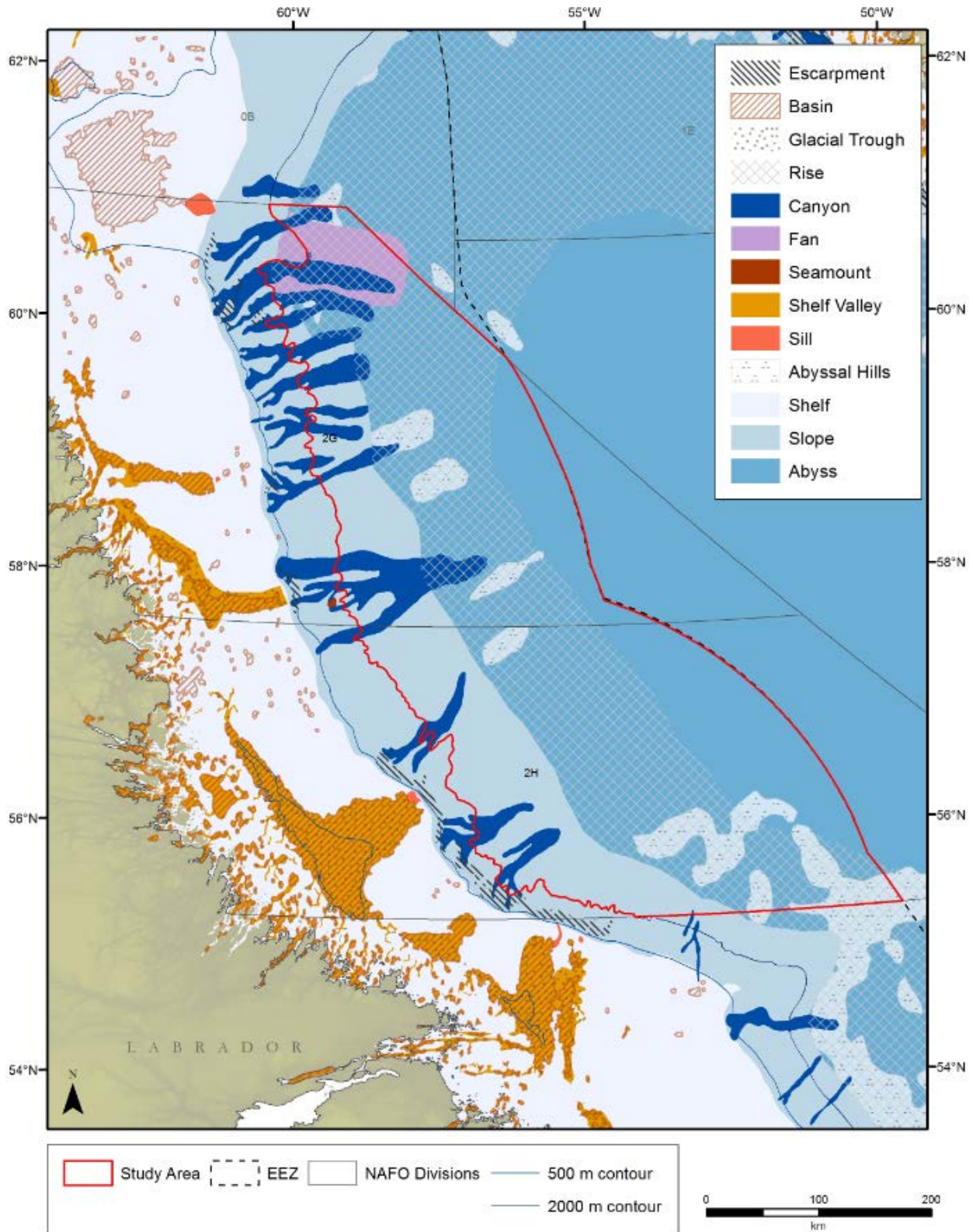


Figure 2: Geomorphic seabed habitat features (Harris et al. 2014) of the Labrador Sea in NAFO zones 2G and 2H. The red line indicates the boundaries of the Labrador Sea Frontier Area. Note some features in waters less than 500m are not shown. GIS layers acquired from [Blue Habitats Website](#).

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Large research vessels such as the Canadian Coast Guard's *Amundsen* are usually equipped with multi-beam sonar units capable of surveying the depths of the LSFA and thus any cruises on such vessels should include multi-beam data collection. With appropriate planning, smaller multi-beam units can be mounted temporarily on vessels of opportunity and would also be capable of mapping the shallower portions of the LSFA (2,000-2,800 m). Not only will these data start the habitat inventory process but the habitat data will be useful for interpreting the biological samples collected. In the meantime, existing bathymetry data can be useful in optimizing study design and in predicting important ecological processes. For example, canyons leading into the study area have been mapped along the continental slope, and these structures are known to serve as conduits of nutrients and sediments from the shelf habitats to bathyal and abyssal habitats. Similarly, additional processing of coarse bathymetry data (e.g., Relative Position Index and Terrain Ruggedness Index; Riley et al. 1999) can provide an indication of heterogeneity of habitats across the LSFA, which would be useful when designing collections aimed at characterizing biological diversity.

## OCEANOGRAPHY

### Available information

Knowledge of the LSFA's oceanography is based on historical data, previous studies and recent data collected by DFO's [Atlantic Zone Monitoring Program](#) (AZMP) (Therriault et al. 1998) and the Labrador component of the [Atlantic Zone Offshore Monitoring Program](#) (AZOMP). The status of the physical oceanographic environment in the Labrador Sea, based on the AZOMP data, is published as part of both the AZMP and the Fisheries Oceanography Committee of NAFO's Scientific Council (Yashayaev et al. 2014, Yashayaev et al. 2016). In addition, sea surface temperature (SST) data derived from infrared satellite imagery of the Northwest Atlantic, including the LSFA are used to characterize annual cycles and trends in the Labrador Sea.

The general circulation in the LSFA is dominated by the offshore Labrador Current that flows south-eastward along the area's western boundary. The current is part of the large-scale Northwest Atlantic circulation consisting of the West Greenland Current that flows northward along the west coast of Greenland, a branch of which turns westward and crosses the northern Labrador Sea forming the northern section of the Northwest Atlantic sub-polar gyre. Near the northern tip of Labrador, outflow through Hudson Strait combines with the east Baffin Island Current and flows south-eastward along the Labrador coast, sometimes referred to as the inshore Labrador Current (Figure 3) (Chapman and Beardsley, 1989; Lazier and Wright 1993). The inshore branch over the Labrador Shelf is strongly influenced by the seabed topography, following the various cross-shelf saddles and inshore troughs. Most of the transported volume however, remains offshore at the edge of the continental shelf and seaward in the deeper waters of the LSFA.

Ocean circulation derived from the historical [Argo float](#) data at the 1,000 m level shows the strongest currents flowing south-eastward following the continental slope at about the 2000 m isobath. This flow forms a boundary that separates the cold and fresher shelf water and the relatively warm and saline waters of the Labrador Sea and nearly coincides with the westward boundary of the LSFA (Figure 1). Mean currents over the Labrador Slope region at 1000 m depth based on ARGO data from 2000-2013 typically range from 10-15 cm/s. Further offshore currents are generally around 7 cm/s decreasing to very weak values in the centre of the subpolar gyre (Figure 3 right panel, Yashayaev, BIO, 2017, pers. comm.). More information on the Canadian contribution to the international ARGO program by the Bedford Institute of Oceanography is available [online](#).



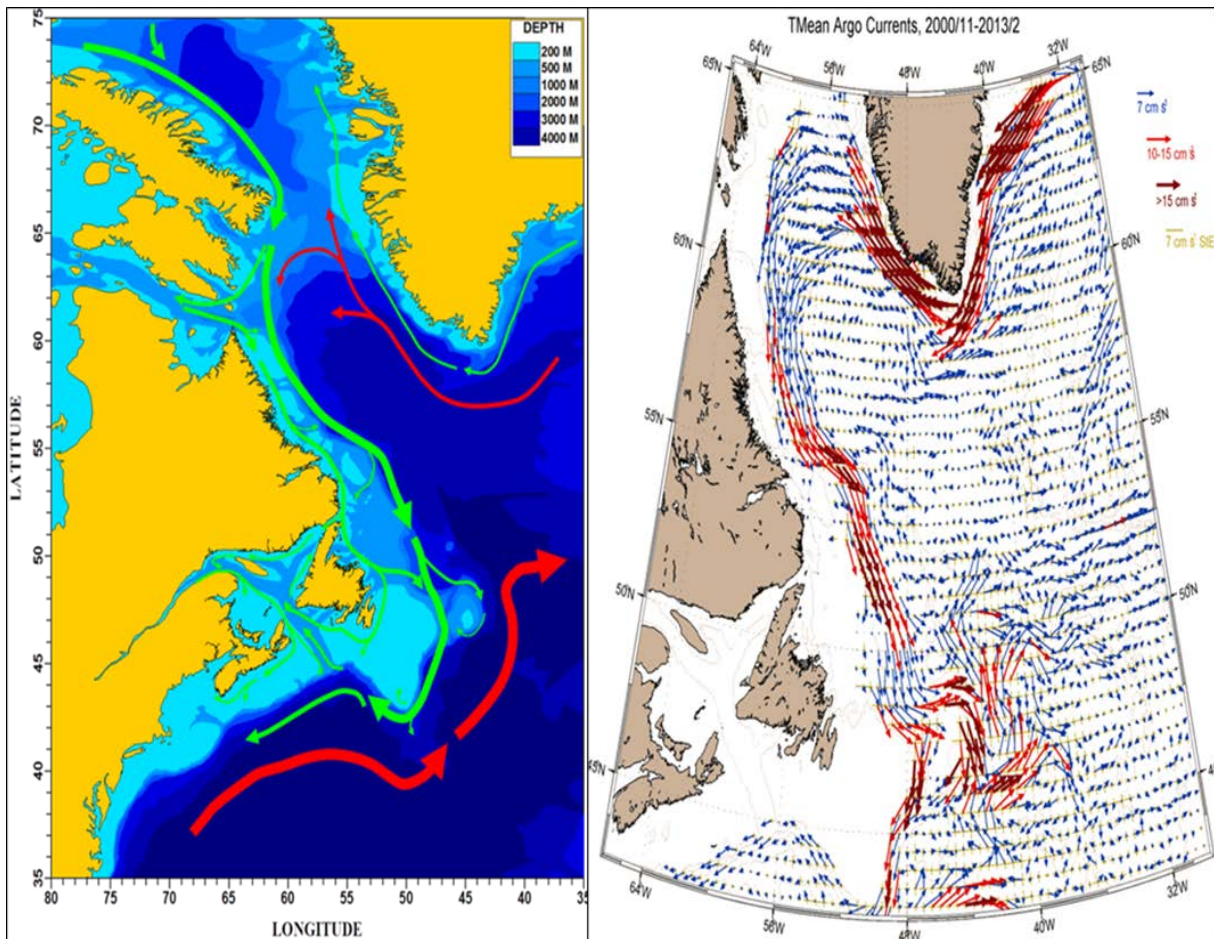


Figure 3: A schematic of the general surface oceanic circulation in the Northwest Atlantic (left panel) and a detailed map of the currents at 1000 m depth as measured by the ARGO program data collected from 2000 to 2013 (right panel). Map of Argo derived currents courtesy of I. Yashayaev, BIO.

Sea Surface Temperature (SST) data based on infrared satellite imagery of the Northwest Atlantic, including the LSFA is available as weekly or bi-weekly composites. The Pathfinder 5.2 SST data are available at a resolution of 4 km with 7 day composite averages from 1981 to 2012 (Casey et al. 2010). The National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) SST data are available as bi-weekly composites from 1997 to 2018. These data sets have been used by the AZMP to construct SST time series for the central and northern Labrador Sea as well as other defined areas throughout the Atlantic Zone (Figure 4, top right panels) (Colbourne et al. 2017 and Colbourne et al. 2018).

The annual cycle of SST within the central Labrador Sea box (Figure 4) varies over the year; the average (1981-2010) winter (January-April) temperature is about 2°C and the average maximum temperature for the area is about 8°C in August with a slightly higher value in August of 2016 when SST was near 9.5°C (Figure 5). From August the temperature decreases almost linearly during the fall period to just over 2°C by December. Annual SST based on a standardized composite of all five areas in Figure 4 shows an increasing trend in temperature throughout the Labrador Sea from the low in 1984. SSTs were mostly below the mean from 1982 to 1999 after which they increased to above the mean, reaching a peak in 2010. In the most recent years (2012 to 2016) SST values have trended downward, with 2015 showing negative anomalies in most areas (Figure 5).

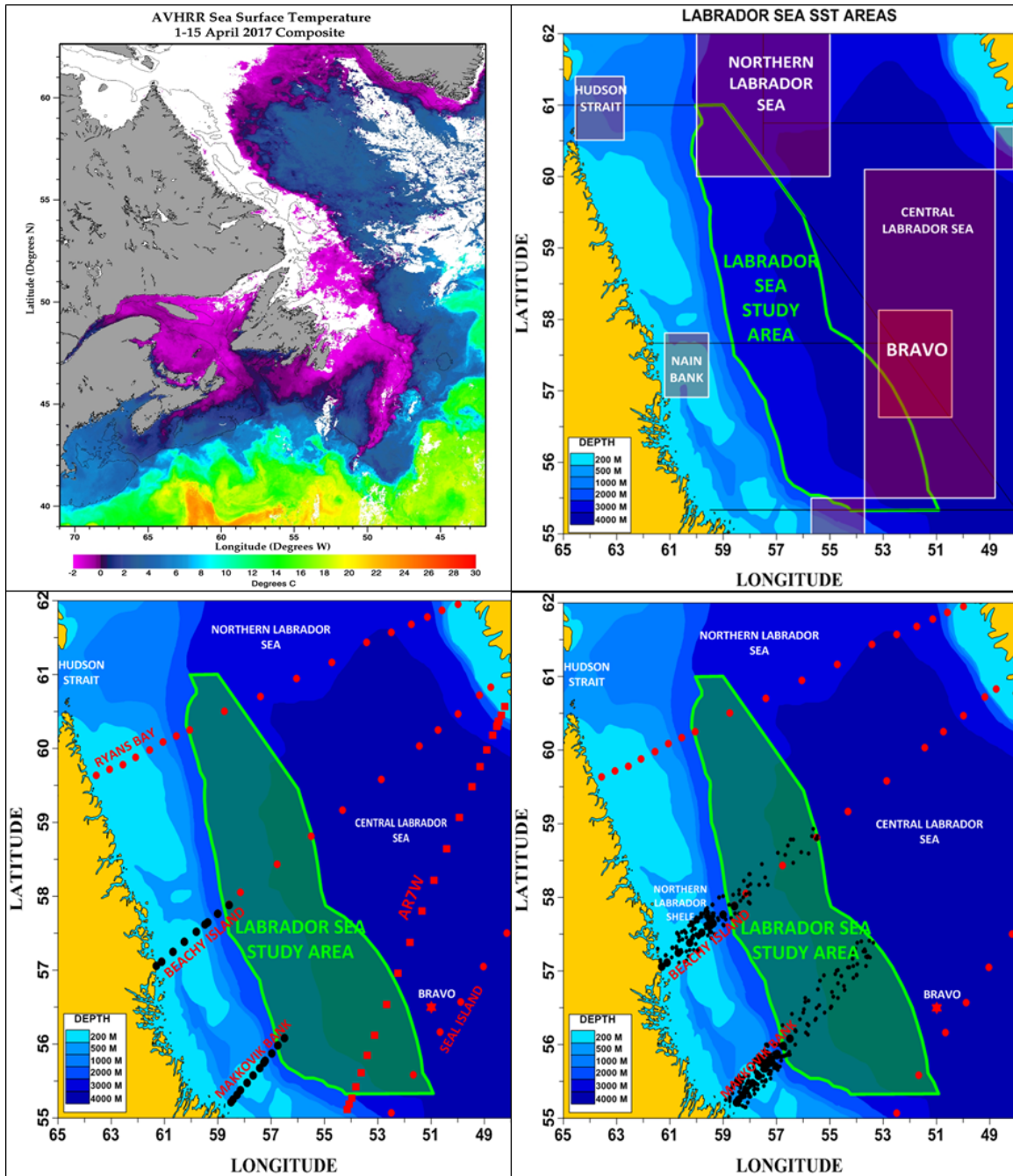


Figure 4: Sea surface temperature in April of 2017 (top left panel) and the areas in the Labrador Sea where SST time series were constructed (top right panel). The white along the coast of Labrador and Newfoundland is sea ice while the white elsewhere is clouds. The data are available from NOAA AVHRR satellite SST data archive at BIO. Standard oceanographic stations established by the International Commission of the Northwest Atlantic Fisheries (ICNAF, now NAFO; red dots), the AZMP (black dots) and the AZOMP (red squares) (bottom left panel). Standard ICNAF (red dots) and AZMP collections (black dots) including historical summer oceanographic data (bottom right panel).

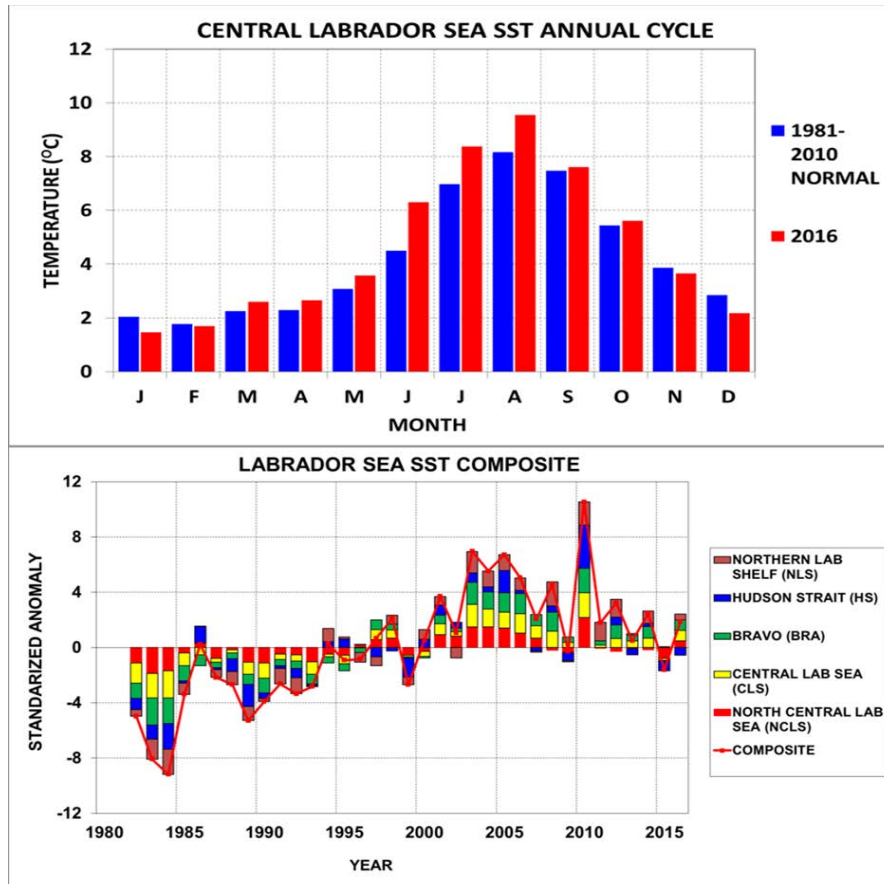


Figure 5: The long-term average and the 2016 sea surface annual temperature cycle (top panel) for the central Labrador Sea (area shown in Figure 4) and the standardized annual SST anomalies (bottom panel) from the five subareas shown in Figure 4 (top right panel) for the Labrador Shelf and Sea regions.

An extensive archive of historical temperature and salinity profile data collected throughout the Northwest Atlantic is available from archives at the Ocean Science Branch (OSB) of Fisheries and Oceans Canada in Ottawa and also maintained in regional data archives at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's, NL. These measurements have been collected along standard sections and stations during ICNAF, NAFO, AZMP, AZOMP surveys and by other research and ships of opportunity dating back to the 1920s. Before the 1960s, most of the data were collected at standard nominal depths using water-sampling bottles fitted with reversing thermometers. Since the 1960s and up to the present, a considerable amount of data was also collected using mechanical and electronic bathythermographs and since the late 1970s conductivity-temperature-depth (CTD) recorders have been used extensively. The distribution of all T/S profiles within the LSFA shows good spatial coverage during all seasons (Figure 6).

Since the early 2000s, the international ARGO float program has greatly enhanced the temporal and spatial coverage of temperature and salinity profile data over the depth range of 0 to 2000 m in the LSFA. As a result, the annual temperature and salinity cycles for the LSFA are well defined with profile data available for all months in recent years. The monthly distribution of profiles based on the historical data archive show the highest number in the summer months with over 350 profiles collected in July and August and the lowest in the winter months with about 100 profiles. In 2017, all months had at least one profile (November and December) with 5 to 7 profiles in most other months for a total of 49 T/S profiles.



The number of profiles within the LSFA in recent years range from 19 in 2008 to 100 in 2015 with a reasonable number available during most years since 1951 (Figure 7). In general, these historical data are sufficient to construct seasonal climatologies of the horizontal temperature and salinity distributions at specific depths, as well as historical time series of annual temperature and salinity anomalies within the LSFA.

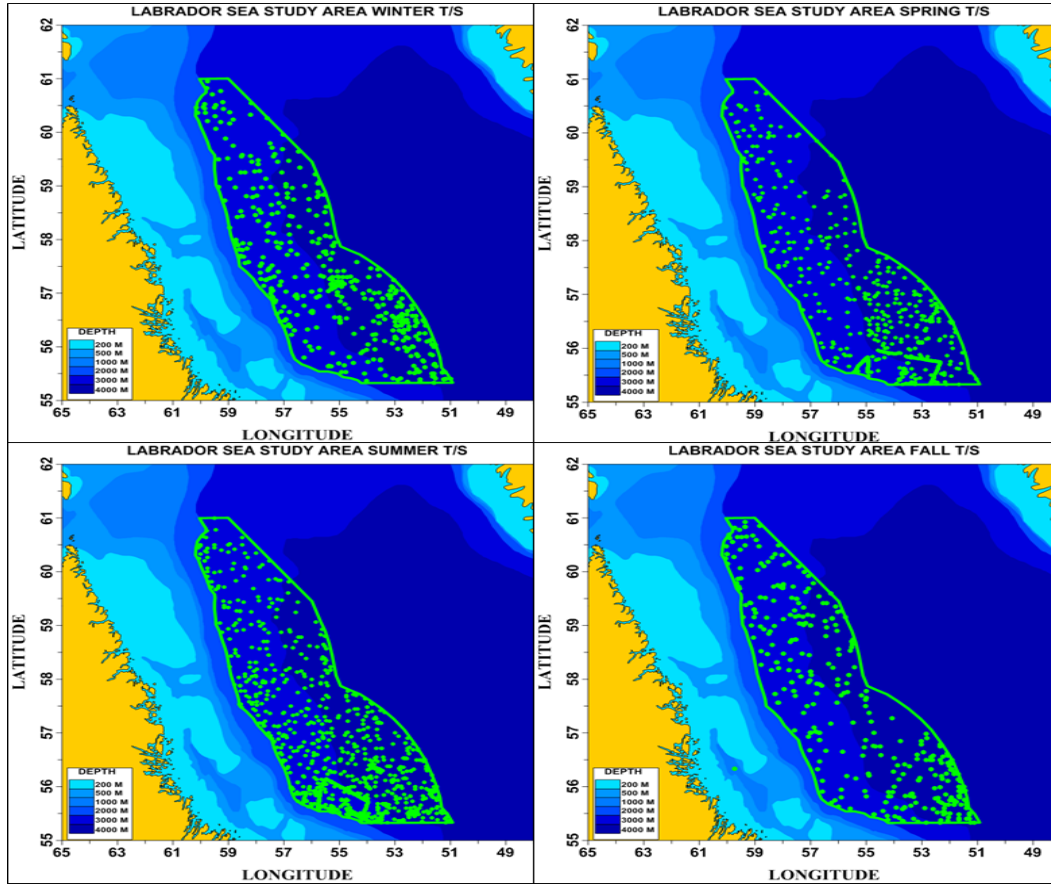


Figure 6: Maps showing the seasonal locations of historical temperature and salinity profiles in the LSFA from 1928 to 2017.

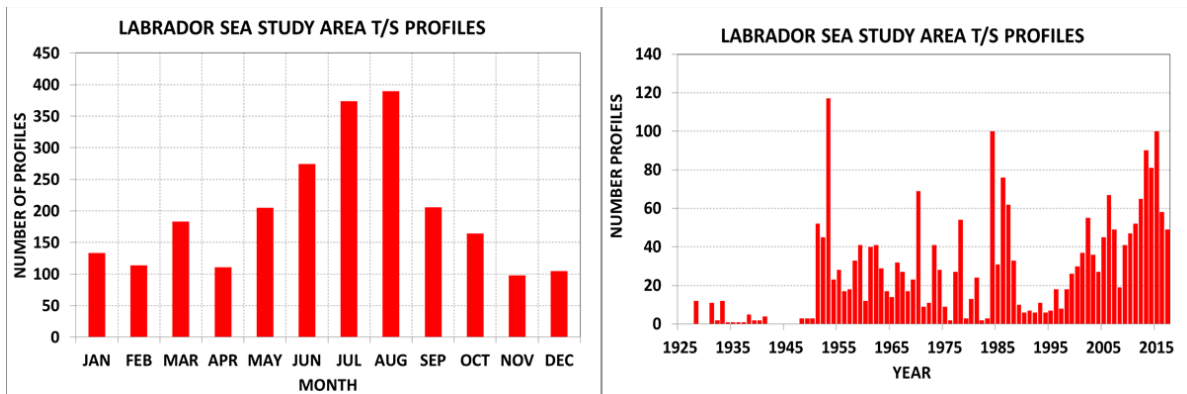


Figure 7: The number of historical temperature and salinity profiles in the LSFA by month (left panel) and by year (right panel).



Upper-layer temperature based on the historical data shows a strong annual cycle with minimum winter values of about 3°C and maximum values of about 8°C occurring during the summer (Figure 8). The annual time series based on all data averaged over the LSFSA shows a decreasing temperature trend since the 1960s that reached a minimum of about 2°C below normal in the early-1990s. Since then, there has been an increasing trend with values during the most recent years varying about the mean.

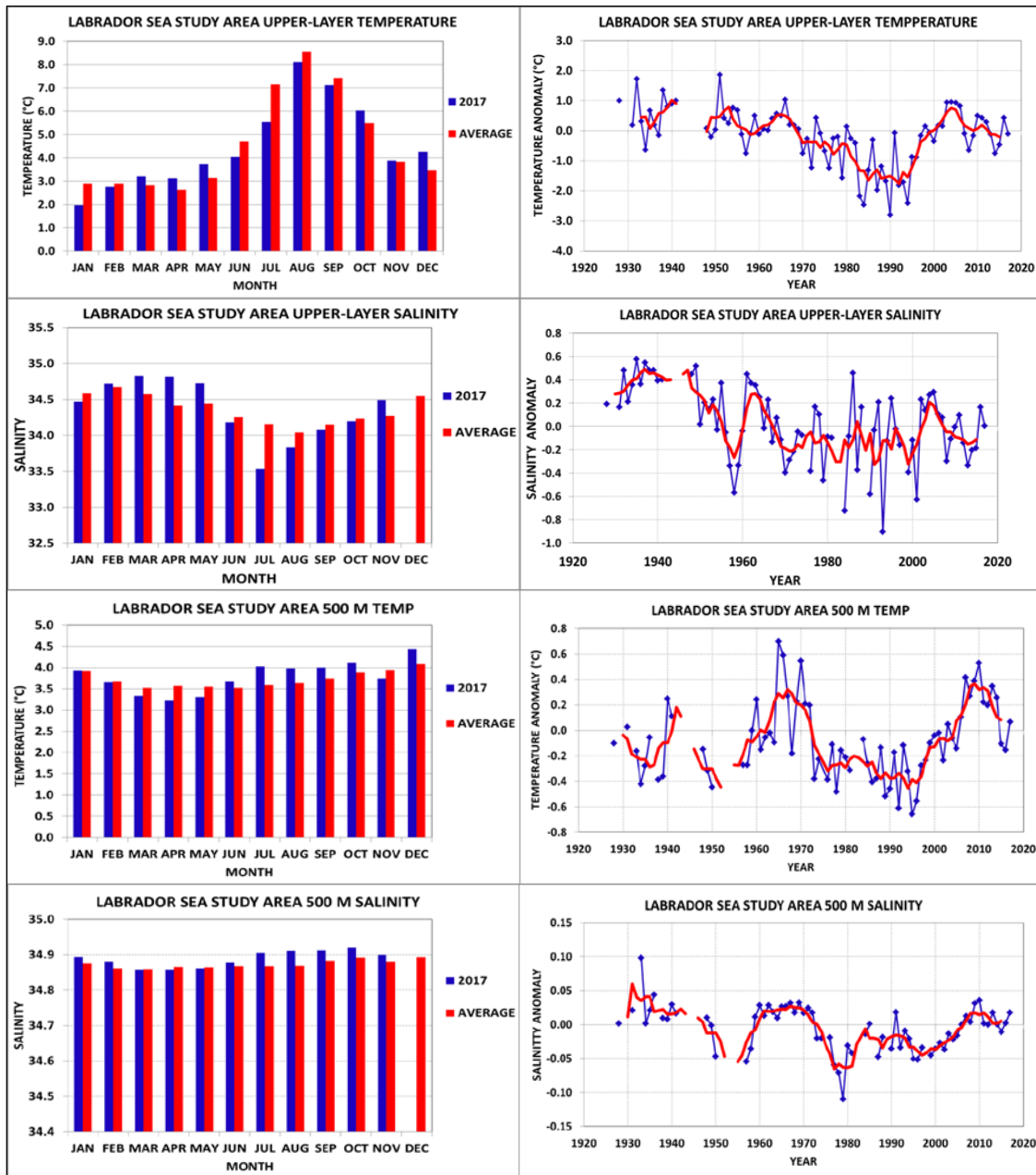


Figure 8: The 2017 and the average annual temperature and salinity cycles for the upper near-surface layer and at the 500 m depth level within the LSFSA (left panels) and the corresponding long-term trends in the temperature and salinity within the LSFSA (right panels).

Upper layer salinity also shows a strong annual cycle with minimum values of about 34 Practical Salinity Units (PSU) occurring in the summer and maximum of >34.5 PSU during the winter

months. The long term trend in salinity shows a high degree of annual variability with a general decreasing trend of about 0.4 PSU since the 1940s. At 500 m depth, temperature and salinity vary between 3.5°C and 4°C and 34.8 PSU and 34.9 PSU with no significant annual cycle (Figure 8). The temperature and to a lesser extent the salinity time series however show significant trends, with record low values in the 1990s, a recent increasing trend but near-normal values in the past 3-years.

The spatial temperature and salinity structure at 100 m depth during both winter and summer show strong longitudinal gradients at the western boundary of the LSFA with an almost uniform latitudinal temperature and salinity field. The western boundary of the LSFA coincides with the thermohaline front separating the cold-fresh Labrador Shelf-Slope water from Labrador Sea water (Figure 9). During the winter the temperature values at 100 m within the LSFA varies from <math>2^{\circ}\text{C}</math> at the western boundary to between

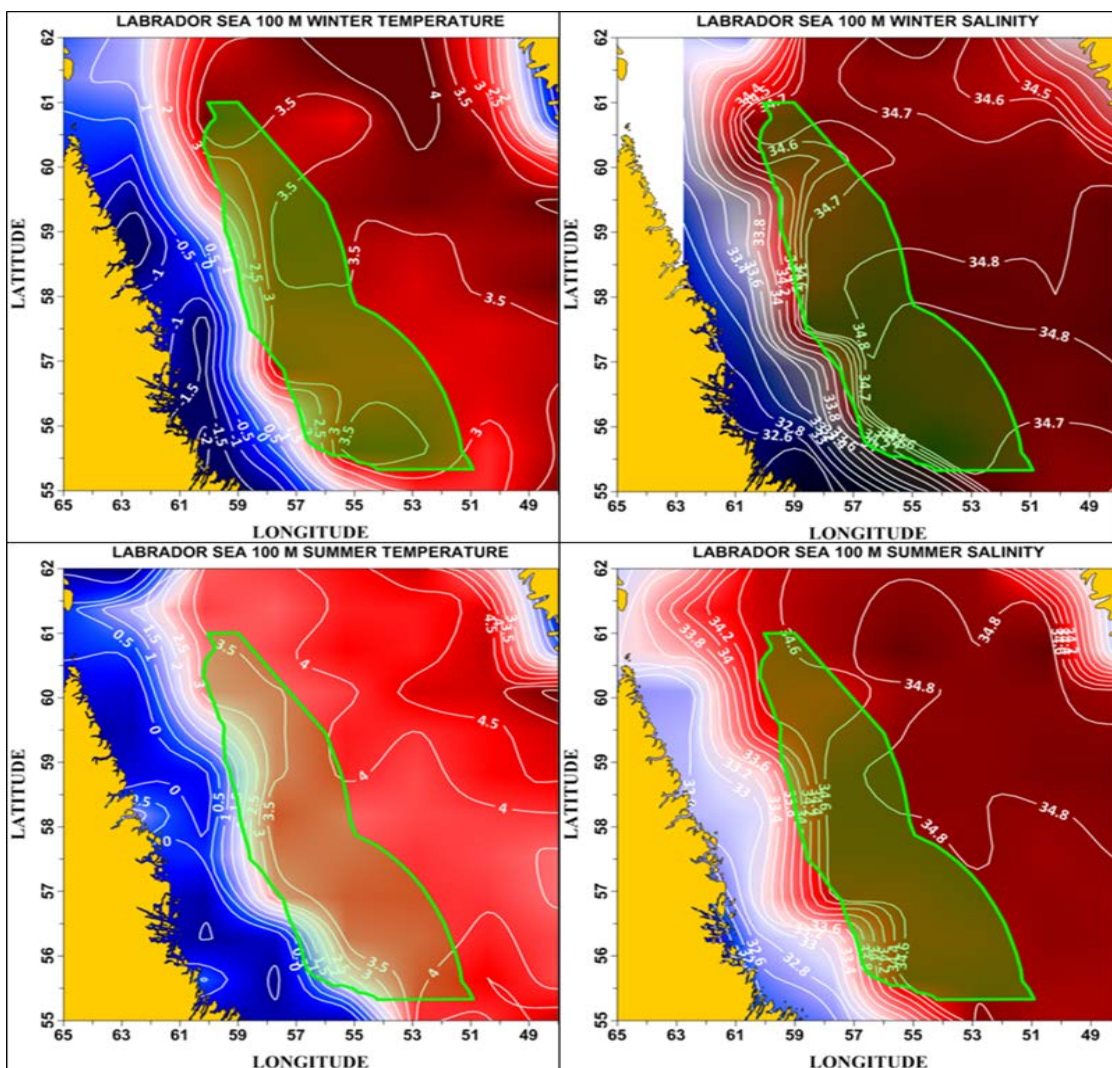


Figure 9: The winter (top panels) and summer (bottom panels) horizontal temperature and salinity fields at 100 m depth in the Labrador Sea based on all historical data. The LSFA is outlined and shaded in green.



The dominate thermal features along the extended Beachy Island section (Figure 4, bottom panels) include the mass of cold water overlying the shelf during the summer that is isolated from the warmer higher density water of the continental slope region and the Labrador Sea. This winter chilled water mass is commonly referred to as the cold-intermediate-layer (CIL) (Petrie et al. 1988) and extends offshore to the western boundary of the LSFA (Figure 10).

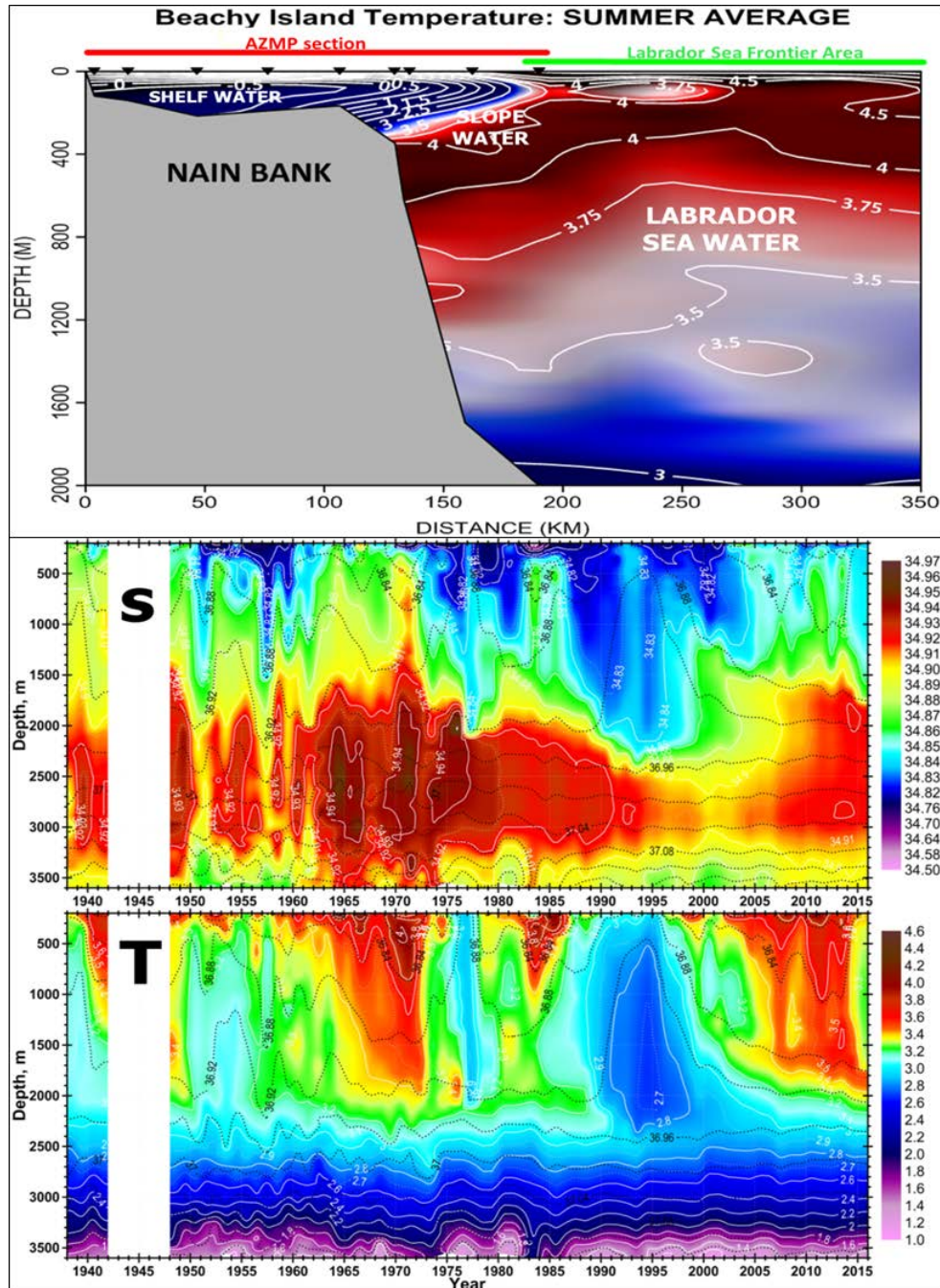


Figure 10: Contours of summer temperature (in °C) along the Beachy Island section (Figure 4) extended into the LSFA using all historical data. AZMP stations along the section are indicated by the symbols at the top. The red/green bars indicate the spatial extent of the AZMP Section and the LSFA (top panel). The historical salinity (in PSU, middle panel) and temperature (in °C, bottom panel) time series in the Labrador Sea based on historical including ARGO data (courtesy of I. Yashayaev, BIO, 2017).

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Temperatures seaward of the shelf break in the Labrador Sea and the LSFA generally range from >4.5°C near the surface to 3.75°C at 1000 m to 3°C at 2000 m depth.

The time series of annual average T/S profiles based on all historical data including the recent ARGO data from the central Labrador Sea is also shown in Figure 10. Of particular note is the significant cold-fresh period during the 1990s corresponding to intense winter convection in the Labrador Sea that penetrated to 2000 m depth. Since the late 1990s and early 2000s temperatures in the Labrador Sea have experienced a warming trend up to at least 2014. Recently however there has been a progressive deepening of winter convection in the Labrador Sea reaching to 2100 m in 2016, similar to conditions observed in the early 1990s (Yashayaev and Loder 2017).

### **Species and/or Habitats of Interest**

Much of the interest in studying the Labrador Sea arises from the fact that its oceanography is of global significance. The Labrador Sea is one of only a few regions of the world that undergoes deep water convection (i.e., it delivers oxygenated surface waters to deep ocean depths). This process is driven in part by the presence of sea ice and will be influenced by climate-related changes to surface sea temperature. Also, the North Atlantic, including the Labrador Sea, has the highest marine concentrations of anthropogenic CO<sub>2</sub> on the globe (Sabine et al. 2004) and these levels continue to rise (Yashayaev et al. 2016).

### **Key Uncertainties and Approaches to Address Data Gaps**

The AZMP is primarily a shelf-based oceanographic monitoring program and as such, sampling within the LSFA is restricted to a few off-shelf stations along the Beachy Island and Makkovik sections. It remains unclear whether the patterns in biogeochemical conditions observed on the Shelf are consistent within the LSFA.

Future oceanographic monitoring in the LSFA should consider extension of current AZMP sections that would permit analyses of biophysical connectivity between Shelf and the Labrador Sea Basin and evaluate seasonal changes in biota and physical conditions. Given the importance of the Labrador Sea in air-sea dynamics and exchange of carbon dioxide within the deep basin, additional sampling efforts should be considered to address ocean acidification (Yashayaev et al. 2016). The limited opportunities to conduct ship-based oceanographic monitoring means additional study of the oceanography of the LSFA will likely require investment in autonomous vehicles fitted with scientific instruments (e.g., ocean gliders), long term deployments of automated collection devices deployed on moorings (e.g., sediment traps for demersal productivity) and/or working collaboratively with other interested research teams. Collaborations hold considerable potential given the international interest in studying oceanography in the Labrador Sea (e.g., Bedford Institute of Oceanography (BIO), Ventilation Interaction and Transports across the Labrador Sea (VITALS), Overturning in the Subpolar North Atlantic Program (OSNAP) and the recently formed DFO NOAA Ocean Acidification Working Group).

## **PLANKTON**

### **Available information**

#### **Phytoplankton**

Large-scale ocean colour imagery across the Northwest Atlantic reveals intense phytoplankton blooms across the Labrador Sea (Figure 11). Biological studies conducted along the Atlantic



Repeat Hydrography Line 7 (AR7W) section by the Bedford Institute of Oceanography (BIO) indicate the predominance of *Phaeocystis* spp. (mucous-forming colonies) algae in these large-scale blooms in recent years. During the Fish Characterization Cruise August 11-28, 2017, phytoplankton samples were taken using a 4 liter Niskin bottle, at 30 m, and plankton net (20  $\mu\text{m}$ ) from 30 m to the surface. Preliminary results show that these samples mainly consist of a mixture of diatoms and dinoflagellates with a few flagellates present (Figure 12).

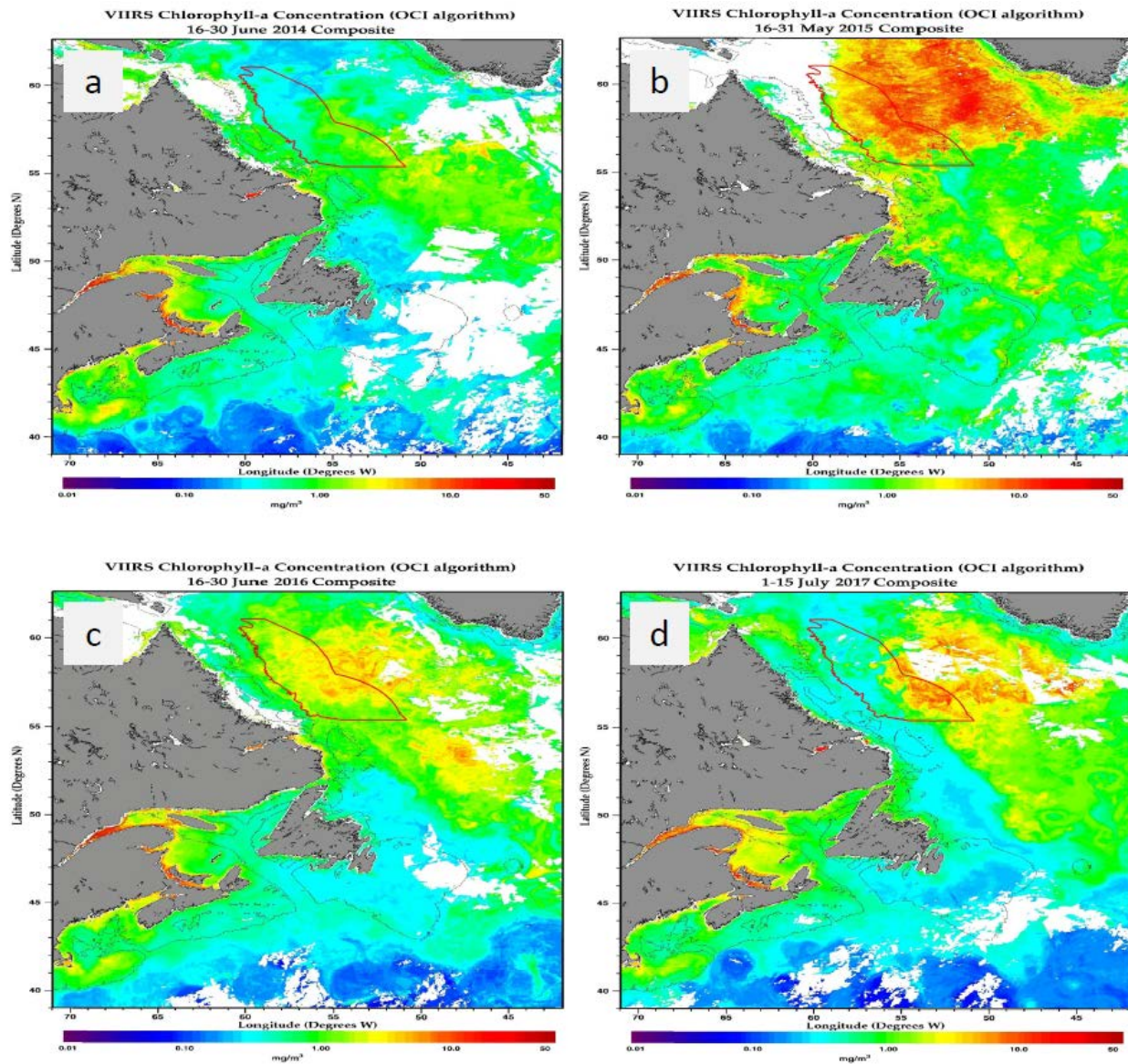


Figure 11: Ocean color imagery across the Northwest Atlantic showing intense phytoplankton blooms in recent years in the Labrador Sea. a) 16-30 June 2014, b) 16-31 May 2015, c) 16-30 June 2016, d) 1-15 July 2017. The Labrador Sea Frontier Area boundary is indicated in red. Imagery acquired from [BIO: Semi-Monthly Composites](#).

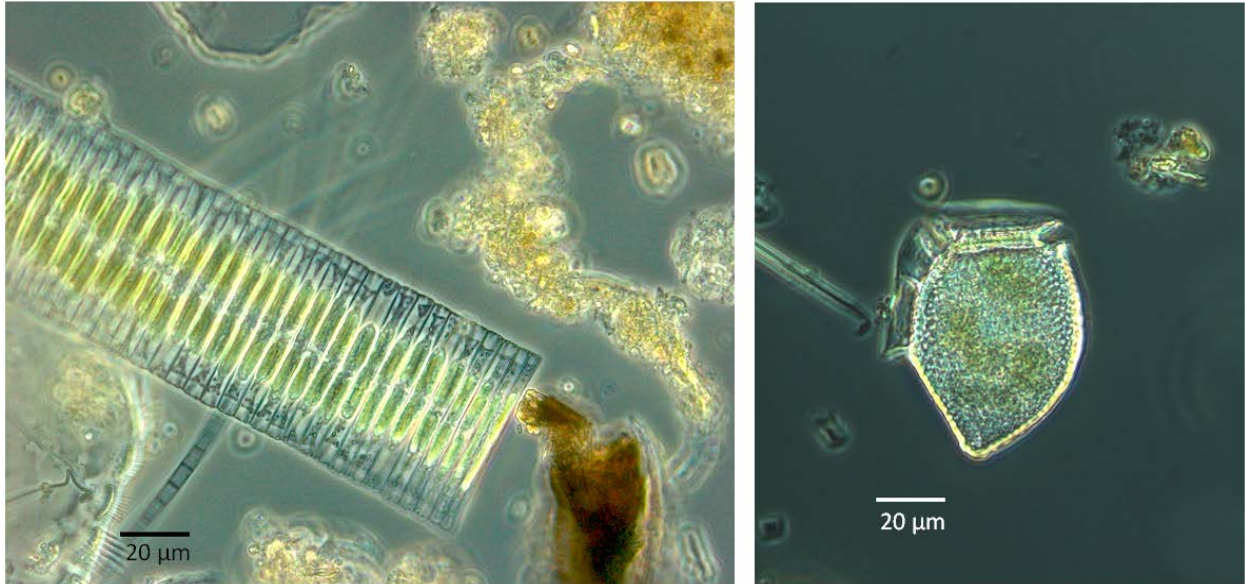


Figure 12: Two of the most common phytoplankton taxa (left: chain of pennate diatoms; right: dinoflagellate) obtained during the Fish Characterization Cruise.

Light, nutrients and stratification are all important factors governing the phytoplankton production and growth dynamics. The available level of nutrients in the upper layer of the water column is determined by the extent of the vertical mixing in the water column during winter (Harrison et al. 2013). The depth of the convection in the Labrador Sea is dependent on the hydrographic conditions, which largely is a response to heat loss to the atmosphere, heat and salt gained from Atlantic water inflow, and freshwater input through sea ice, melt water, continental runoff and precipitation. During cold winters the surface water may experience increased cooling leading to higher density and deeper convective mixing. In mild winters there is less heat loss to the atmosphere and a stronger influence from the warm and saline Atlantic waters, promoting stronger stratification and shallower convective mixing (Yashayaev et al. 2016). As the sun heats up the surface waters in spring, the upper layer stratifies. The extent of the mixing will determine the level of nutrients available in the surface waters, hence setting the lower limit on the magnitude and duration of the spring bloom (Harrison et al. 2013).

Phytoplankton biomass (chlorophyll *a*) within the LSFA was estimated using GLOBCOLOUR (GlobColour 2007; [Globcolour Website](#)) remote sensing imagery processed with a semi-analytical bio-optical model referred in the literature as the GSM model (Maritorena and Siegel, 2005, Maritorena et al., 2010). Biological points of interest derived from Chl *a* concentration cycles are calculated following Fuentes-Yaco et al. (2016). The approach fits a function to the satellite-derived data points using a five-parameter logistic equation (Fuentes-Yaco et al. 2013), modified following Ricketts and Head (1999) that enables the fitted curves to be non-symmetrical on either side of the maxima. Spring blooms (2003-17) in the LSFA are on average initiated on April 16<sup>th</sup> ± 3 days [SE], while the earliest initiation of the spring bloom was on April 2<sup>nd</sup> in 2010 and the latest was on May 7<sup>th</sup> 2007 (Figure 13). The average phytoplankton concentration at the peak of the spring bloom was 1.61 ± 0.02 [SE] mg m<sup>-3</sup>, but values ranged from 1.13 mg m<sup>-3</sup> (2008) to 2.26 mg m<sup>-3</sup> (2003). The fall bloom is more variable than the spring bloom in terms of timing of initiation, duration of the bloom and the magnitude.



The fall bloom is initiated on September 4<sup>th</sup> ± 4 [SE] days, lasting for 135 ± 10 [SE] days, and ending on January 18<sup>th</sup> (± 10 days [SE]). The longest fall bloom (2010) lasted for 189 days, whereas the shortest (2007) lasted for 80 days. At peak of the fall bloom, the chlorophyll a levels were estimated to range from 0.75 mg m<sup>-3</sup> (2012) to 2.64 mg m<sup>-3</sup> (2010), with an average of 1.15 ± 0.13 [SE] mg m<sup>-3</sup>.

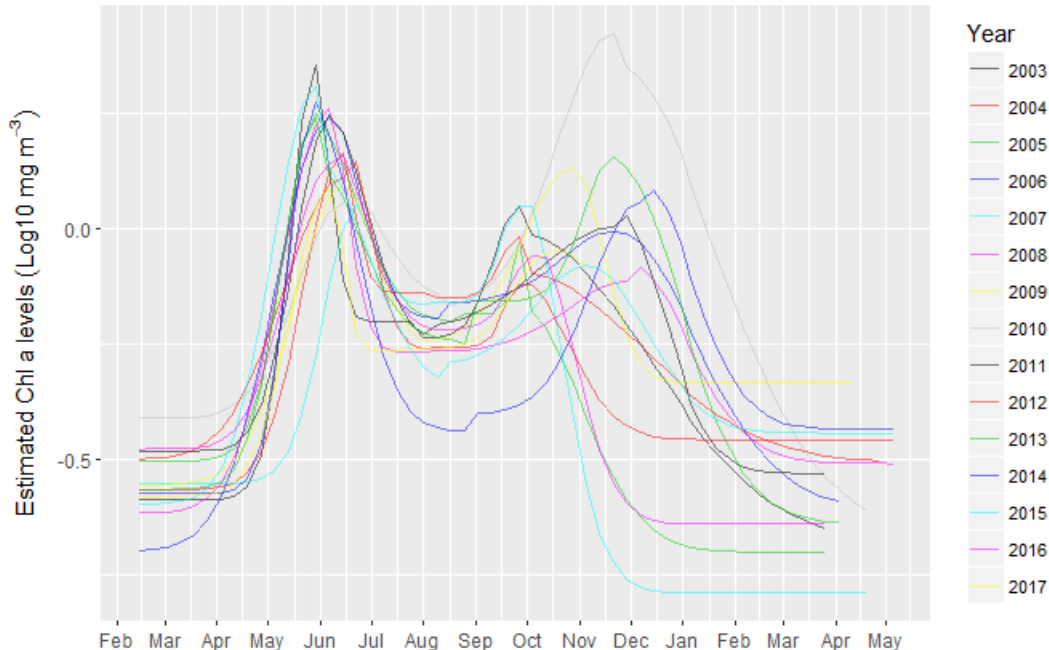


Figure 13: Estimated chlorophyll a levels during the spring and fall phytoplankton blooms in the Labrador Sea Frontier Area, as measured from Globcolour remote sensing imagery.

## Zooplankton

Zooplankton are important in the marine system as grazers of primary production, prey for higher trophic levels and drivers of carbon and nutrient cycles (Pepin 2013; Gjerdrum et al. 2008; Keister et al. 2012; Gavrilchuck et al. 2014). Zooplankton are not only important in the pelagic system but are also known to support benthic communities through sedimentation of phytodetritus, particulate-organic-matter (POM) and food falls (Ruhl et al. 2004; Gale et al. 2013). Characteristic zooplankton taxa in the offshore Labrador Sea are the copepods *Oithona* spp., *Microcalanus*, *Scolecithricella minor*, *Calanus finmarchicus*, *C. hyperboreus*, *Metridia* spp., *Euchaeta* spp., krill (Euphasids) and amphipods (mainly *Themisto libellula*; Head et al. 2003; Pepin 2013). The copepod *C. finmarchicus* is the main contributor to mesozooplankton biomass throughout the North Atlantic and the Labrador Sea has been identified as one of the five main hotspots of *C. finmarchicus* (Heath et al. 2004). During spring and summer, *C. finmarchicus* have its highest abundances over the shelf with younger stages relatively more abundant than older stages (Pepin 2013). In winter the highest abundance *C. finmarchicus* is found in the Labrador Sea where they overwinter in a state of diapause aggregating at depth > 400 m with abundances of >15 000 m<sup>2</sup> (Heath et al. 2004; reviewed by Hirche 1996). During diapause, their metabolic rate is lowered in a similar way to hibernation for terrestrial animals. During diapause, copepods can survive up to 9 months on the lipid reserve they build up over the summer (reviewed by Hirche 1996). In addition to providing reserves to survive the winter, lipid reserves provide energy for molting to the adult stage, including the development of gonads and the ascent to the surface in spring

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(Jónasdóttir 1999). The lipid reserve mainly consists of wax esters (Jónasdóttir 1999) and can make up 25-85% of total dry weight (Vogedes et al. 2010). In copepod stage CV they have an average caloric dry weight content of 39.5 kJ g<sup>-1</sup> (Michaud and Taggart 2007). The abundance of non-copepod zooplankton in the area, which is mostly composed of gelatinous and carnivorous zooplankton, has increased in recent years (DFO 2017; Pepin et al. 2017). The biomass of different size fractions of zooplankton shows some reciprocal changes over time and combined size fractions suggest an overall reduction in zooplankton biomass ongoing since a peak value was observed in 2007.

The majority of information on zooplankton in the Labrador Sea comes from the shelf and south of the LSFA from the AZMP (sampling protocol see Mitchell et al. 2000), the AZOMP, and the Norway-Canada Comparison of Marine Ecosystem (NORCAN) program. Data have been collected using a Continuous Plankton Recorder (CPR), 202 µm vertical net fitted on a 0.75m diameter ring and Optical Plankton Counter (OPC) (Head et al. 2003; Pepin 2013; Melle et al. 2014; Heath et al. 2004). In addition, trawling has shown to be effective in obtaining samples of larger zooplankton such as amphipods and shrimp, and active acoustic data recorded with multi-frequency scientific echosounders can provide information on the vertical distribution and relative abundance of pelagic organisms (Pepin 2013).

### **Species and/or Habitats of Interest**

As limited knowledge on plankton communities exists from the LSFA, establishing an inventory of species inhabiting the region would be of great interest. In addition, it would be relevant to study predator-prey interactions and how they are affected under different environmental and climatic scenarios (i.e. changes in temperature, salinity, and current velocity, depth of the winter convection, and timing and depth of spring stratification).

Additional analyses of existing datasets could provide new information on population connectivity of benthic-pelagic species. Ice-ocean models representing dominating currents could be used to quantify larval transport, to identify potential seeding areas within the LSFA, and to estimate the destination of larvae produced in the LSFA. This is illustrated with a biophysical particle-tracking model for northern shrimp (*Pandalus borealis*) larvae, where ocean currents (using the Hybrid Coordinate Ocean Model (HYCOM)) were combined with information on shrimp larval swimming behaviour (Le Corre et al. 2018; Figure 14). These pilot analyses suggest: (1) larvae with a long pelagic phase released on the shelf in the north of Labrador (Div. 0B and Hudson Strait) end up on more southerly portions of the Labrador shelf (in Div. 2GHJ), (2) the Labrador Sea release experiment showed potential retention of a significant proportion of the larvae in the LSFA, and (3) the larvae released from the Greenland shelf may be transported to the LSFA.



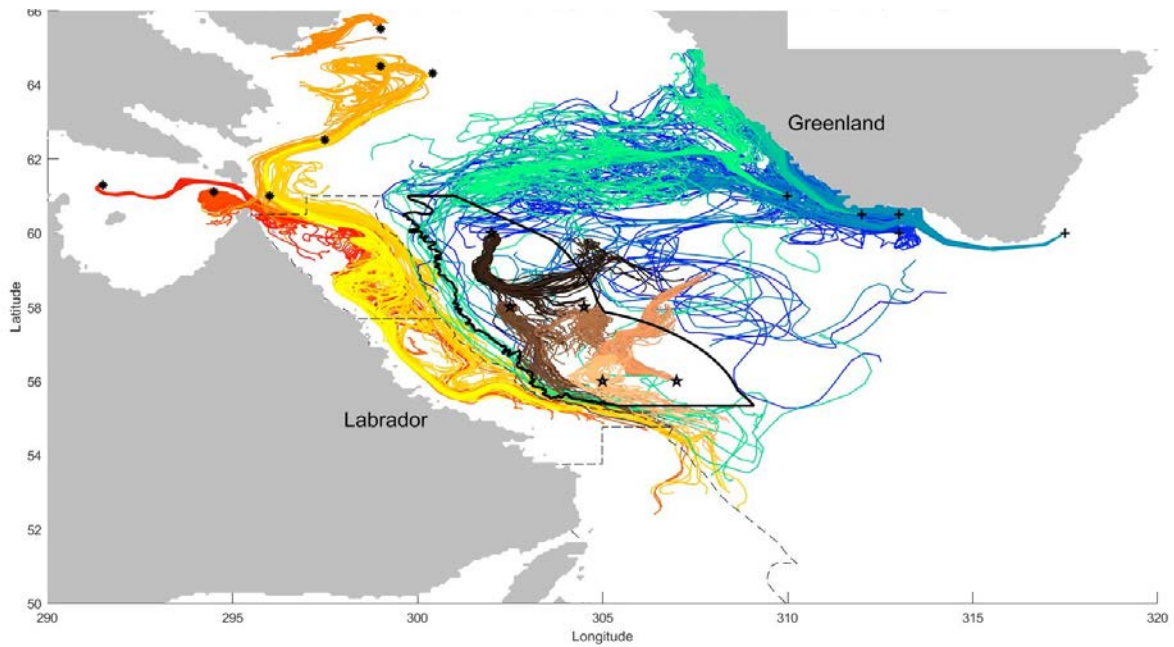


Figure 14: Three simulated larval release events at seven different sites north of Labrador (black dots), five sites in the Labrador Sea Frontier Area (black stars) and five sites on the Greenland shelf (black crosses). Each simulation is represented by a different color. Larval trajectories were estimated using a connectivity modeling system, (Paris et al. 2013) incorporating currents from the Hybrid Coordinate Ocean Model (HYCOM) in 2010 for northern Labrador and Labrador Sea releases, and HYCOM 2015 for the Greenland releases. Fifty larvae were released per site and were permitted to drift and disperse for sixty days with a random-walk.

### Key Uncertainties and Approaches to Address Data Gaps

While an understanding of plankton dynamics is relatively strong in the Labrador Sea region, collections from within the LSFA remain sparse. Given the unique oceanography in the LSFA, verification that these plankton dynamics extend to this area is important. As stated for oceanography, efforts should be made to extend the sampling programs AZMP and AZOMP to include the LSFA. AZMP and AZOMP data can also be supplemented by acoustic sampling of the water column (from moorings or ship-based) to understand the depth distribution of pelagic organisms as well as establishing baseline environmental DNA (eDNA) collections. The trophic links of zooplankton should also be explored through diet analyses of higher organisms (i.e. stomach content and tissue stable isotope and fatty acid analyses). Sediment traps, set on moorings (see Appendix 1), could provide important information on food delivery to benthic habitats; which may be affected by the region's deep-water convection.

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## BENTHIC COMMUNITIES

### Available information

Information on benthic organisms occupying the LSFA are very scarce as most benthic studies in Atlantic Canadian waters have been conducted on the continental shelf and slope. Preliminary results from the baited camera survey during the Fish Characterization Cruise (600-3,015 m) show the presence of polychaetes, *Pennatula* sp. sea pens, brittlestars (Ophiurida) and shrimp (Caridea) at depths exceeding 2,000 m (Figure 15). Quantitative analyses of the data are in progress. Previous studies have shown that benthic organisms play an important role in the deep-sea community and that the species composition changes with depth (Haedrich et al. 1980; Rex 1981; Howell et al. 2002 in Gale et al. 2015). In the waters off New England, Haedrich et al. (1980) characterized eight different depth zones (Table 2) from the continental shelf to the abyssal plain (40-4968 m). Four of the depth zones (Zones 3-6, 600-3015 m) fall within the depth ranges sampled during the Fish Characterization Cruise, and three depth zones (Zones 5-7, 2,000-3,500 m) fall within the LSFA. Results from the study by Haedrich et al. (1980) showed that decapods, echinoderms and fishes were the dominant megafauna taxa and their abundance, weight and diversity changed between the different depth zones however, there was no clear linear relationship with depth; i.e. the taxa did not show the same pattern of change across depth zones. Haedrich et al. (1980) used trawls to obtain the samples and calculated abundance and biomass per hour trawled. In addition to being important structural components of deep-sea ecosystems, large epibenthic animals such as seastars (asteroids) have an important role in the deep-sea food web and disturbance (Gale et al. 2013).

Table 2: Depth zones from the continental shelf to the abyssal plain. Adapted from Haedrich et al. (1980).

Zone	Name	Depth
1	Continental shelf	40-246 m
2	Upper continental slope	283-650 m
3	Middle continental slope	653-1290 m
4	Lower continental slope	653-1290 m
5	Transitional region	2116-2481 m
6	Upper continental rise	2504-3113 m
7	Middle continental rise	3244-3740 m
8	Abyssal plain	3879-4968 m

Smaller macrofaunal (retained with a 420 µm sieve) elements of the benthic community include polychaetes, gastropods, cumaceans and bivalves. In other areas of the western Atlantic these taxa have shown the highest abundance between 2,300 and 2,800 m (Rex 1981). Even smaller meiobenthic copepods have been less studied; however (Rex 1981) found that the diversity off Cape Hatteras, North Carolina, USA, increased towards 3,000 m to rapidly decrease with distance from the middle continental rise towards the abyssal plain. Although a full comparison has not been made, meiobenthic copepods appear to be more diverse than the polychaetes,

which are the most diverse group of the macrofauna (Rex 1981). Time series data from the deep sea are extremely rare, however a study from the northeast Pacific (Ruhl and Smith Jr. 2004) indicates that deep-sea benthic communities are responsive to climate events such as El Niño and La Niña. While environmental conditions such as temperature and salinity are considered much more stable in the deep sea than in shallower shelf waters (Rex 1981), deep-sea inhabitants still rely on the production of surface waters as a source of energy. Epi-pelagic production and resulting particulate organic carbon are more directly affected by climatic cycles and provide a mechanism to introduce temporal variability to deep-sea benthic communities (Ruhl and Smith Jr. 2004).



Figure 15: Baited video captures of a brittlestar (ophiurida; red circle, left panel) and an Aristeidae shrimp (right panel) in the Labrador Sea Frontier Area.

### Species and/or Habitats of Interest

The paucity of information on deep-sea benthic organisms in the LSFA limits the ability to define species and habitats of particular interest. Echinoderms are likely to form an important structural component of the deep-sea ecosystems where these taxa likely initiate key ecological processes (e.g., disturbance regimes; Ruhl and Smith Jr. 2004). The association of some benthic species with fragile deep-sea coral habitats (Mortensen and Buhl-Mortensen 2005, Buhl-Mortensen et al. 2010, Baillon et al. 2012, De Clippele et al. 2015; Gale et al. 2015) in the North Atlantic suggests that coral and sponge habitats may be important to other benthic organisms should they occur in abundance in the LSFA.

### Key Uncertainties and Approaches to Address Data Gaps

The absence of benthic collections in the LSFA is a principal data gap. Even though deep-sea benthic communities group by bathymetry into a few general ubiquitous assemblages, the exact depths at which they occur and the specific structural components differ according to region (Haedrich et al. 1980, Gale et al. 2015). Furthermore, several other factors beyond depth (e.g., temperature, substrate, presence of other fauna, and climate cycle) influence the distribution of benthic taxa (Haedrich et al. 1980, Ruhl and Smith Jr. 2004, Gale et al. 2015). Therefore, while studies from other areas provide useful starting points, region-specific information is important to defining the community composition within the LSFA, particularly given its unique oceanographic conditions (i.e., globally significant downwelling and high levels of anthropogenic carbon).

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Perhaps more glaring is the general lack of information regarding the life history and ecological roles of many deep-sea benthic species (Gale et al. 2015). If the LSFA's ecology mirrors that of adjacent slope habitats (e.g., Baillon et al. 2011, Gale et al. 2013), a functional understanding of the LSFA's ecology will require a better understanding of the role and influence of the benthic species.

Improving our understanding of benthic communities in the LSFA will be challenging. During the 2017 survey, baited cameras recorded some benthic megafauna but the areal coverage of this technique is poor (Haedrich et al. 1980). Baited cameras, commonly used for fish, may draw in some species from a larger area but methodological modifications may be required to account for the more limited mobility of benthic taxa relative to fish. Camera observations are also very limited in detecting infaunal communities, which may play a particularly important role in soft-bottomed habitats where epifauna is likely to be less diverse.

Most widespread inventories conducted in deep-sea environments used deep-water trawls, dredges or remotely operated vehicles (ROVs). Relative to fixed and ROV-mounted cameras, the sampled area of mobile collection gear is increased by many orders of magnitude (Haedrich et al. 1980) and it also allows collections of individuals for more detailed scientific examination (e.g., taxonomy, laboratory studies). While mobile collection gear would provide important data, trawling in the depths that characterize the LSFA is beyond the currently configured capability of existing Coast Guard vessels and would require procurement of these specialized services. A smaller dredge may be more practical and could be deployed off locally sourced commercial vessels. ROVs provide the opportunity to visually explore behaviour of benthic organisms while allowing for limited sample collection. Unfortunately only specialized ROVs (e.g., ROPOS) can access the depths of the LSFA.

Other methodological alternatives include collections from box cores, eDNA samples, and larval settlement plates. Box cores, like cameras, will provide limited spatial coverage but enable additional study of live specimens. eDNA samples are relatively easy to collect and provide the opportunity to characterize a variety of taxa simultaneously. Currently, eDNA remains largely experimental and will be limited by the availability of taxa-specific markers but the DNA in samples can be fixed and archived as baseline information until methods improve. Finally, larval settlement plates provide a relatively simple means of collecting early life stages of benthic animals and gaining an understanding of settlement and disturbance dynamics in the deep sea. Furthermore, using standardized deployment methods allows samples to be compared to other deep-sea collections worldwide. The principal limitation is that they need to be deployed long enough for meaningful settlement to occur.

Given the above considerations, it is recommended that the feasibility of mobile collection gear (e.g., benthic dredges and/or sledges) be explored and opportunistic sampling be conducted by combining multiple collection methods during gear deployment. For example, settlement plates can be deployed on fixed moorings used to monitor cetacean vocalizations (Appendix 1) and observations of benthic organisms can be recorded during baited camera and ROV surveys. Where feasible, key representatives of benthic ecosystems should be further studied to understand their basic ecology (life cycle and reproductive and feeding ecology).

## **CORALS AND SPONGES**

### **Available Information**

Corals and sponges are sessile organisms that produce complex three-dimensional structures. They are considered to be important ecosystem engineers because they create, modify and

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maintain habitat for other benthic species at macro-habitat (i.e. between colonies), micro-habitat (i.e., between branches), and nano-habitat (i.e., within tissue) spatial scales.

The functional roles that corals and sponges play in benthic ecosystems have been well documented (Bell 2008, Buhl-Mortensen et al. 2010, Baillon et al. 2014a) and can include protection from predators (Wulff 2006), shelter from bottom currents (Zedel and Fowler 2009), forage areas (Buhl-Mortensen and Mortensen 2004), nurseries for young (Aldrich and Lu 1967, Mercer 1968, Baillon et al. 2012) and a source of food for other animals (e.g., Gale et al. 2013). Accordingly, coral and sponge habitats are associated with elevated biodiversity (Cerrano et al. 2010).

The bulk of knowledge regarding the distribution of corals and sponges in Canadian waters is derived from random stratified research trawl surveys (Treble et al. 2000, Treble 2002 and 2009, Wareham and Edinger 2007, Kenchington et al. 2010, 2016), complimented by opportunistic collections by Fisheries Observers on board commercial fishing vessels (Wareham and Edinger 2007, Wareham 2009). In the Eastern Arctic Region, DFO (NAFO Zone 2H) and the Northern Shrimp Research Foundation (NSRF, NAFO Zones 0A and 2G) conduct trawl surveys for Greenland halibut and shrimp in NAFO Divisions 2G and 0AB (see Treble et al. 2000, Treble 2002, Treble 2009). However data collection from DFO and NSRF surveys in this region have been restricted to 'trawlable' bottoms due to gear limitations of the trawl, and as a result, very little is known about hard substrate environments as well as waters beyond the gear limits (750 m for NSRF surveys in NAFO Zone 2G and 1,500 m for DFO surveys in NAFO Zone 2H). Nevertheless, the baited camera and long-line survey conducted during the Fish Characterization Cruise noted both taxa in the LSFA (Figure 16).

Predictive modeling approaches have been used to infer distributions on hard substrates into bathyal (200-3,000 m) and abyssal (3,000-6,000 m) zones. Using coral species and functional groups, maximum entropy (Maxent) models were generated by Gullage et al. (2017) and showed suitable habitat along the continental shelf break and within canyons.

Guijarro et al. (2016) also identified significant concentrations of corals and sponges with random forest machine-learning techniques and predicted that these taxa would occur from the continental slope out into the depths that characterize the LSFA. Knudby et al. (2013) also predicted the distribution of sponges out to 2,500 m using a species distribution model for the Labrador Shelf region. That study predicted high probabilities of occurrence along the continental slope where minimum salinity and current thresholds were exceeded (Knudby et al. 2013). However, model results for these studies have not been validated beyond trawlable depths.

In the shallower waters (<1,500 m) of the Northwest Atlantic, distributions of corals and sponges have been documented from the Grand Banks of Newfoundland to Baffin Bay in the Canadian Arctic (Wareham and Edinger 2007, Wareham 2009). For the most part, they are found along the continental shelf edge and slope with the exception of soft corals, which are common on the shelf (see Kenchington et al. 2016). As in other areas of the world (Hall-Spencer et al. 2002, Clark and O'Driscoll 2003), benthic surveys and fishing activities are altering coral and sponge habitats. Taxa such as large gorgonians (e.g., *Paragorgia arborea* and *Primnoa resedaeformis*) are highly sensitive to anthropogenic disturbances due to their brittle nature, extremely slow growth and long life span (Sherwood et al. 2006, Sherwood and Edinger 2009). Based on growth alone, recovery from fisheries impacts will take decades to centuries and resilience to physical (e.g., clipped, injured or disoriented) or chemical (e.g., sponges) damages are still unknown but may increase predation, parasite loads, and/or disease (see review Clark et al. 2016). Interestingly, the highest abundance of large gorgonian corals, particularly the long-lived species *Primnoa resedaeformis* and the very large species *Paragorgia arborea* in the Newfoundland and Labrador region occurs at the northeast shelf edge of Saglek Bank,

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immediately adjacent to the LSFA (Wareham & Edinger 2007). This area has the only known location of extensive subfossil *Primnoa* corals of these species in the region, suggesting that these ecosystems have been present for several thousands of years (Sherwood et al. 2008).

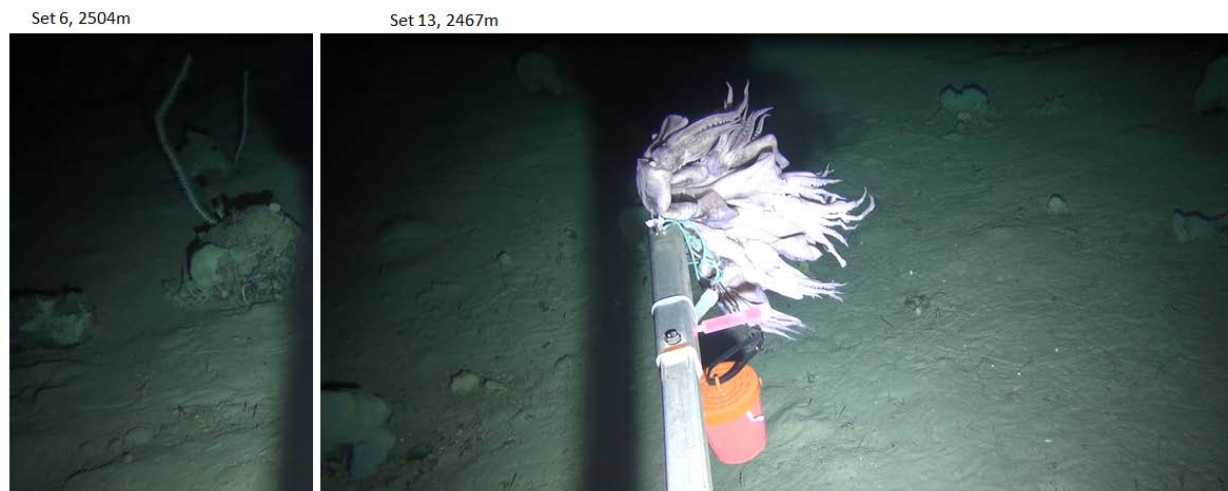


Figure 16: Bamboo corals (left panel) and sponge fields (right panel) observed during baited camera surveys in the Labrador Sea Frontier Area in August 2017. Set locations correspond to those presented in Figure 17.

### Species and/or Habitats of Interest

The ecological importance of coral and sponge habitat to other benthic and demersal species, along with their sensitivity to anthropogenic impacts, make coral and sponge taxa of interest in the LSFA. While the LSFA remains largely unstudied for these taxa, both corals and sponges were documented by drop cameras and through long-line catches in waters >2,000 m in 2017. Furthermore, the Labrador Sea (principally the adjacent Hatton Basin and Saglek Bank) has been recognized as a key area for corals and sponges (MPA News 2007, Wareham et al. 2010, Kenchington et al. 2016). Hard bottoms, steep bathymetric gradients and canyon habitats represent habitats of interest for corals and sponges (Figure 2; Mortensen and Buhl-Mortensen 2005, Edinger et al. 2011, Baker et al. 2012) as they are more likely to contain coarse substrates and/or be associated with currents that deliver food; factors that potentially affect coral and sponge distribution (Baker et al. 2012; Meredyk 2017).

### Key Uncertainties and Approaches to Address Data Gaps

Knowledge of coral and sponge distributions in the Northwest Atlantic is particularly limited at depths beyond the continental slope, due to the logistics of accessing deep remote areas and the associated costs of deep-sea research. In more well-studied depths, much of the distributional knowledge is derived from surveys of trawlable habitat, which may not reflect the ideal substrates for important coral taxa (e.g., large gorgonians) (Buhl-Mortensen and Mortensen 2004, Mortensen and Buhl-Mortensen 2005). In addition to important distribution information, knowledge of basic life-history traits of coral species (e.g., reproduction, fecundity, mode, age at reproduction, sex, and larval dispersal; Sun et al. 2010, Mercier and Hamel 2011, Mercier et al. 2011a,b, Baillon et al. 2014b) is sparse. Even less is known for sponges, a group for which species-level taxonomy is poorly understood (though a guide to Arctic sponge species is nearing completion, Curtis Dinn, University of Alberta, pers. comm).

In the LSFA, coral and sponge knowledge is particularly scarce. To our knowledge, the only biodiversity information on corals and sponges is derived from a small sample of baited drop



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cameras (Figure 16) and long-line sets from the 2017 Fish Characterization Cruise. Photos generated from this mission captured bamboo corals (family *Isididae*) and sponges but spatial coverage and sample sizes were very limited. Consequently, little is known on the factors (e.g. substrate, food) that may limit coral and sponge distribution at these depths. Furthermore, understanding how coral and sponge communities are connected in the LSFA to high priority habitats in Hatton Basin is also not known.

The large scale of the LSFA and the scarcity of information related to corals and sponges at those depths (>2,000 m) impose significant challenges to addressing the existing data gaps. However, habitat-based models, supported with targeted *in-situ* ground-truthing, will likely provide the best investment for understanding of coral and sponge communities in the LSFA. Multi-beam habitat classification should be conducted and the resulting maps can form the basis for identifying available habitat types, applying existing habitat-based models and maximizing at-sea efforts to validate model results.

Inventories of corals and sponges can be done opportunistically (e.g., during baited camera surveys, long-line efforts and/or box cores) but ideally these will supplement targeted collections (e.g., with ROVs, benthic dredges and/or sledges) using sampling designs that are informed by multi-beam derived habitat maps. Other non-invasive techniques, such as eDNA, may be useful for characterizing coral and sponge communities as well as their associations with other taxa.

Finally, where feasible, study of preserved and live specimens should be conducted to document the life-history traits of key coral and sponge taxa in the LSFA. In particular, the study of early life stages will greatly enhance the realism of larval transport models that have been applied elsewhere (Mercier et al. 2013, Young et al. 2018).

## FISH

### Available Information

The bulk of knowledge on fish distribution, biomass and diversity in Canadian waters is derived from research vessel (RV) surveys and harvester logbooks. The LSFA overlaps with the NAFO Division 2G and 2H (Figure 1); however the RV surveys and fishing activity within these Divisions are restricted to depths shallower than 1,500 m. Consequently, information on fish community structure and distribution are limited in the LSFA. The intensity of RV surveys (1976-present) on the Labrador Shelf and upper slope in Division 2G and 2H varies and is comprised of data collected with Engel (1976-94) and Campelen (1995-present) trawls. Division 2G data is made up of 351 sets of which 5% is from depths greater than 1,000 m and Division 2H contains 1,320 sets, with 10% of the sets below 1,000 m. The RV data from Campelen trawls (1996-2016) shows that the fish species dominating the biomass of NAFO Divisions 2G and 2H are benthivores and piscivores such as deepwater redfish (*Sebastes mentella*), Greenland halibut (*Reinhardtius hippoglossoides*), blue hake (*Antimora rostrata*) and different species of grenadiers (Table 3). Lanternfishes (Myctophidae) are the most dominant planktivore in the community, which is a notable difference to more southern areas of the Newfoundland Shelf, where capelin (*Mallotus villosus*) dominate. Due to the strong effect of depth on community structure in demersal fish (Priede 2017), the fish community structure observed along the Labrador shelf break is not likely to be seen at depths of the LSFA. In contrast, pelagic habitats, and their lanternfish-dominated fish communities, could extend in surface waters from the shelf break into the LSFA (Pepin 2013). Given the distinct biophysical conditions (currents, temperature and water chemistry; see Oceanography Section) of the LSFA and the shelf, even connections amongst the pelagic fish community cannot be assumed.

Table 3: Taxa dominating the biomass of fall RV survey catches (Campelen trawl, 1996-2016) in waters greater than 500 m in NAFO Divisions 2G (n=41) and 2H (n=324).

Rank	Species	Scientific Name	Biomass (metric tons)
1	Deepwater Redfish	<i>Sebastes mentella</i>	15.6
2	Greenland Halibut	<i>Reinhardtius hippoglossoides</i>	11.7
3	Roundnose Grenadier	<i>Coryphaenoides rupestris</i>	4.6
4	Blue Antimora/Violet Cod	<i>Antimora rostrata</i>	2.2
5	Roughhead Grenadier	<i>Macrourus berglax</i>	2.1
6	Kaup's Arrowtooth Eel	<i>Synaphobranchus kaupi</i>	1.2
7	Bathytroctes sp.	<i>Bathytroctes</i>	1.1
8	Lanternfish	<i>Myctophiidae</i>	0.5
9	Northern Wolffish	<i>Anarchichas denticulatus</i>	0.4
10	Northern Shrimp	<i>Pandalus borealis</i>	0.4
11	Marlin-spike Grenadier	<i>Nezumia bairdi</i>	0.4
12	Spinytail Skate	<i>Raja spinicauda</i>	0.4
13	Black Dogfish	<i>Centroscyllium fabricii</i>	0.3
14	Greenland Shark	<i>Somniosus microcephalus</i>	0.3
15	Goiter Blacksmelt	<i>Bathylagus euryops</i>	0.3
16	Atlantic Cod	<i>Gadus morhua</i>	0.2

The methods used to characterize the fish fauna during the Fish Characterization Cruise included co-located long-line (11 stations; 3 km along the sea bed, 600 hooks per line, hook size: 14, 15 and 16), baited cameras (8 of 11 stations) and eDNA collections (10 of 11 stations). The long-line survey of the 2017 Fish Characterization Cruise was based on the methods of Murua and de Cardenas (2005) and conducted in the LSFA and the adjacent slope (600-3,000 m). Samples were obtained from two transects along a depth gradient from the upper continental slope (600 m) down to the upper continental rise (3,015 m; Figure 17). Catch data from long-lines show that there is a difference in the species composition and dominant species above and below ~2,000 m (Figure 18). The long-line catch above 2,000 m were more diverse than the catch below 2,000 m, with 11 and 6 taxa represented, respectively. Numerically dominant fish taxa above 2,000 m were Greenland halibut, grenadier spp. and wolffish spp., whereas below 2,000 m, Blue hake, Armed grenadier and skate spp. dominated. Baited camera sets at depths greater than 2,000 m were generally visited by the same species (Table 4; Figure 19 and 20).



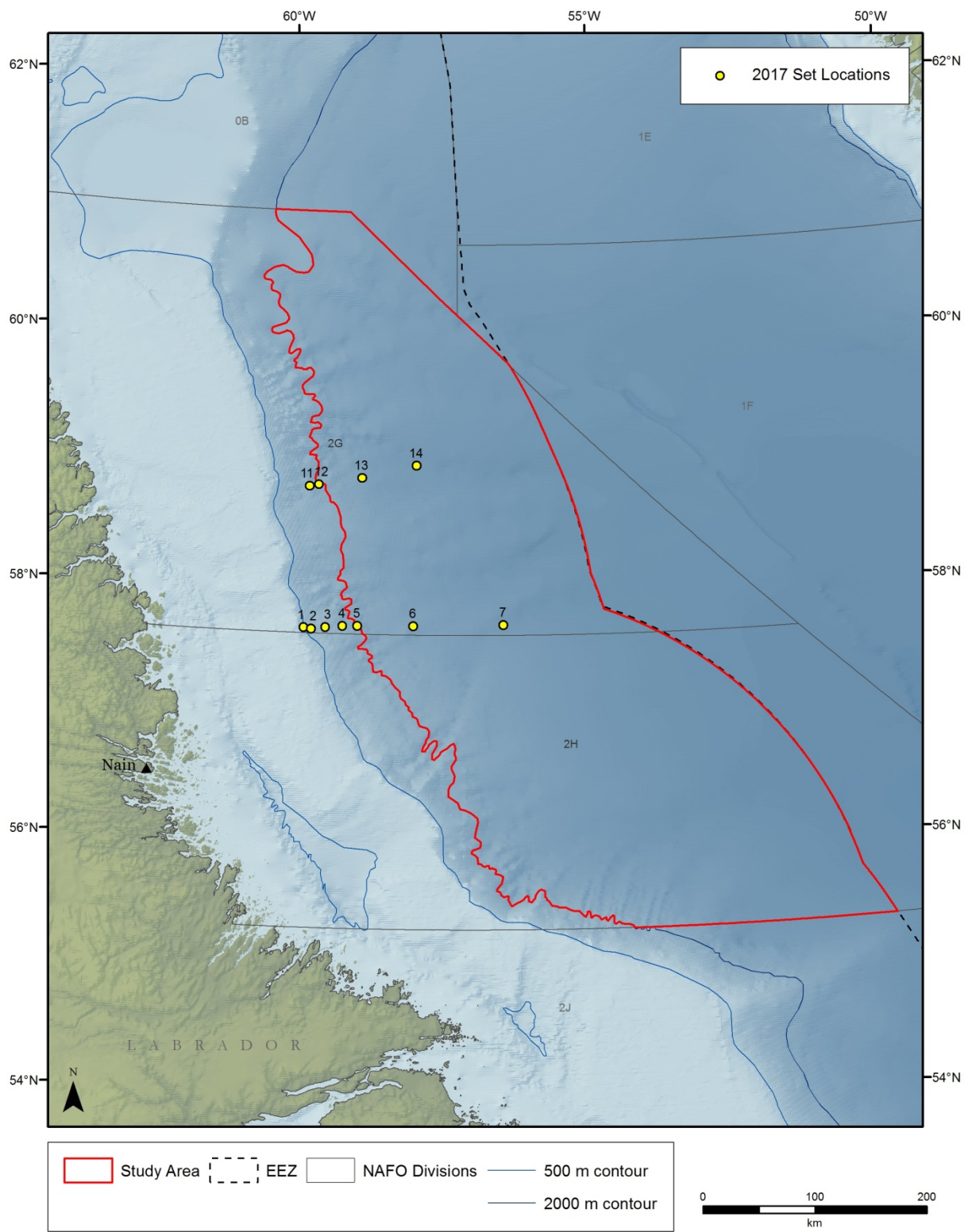


Figure 17: Sample locations of the 2017 Fish Characterization Cruise in the Labrador Sea Frontier Area.

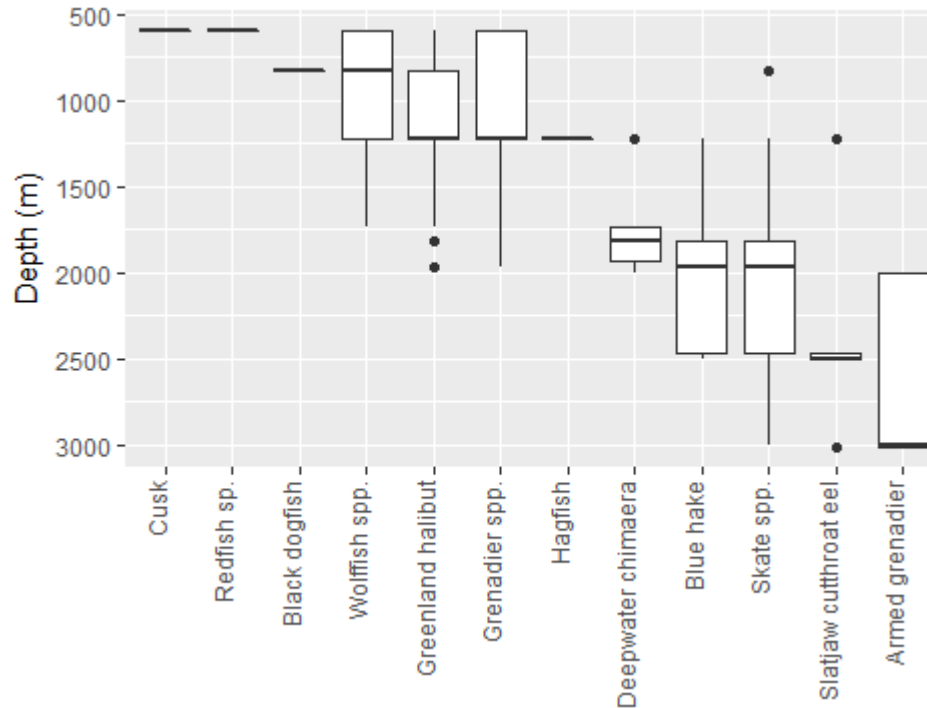


Figure 18: Fish species depth distributions of catches from 12 long-line sets in the Labrador Sea Frontier Area and adjacent slope habitat.

While no other demersal fish data from waters exceeding 2,000 m depth exists from eastern Canadian surveys, the findings of Murua and de Cardenas (2005) from the deep international waters off NAFO Divisions 3MNL mirror the species obtained during the Fish Characterization Cruise. Specifically, depth gradients in the catch composition of their long-line sets were apparent, with a pronounced shift in the fish community at depths greater than 2,000 m. The fish community composition at these depths was similar to the preliminary observations in the LSFA in that they comprised principally of Armed grenadier, skates and Blue hake. At more distant deep water sites at the mid-Atlantic ridge (Fossen et al. 2008), east Greenland (Haedrich and Krefft 1978) and off New England (Haedrich et al. 1980), Armed grenadier and Blue hake also dominated catches at depths greater than 2,000 m. Two of these distant deep water studies (Fossen et al. 2008 and Murua and de Cardenas 2005) also reported declining catches as depths increased beyond 1,500 m, whereas declines didn't occur until depths exceeded 2,500 m in another (Haedrich et al. 1980). Despite declining catches at greater depths, fish taxa can dominate the available biomass at depths associated with the LSFA (Haedrich et al. 1980) and fish diversity has been shown to peak at depths between 1,900 and 2,300 m (Rex 1981). These results collectively suggest that fish are likely to be an important ecological component in the LSFA. Furthermore, the dominant components of deep water communities may be fairly homogeneous across large spatial scales and therefore more distant studies may be of use in predicting communities in the LSFA. Nevertheless, the less dominant components from those two previously studied regions differed and reinforce the need for site-specific surveys (Haedrich et al. 1980).

Table 4: Summary of fish observations from baited camera sets in the Labrador Sea, reporting first arrival times ( $t_0$ ) and abundance ( $N_{\max}$  - maximum number of individuals observed within a single frame).

-	Station	1	2	6 <sup>a</sup>	7 <sup>a</sup>	11	12	13 <sup>a</sup>	14 <sup>a</sup>
Deployment Details	Date	15 Aug 2017	16 Aug 2017	19 Aug 2017	20 Aug 2017	25 Aug 2017	24 Aug 2017	23 Aug 2017	22 Aug 2017
	Latitude N (deg min sec)	57 42 55	57 42 04	57 44 35	57 44 93	58 49 74	58 50 54	58 54 12	59 00 44
	Longitude W (deg min sec)	59 31 82	59 25 10	57 51 95	56 29 82	59 31 10	59 22 41	58 41 92	57 50 61
	Depth (m)	600	825	2504	3015	1738	1969	2467	3000
	Duration (hh:mm) <sup>b</sup>	00:31	09:54	00:37	06:40	02:14	05:19	00:56	01:05
Taxa to ( $N_{\max}$ )	Armed grenadier ( <i>Coryphaenoides armatus</i> )	-	-	3 (21)	7 (24)	-	-	3 (11)	13 (23)
	Blue hake ( <i>Antimora rostrata</i> )	-	93 (1)	8 (8)	-	1 (9)	5 (9)	7 (10)	-
	Slatjaw cutthroat eel ( <i>Synaphobranchus kaupii</i> )	4 (5)	10 (4)	-	-	100 (1)	235 (1)	-	-
	Skate ( <i>Rajella</i> sp.)	-	-	-	298 (1)	-	-	56 (1)	-
	Skate ( <i>Amblyraja</i> sp.)	-	-	-	-	67 (1)	210 (1)	-	-
	Lanternfish (Myctophidae unknown)	20 (1)	146 (1)	-	-	-	-	-	-
	Deep-water arrowtooth eel ( <i>Histiobranchus bathybius</i> )	-	-	-	61 (1)	-	-	-	35 (1)
	Roughhead grenadier ( <i>Macrourus berglax</i> )	-	501 (1)	-	-	57 (1)	-	-	-
	Unknown (small mesopelagic)	-	146 (1)	-	-	0 (1)	-	-	-
	Greenland halibut ( <i>Reinhardtius hippoglossoides</i> )	-	333 (2)	-	-	-	18 (2)	-	-
	Smalleyed rabbitfish ( <i>Hydrolagus affinis</i> )	-	-	-	-	-	278 (1)	-	-
	Atlantic hagfish ( <i>Myxine glutinosa</i> )	-	8 (4)	-	-	-	-	-	-
	Northern wolffish ( <i>Anarhichas denticulatus</i> )	-	79 (1)	-	-	-	-	-	-
Unidentified taxa	-	245 (1)	-	-	-	-	-	-	

<sup>a</sup>Sites within the Labrador Sea Frontier Area.

<sup>b</sup>Duration of interpreted video was limited by battery life and truncated in cases where the camera frame was overturned.

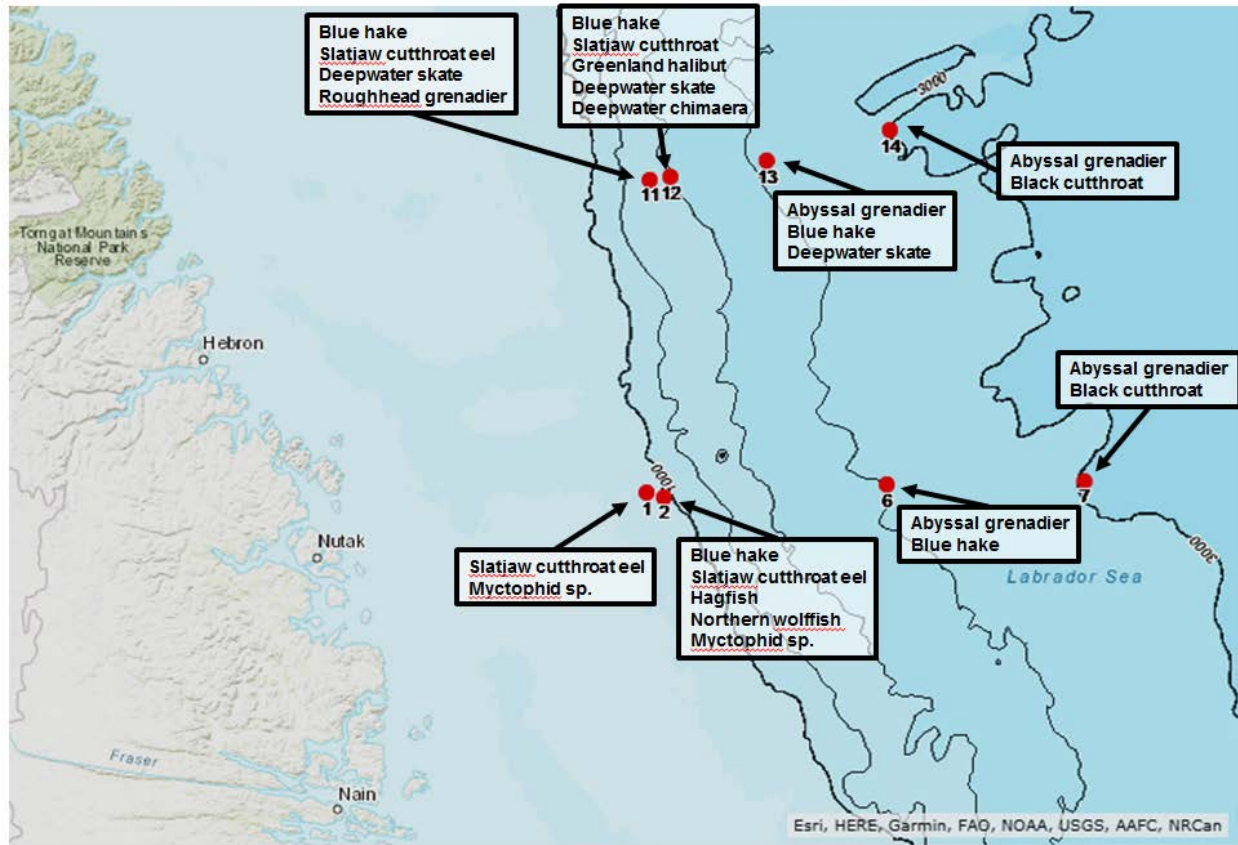


Figure 19: Distribution of fish taxa observed in baited camera surveys in the Labrador Sea Frontier Area.



Figure 20: Blue hake and Armed grenadiers visiting a baited camera station in the Labrador Sea Frontier Area (depth: 2504 m).

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In deep water environments, small meso-pelagic species such as lanternfish (Myctophidae), bristle mouths (Gonostomatidae), hatchet fish (Sternopychidae) and barbeled dragonfish (Stormiidae) are thought to dominate the water column (Priede 2017). While few data collections have been conducted within the LSFA, sampling further to the south in the western Labrador Sea indicate widely distributed myctophids, such as glacier lanternfish (*Benthosema glaciale*), play an important role in transferring energy from secondary producers such as copepods, to higher levels of the food chain (Pepin 2013). Some taxa of meso-pelagic fish maintain species-specific depth ranges (Priede 2017), whereas others such as the lanternfish conduct nocturnal feeding migrations (Pepin 2013; Priede 2017).

The importance of lanternfish in the pelagic waters in the northern Labrador Sea was confirmed by Sheehan et al. (2012), who found them, together with lumpfish (*Cyclopterus lumpus*), redfish (Sebastidae) and squid in abundance in midwater trawls. Other species of note were sand lance (*Ammodytes americanus*), Arctic rockling (*Gaidropsarus argentatus*) and Greenland halibut. Among this pelagic fish community in the Labrador Sea were Atlantic salmon (*Salmo salar*) post-smolt and adults, who migrate from distant natal rivers ranging from Maine to Labrador (Reddin and Short 1991) to feed on a diversity of prey species including amphipods, squid and fish in the Labrador Sea (Sheehan et al. 2012). Lanternfish were also observed on the drop camera from the Fish Characterization Cruise but only at depths along the adjacent slope (Table 2 and Table 4).

### **Species and/or Habitats of Interest**

The pelagic habitats of the LSFA are important feeding grounds for Atlantic salmon and may support members of several Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed populations (COSEWIC 2010). Lanternfish are species that likely play a critical ecological role in the LSFA as they are the principal means of transferring energy from secondary producers to higher elements of the food web as well as moving nutrients through the water column during their vertical migrations.

In the deep sea, principal species (Armed grenadier and Blue hake) of the LSFA are not currently commercially harvested or known to be at risk. Captured skates remain to be identified but it is unlikely that the species found within the LSFA are used commercially at shallower depths or have *Species at Risk Act* (SARA) or Committee on the Status of Endangered Wild Life in Canada (COSEWIC) status. In adjacent slope habitats, commercial species such as Greenland halibut, Roughhead grenadier and Deepwater redfish occur. Of these Roughhead grenadier (Special Concern) and Deepwater redfish (Threatened) are listed as COSEWIC species. Wolfish occur on the slope and Northern wolfish and Spotted wolfish were captured during the 2017 Fish Characterization Cruise, and these fish have Threatened SARA and COSEWIC status. None of these commercial species or species of conservation concern are thought to commonly occur in the depths of the LSFA, although a few were captured close to 2,000 m during the Fish Characterization Cruise. In general, deep water species are slow growing, long-lived, late to mature and have low fecundity (Devine et al. 2006; Priede 2017). These life history traits make them less resilient to anthropogenic disturbance such as fishing (Devine et al. 2006). While little harvesting pressure exists in the LSFA, deep water fish species have been negatively affected elsewhere; sometimes catastrophically (Priede 2017).

The near absence of demersal habitat information in the LSFA provides little opportunity to identify sensitive or ecologically important habitats. Baited camera surveys and bycatch from long-lines set in the LSFA indicate the presence of corals and sponges at depths greater than 2,000 m. Such structure forming species are important to fish in other areas (Gilkinson and Edinger 2009; Baillon et al. 2012) and would be anticipated to be an important habitat feature in the LSFA.



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## Key Uncertainties and Approaches to Address Data Gaps

The general absence of field activities within the LSFA leaves significant uncertainty and data gaps. Beyond depth, little in the way of habitat data exists for the LSFA. Similarly, aside from the Fish Characterization Cruise in 2017 and the pelagic trawls conducted by Sheehan et al. (2012), virtually no data on fish communities are available. While some inference can be made from other deep sea locations in the Atlantic (Haedrich and Krefft 1978, Haedrich et al. 1980, Murua and de Cardenas 2005, Fossen et al. 2008, Pepin 2013, Parzanini et al. 2017), details of fish community structure varies by region (Haedrich et al. 1980) and more LSFA-specific information is required for a robust characterization. The collections of 2017 did provide important information; however, interpretation of these data should be done with the caveats that samples were few, the gear used was focused on demersal species and was biased to species that are predisposed to taking bait (e.g., studies from other areas show 20-50% of deep sea fish species respond to bait; Priede et al. 2017). Other important aspects of the ecology of the LSFA's inhabitants (e.g., movement, trophic and reproductive ecology, connectivity) remain undocumented, but samples collected in 2017 may provide some important information. For example, existing research on Blue hake (Wenner and Musick 1977, Kulka et al. 2003; Fossen and Bergstad 2006), including collections from the Labrador slope, highlight the notable absence of mature individuals. Blue hake captured in the LSFA show a high prevalence of mature individuals and have provided the first ripe gonads collected (Figure 21) since Werner and Music 1975; Kulka et al. 2003; Fossen and Bergstad 2006; Gordon and Duncan 1985. These findings suggest that the importance of the LSFA to Blue hake reproductive ecology extends across broader spatial scales.

Addressing knowledge gaps is impeded by the remote location and the difficulty (time, technology and cost) of sampling extremely deep habitats. Longline and baited camera deployments have proven relatively cost-effective, provided useful information in the LSFA and in other deep-sea locations (e.g., Henriques et al. 2002, Fossen et al. 2008), and should be continued to improve sample sizes. However, complimentary techniques could be used to address biases related to habitat and the reliance on bait. For example, meso-pelagic sampling via IGYPT (e.g., Pepin 2013) or IKMT trawls or by setting hooks on the vertical lines of longline sets (e.g., Fossen et al. 2008) could provide important information for fish that utilize the water column. Hydroacoustic techniques can be used to survey broader areas for meso-pelagic fish and plankton, particularly when coupled with other capture methods. Though still in developmental stages, eDNA techniques (e.g., Thomsen et al. 2016) could provide information on species that are not attracted to bait and could be collected in any zone of the water column (epi-pelagic, meso-pelagic and demersal environments). Finally mobile video platforms (benthic sledges, drift cameras or ROVs), used in benthic surveys, could also provide useful information on the fish community and would be less biased to predatory/scavenging species. Concurrent research is needed on collected fish samples to identify predator-prey relationships of LSFA species (i.e., stomach content analyses of fish, birds and marine mammal predators) as well as basic life history parameters (e.g., growth, age at maturity, fecundity). Since cost and time will constrain sampling activity, efforts should be made to link collections from the LSFA to other studies, where appropriate, in order to leverage understanding of deep sea fish communities as well as identifying unique elements of the LSFA.

Finally, fish-habitat associations and sensitive habitats are reliant upon improved habitat information. Multi-beam sonar surveys should be conducted during field operations to begin the process of identifying and characterizing bottom habitats.



Figure 21: Ripe gonad of Blue hake. The demarcations are in cm.

## SEABIRDS

### Available Information

There are two main data sources that inform our understanding of the distribution and abundance of marine birds in the LSFA: at-sea marine bird surveys and tracking studies. Data from at-sea surveys are available dating back to the 1960s, as part of Programme Intégrée de Recherche sur les Oiseaux Marins (PIROP). This program was renewed in 2006 as the Eastern Canadian Seabirds at Sea (ECSAS) program, which included updates with modern protocols

that allow for distance sampling and true density estimation. Due to its remoteness, the Labrador Sea has not received the same sampling effort as the other eastern Canadian regions have; this gap was identified in the context of offshore oil and gas interests in the Labrador Sea. In 2013, the Environmental Studies Research Fund (ESRF) funded a 3-year study to augment data collection of pelagic seabirds in the Labrador Sea, which filled in a number of gaps (Fifield et al. 2016, Figure 22). Efforts to use predictive species distribution modeling are underway, in an attempt to estimate distributions and abundances of seabirds outside of surveyed regions (Fifield et al. 2017).

With the advent of miniaturized telemetry and data-archiving devices suitable for marine birds, a wealth of annual tracking has emerged on many marine birds, some of which have been shown to use the LSFA. Although the LSFA was known to host birds throughout the year, it was only recently understood that the Labrador Sea and Davis Strait to the north, host non-breeding birds from colonies as far away as Norway. Even Atlantic puffins (*Fratercula arctica*) from the United Kingdom make excursions into the LSFA and adjacent waters in late summer (Jessop et al. 2013). Taken together it is becoming clear that the LSFA, and adjacent deep waters to the north, south and east are internationally important wintering grounds for a range of Arctic breeding marine birds (Table 5).

Table 5: Marine bird species using the Labrador Sea Frontier Area based on recent tracking and telemetry studies.

Species	Source colonies	Area used	Timing	Source
Thick-billed murre ( <i>Uria lomvia</i> )	Eastern Canadian Arctic	Extensive use of entire LSFA	Mid-winter	McFarlane Tranquilla et al. 2013
Thick-billed murre ( <i>Uria lomvia</i> )	Greenland	Extensive use of entire LSFA	Fall through spring	Frederiksen et al. 2016
Dovekie ( <i>Alle alle</i> )	Svalbard	Northwest portion	Winter	Fort et al. 2013
Atlantic puffin ( <i>Fratercula arctica</i> )	Ireland	Mostly southern portion	August/September	Jessop et al. 2013
Atlantic puffin ( <i>Fratercula arctica</i> )	Mainly Iceland	Mostly southeastern portion	Winter	Fayet et al. 2017
Northern fulmar ( <i>Fulmaris glacialis</i> )	Canadian High Arctic	Throughout	Fall and winter	Mallory et al. 2008
Black-legged kittiwake ( <i>Rissa tridactyla</i> )	Canadian High Arctic, Greenland, Arctic Norway, Faroe Islands	Extensive use of LSFA, especially eastern portions	Fall through spring	Frederiksen et al. 2012
Ivory gull ( <i>Pagophlia eburnean</i> )	Canada, Greenland and Norway (Svalbard)	Extensive use of LSFA, especially northern portions	Winter	Gilg et al. 2010 Spencer et al. 2016

### Spatial and Temporal Occupancy Patterns

The marine bird community occupying the Labrador Sea, especially within the LSFA, is highly seasonal. Due to the distance from the coast, locally breeding seabirds are not expected to use the LSFA in large numbers; the bulk of the marine bird community using the Labrador Sea and the LSFA in particular are more likely non-breeding migrating, staging and wintering individuals.



In terms of pelagic distributions, densities of marine birds recorded in the ECSAS database are generally higher in the LSFA in fall and winter, when compared to spring and summer (Figure 22). This is corroborated by tracking studies, showing many species using the LSFA for fall migration and/or wintering. Predicted densities in fall are notably high, although confidences in those estimates within the LSFA are low due to a lack of survey coverage at that time of year (Figure 22). Seasonal relative species composition is presented in Table 6. Historical data from the PIROP database show similar patterns and are not presented here.

Ivory gulls (*Pagophila eburnea*), an Endangered species under the Species at Risk Act in Canada, and Near Threatened on the IUCN Red List, use the LSFA, and regions to the north, as part of their core wintering area (Spencer et al. 2016).

Tracking studies demonstrate the importance of the Labrador Sea for non-breeding thick-billed murre (*Uria lomvia*) from a range of northwest Atlantic colonies in fall, winter and spring (McFarlane Tranquilla et al. 2013, Frederiksen et al. 2016). Vast numbers of dovebies (*Alle alle*), from the huge colonies in northwest Greenland, pass through the LSFA on fall migration (Fort et al. 2013). Other tracking data show that northern fulmars (*Fulmaris glacialis*), black-legged kittiwakes (*Rissa tridactyla*) and even Atlantic puffins are present in the LSFA at various times of year (Table 5).

Table 6: Seasonal counts of birds observed in the Labrador Sea (2006-2014; Fifield et al. 2017).

Taxon name	Spring	Summer	Fall	Winter	Total
Black-legged Kittiwake	276	933	661	144	2014
Dovekie	698	1609	12489	1287	16083
Northern Gannet	0	3	2	0	5
Large Gulls	407	66	107	147	727
Jaegers	22	28	64	1	115
Murres	536	744	2948	989	5217
Northern Fulmar	1677	3095	926	444	6142
Other Alcids	63	37	298	54	452
Phalaropes	133	245	14	0	392
Atlantic Puffin	22	217	359	15	613
Shearwaters	0	1294	318	1	1613
Skuas	0	4	15	2	21
Storm-Petrels	27	27	1	4	59
Terns	0	12	2	0	14

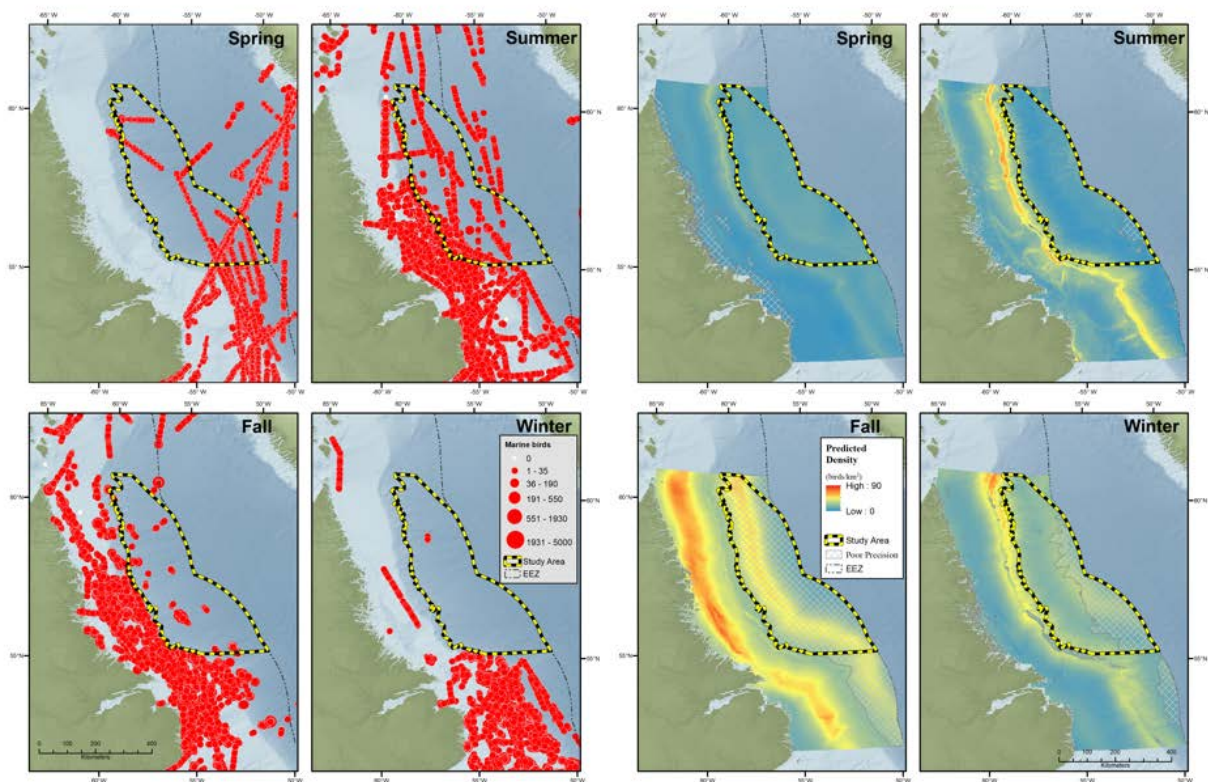


Figure 22: Seasonal locations of observations and relative abundances (A, 2006-17), and predicted densities (B: 2006-14) of seabirds in the LSFA and surrounding waters.

### Species and/or Habitats of Interest

Due to their conservation status as Endangered in Canada, and Near Threatened globally, Ivory gulls are an important species using the LSFA. In fact, the marginal ice zone in the Labrador Sea and Davis Strait is potentially critical non-breeding habitat for the species (Environment Canada 2014).

Thick-billed murres are abundant in the LSFA and are a species of international conservation focus, due to harvests in Iceland, Canada and Greenland, and their susceptibility to fisheries bycatch and oiling (Conservation of Arctic Flora and Fauna 1996). The species uses the entire LSFA extensively which currently provides a refuge where they are not exposed to their usual threats.

The bulk of the global population of dovekie, which breeds in northwest Greenland, travels through the Labrador Sea and adjacent waters on fall migration to wintering areas off southeastern Canada.

### Key Uncertainties and Approaches to Address Data Gaps

In spite of recent increased pelagic seabird survey effort in the Labrador Sea (Fifield et al. 2016, 2017), temporal and spatial gaps remain. Specific to the LSFA, no data were collected in fall, and limited data was collected in winter. These are key periods of migration and wintering for marine birds in the LSFA.

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Marine bird tracking studies are beginning to inform the annual use of the LSFA and adjacent waters; however, gaps remain in the species tracked and source colonies. Coverage, in terms of source colonies and numbers of birds tracked, is quite good for murre, black-legged kittiwakes and Atlantic puffins. Only limited data is available for northern fulmar, a species present in high densities in the Labrador Sea. Given the large numbers of dovekies transiting throughout the LSFA, additional tracking data for that species would be useful to better understand seasonal movements and annual variation in habitat use.

Tracking studies provide data in almost real time, and do not require direct access to the study region, but rather access to potential source colonies. A number of marine bird research programs based at key colonies are ongoing throughout the North Atlantic basin, and these programs are well connected through the Circumpolar Seabird Expert Group (CBird; under the Conservation of Arctic Flora and Fauna [CAFF]). For some potential source colonies, additional funds for transmitters and data costs are all that would be required. For other sites not regularly visited, but thought to contribute birds to the LSFA, a full-scale field team deployment tagging the birds would be needed.

Filling in pelagic survey gaps, requires the placement of a trained seabird observer on vessels transiting the LSFA at key times of year. Beyond the obvious costs of the vessel itself, deploying a seabird observer is not costly and should be considered to augment research cruises.

## **MARINE MAMMALS**

### **Available Information**

Limited baseline information exists in regards to the abundance and distribution of marine mammals on the Labrador Shelf and offshore regions (Lawson et al. 2017). The majority of knowledge on marine mammals in Canadian waters is derived from aerial and acoustic surveys performed by Fisheries and Oceans Canada (DFO) and Research Vessel (RV) opportunistic sightings collected by DFO, the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (ECCC), and non-governmental organizations (NGOs).

### **Cetaceans**

Combined, all of these survey methods mentioned above have produced a total of 4,197 cetaceans detected between 1894 and 2016 at depths exceeding 500 m in NAFO zones 2G and 2H; 25% of which were in waters greater than 2,000 m. The Long-finned pilot whale (*Globicephala melas*) were the most commonly-sighted cetacean in and adjacent to the LSFA (n=2,071); approximately 30% (n=610) of these sightings were in water depths greater than 2000 m (Table 7; Figure 23).

Systematic aerial surveys were conducted by DFO in 2007 and 2016 using a fixed-wing aircraft flown in a replicate zig-zag pattern from the shore to the shelf break. These surveys documented several species of cetaceans and 87 individuals in the western edge of the LSFA (Oceans Division, DFO; Appendix 2). In many cases, cetaceans were seen at or beyond the shelf break, near the offshore ends of planned survey lines. Based on this, questions remain regarding habitat use of cetaceans in the LSFA, particularly in deeper waters beyond the shelf break. It is also important to note that most aerial surveys were not conducted during the fall; a time when more marine mammals use the Labrador Shelf based on long-term acoustic monitoring data (Lawson et al. 2017).

The Canadian Wildlife Service (CWS) also document whale sightings opportunistically during seabird surveys on ships in the North Atlantic. From 2006-16, a total of 146 individuals were

sighted within the LSFA. The species most sighted from this method of observation include; Long-finned pilot whale, Fin whale (*Balaenoptera physalus*), Harbour porpoise (*Phocoena phocoena*), Sei whale (*Balaenoptera borealis*), and White-beaked dolphin (*Lagenorhynchus albirostris*; unpubl. data, Oceans Division, DFO). The White-beaked dolphin was the most commonly-sighted cetacean species during ESRF aerial surveys conducted just west of the LSFA in 2013 and 2014.

Finally, acoustic monitoring data suggest that marine mammal numbers could be higher in other periods that were not monitored with aerial surveys (Lawson et al. 2017). Even during the winter, when sea ice covers much of the Labrador Shelf, marine mammals such as Humpback whale, Fin whale and Pilot whale have been detected using visual and acoustic surveys. Many of these cetaceans potentially move into deeper, ice-free waters of the LSFA in the winter.

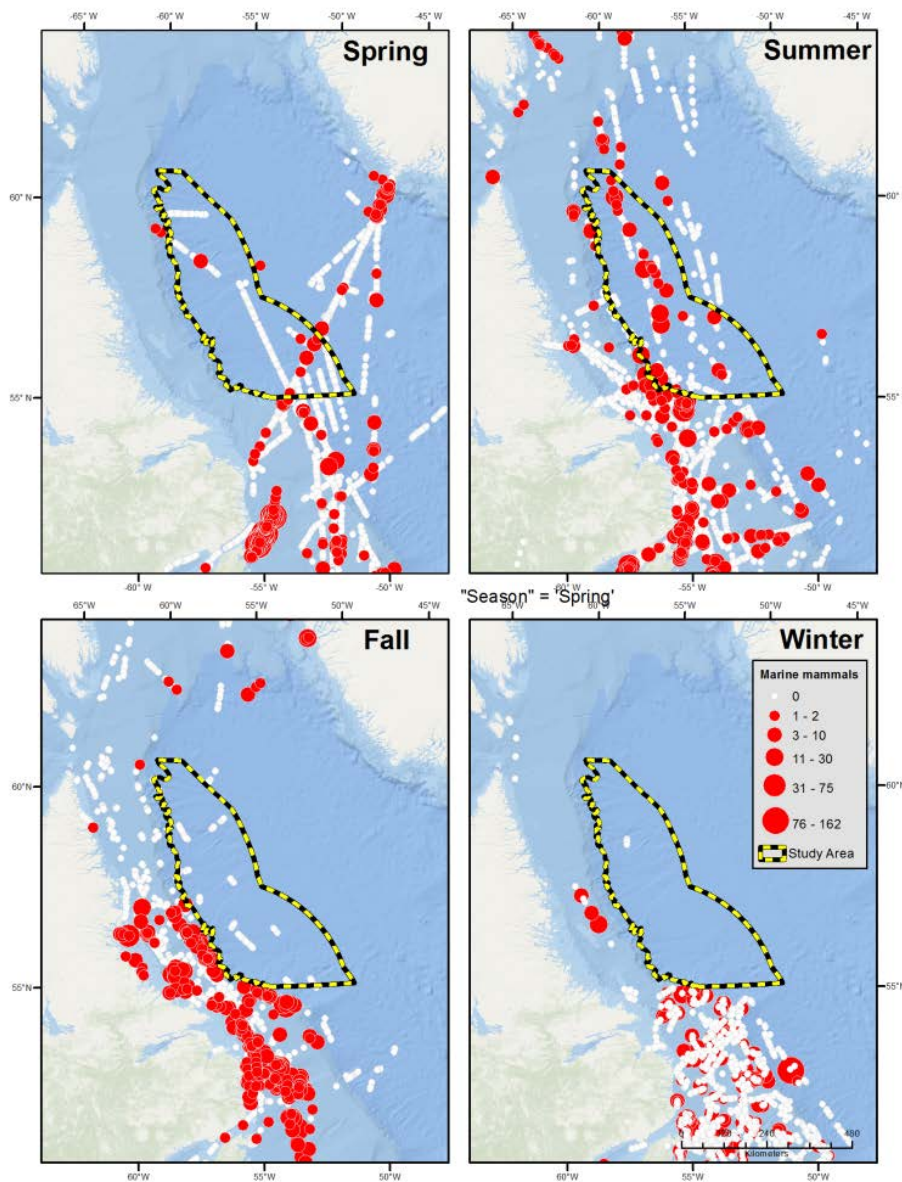


Figure 23: Relative seasonal abundances of marine mammals observed 2005-17 in the Labrador Sea Frontier Area and surrounding waters (ECSAS database).

Table 7: Observations of most common marine mammal species in NAFO zones 2G and 2H in waters greater than 500 m. The species more frequently observed in the deeper zone are indicated with grey shading and symbol † Data from DFO, CWS and NGO surveys.

Rank	Common name	Latin name	500- 2,000 m	>2,000 m	Max. Count
1	Long-finned Pilot Whale	<i>Globicephala melas</i>	1,461	610	2,071
2	Northern Bottlenose Whale	<i>Hyperoodon ampullatus</i>	442	69	511
3	White-beaked Dolphin	<i>Lagenorhynchus albirostris</i>	347	87	434
4	Sperm Whale	<i>Physeter macrocephalus</i>	383	8	391
5	Minke Whale	<i>Balaenoptera acutorostrata</i>	54	9	63
6	Harbour Porpoise	<i>Phocoena phocoena</i>	32	16	48
7	† Atlantic White-sided Dolphin	<i>Lagenorhynchus acutus</i>	12	31	43
8	† Humpback Whale	<i>Megaptera novaeangliae</i>	15	27	42
9	† Fin Whale	<i>Balaenoptera physalus</i>	3	38	41
10	† Killer Whale	<i>Orcinus orca</i>	8	29	37
11	Common Dolphin	<i>Delphinus delphis</i>	30	0	30
12	Risso's Dolphin	<i>Grampus griseus</i>	11	10	21
13	Sei Whale	<i>Balaenoptera borealis</i>	12	7	19
14	Blue Whale	<i>Balaenoptera musculus</i>	3	0	3
-	-	<b>Total</b>	2,813	941	3,756

## Seals

Three species of seal (Harp *Pagophilus groenlandicus*, Hooded *Cystophora cristata*, and Ringed *Pusa hispida*) are known to frequent the shelf area and/or deeper waters of the Labrador Sea. Harp seals are highly migratory and generally use the Labrador coast and shelf area as a migration route (DFO 2011; Stenson 2013). Utilization of these areas is highest after the moulting season (Figure 24). Hooded seals are also highly migratory and spend their time at sea in between breeding and moulting seasons on sea ice. The Labrador Shelf acts as an important foraging area in between these seasons while the Labrador Sea acts as a migratory route (Anderson et al. 2009). For each age and sex class, Hooded seals utilize areas within the LSFA most during the fall (Figure 25). It is thought that Ringed seals spend most of their time, certainly during winter breeding periods, closer to the coast than the larger seal species.



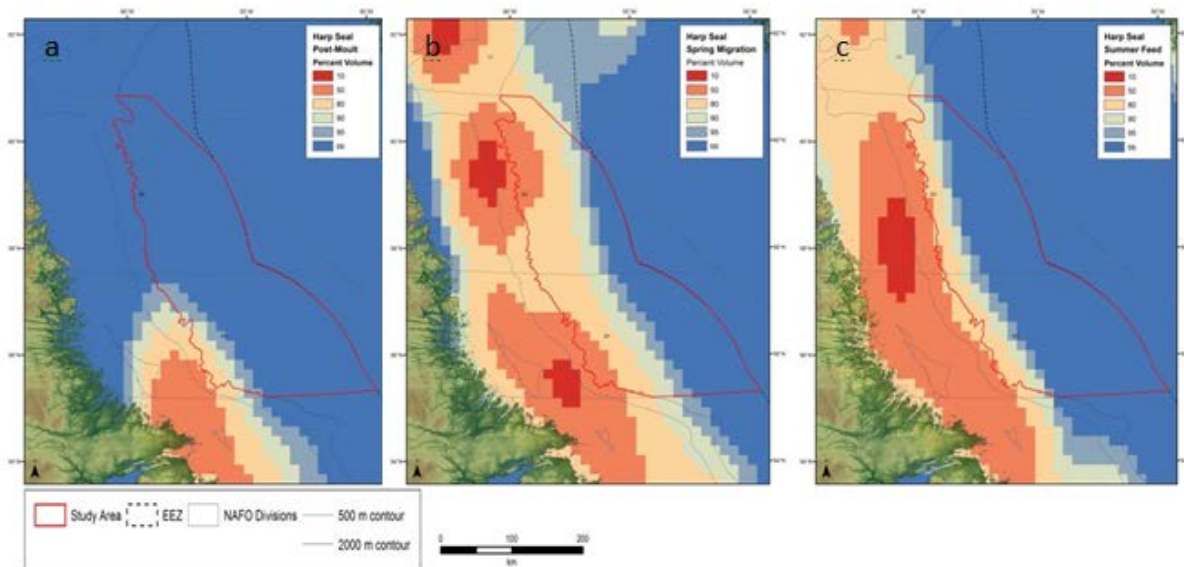


Figure 24: Kernel density surfaces (as described in Ollerhead et al. 2017) of harp seal positions derived from telemetry data for a: post-molt (May to mid-June), b: spring migration (mid-June to July), and c: summer feeding (August-November) time periods. For each of these layers, probability contours (percent volume thresholds) were calculated for 50%, 80%, 90%, and 95% volume. The Labrador Sea Frontier Area is indicated by the red line.

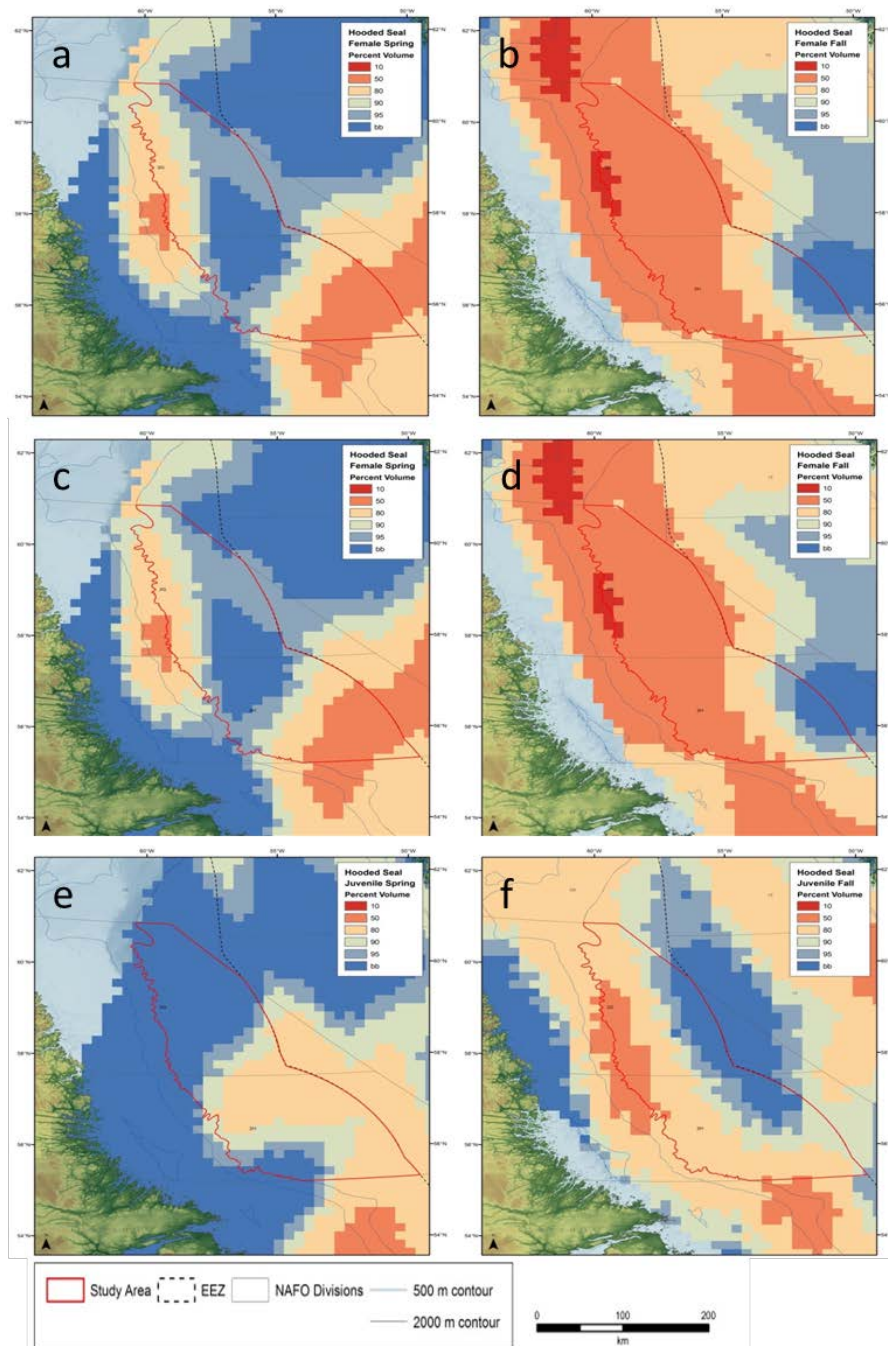


Figure 25: Distribution of female, male and juvenile hooded seals in spring and fall in the Labrador Sea presented as kernel density surfaces (as described in Ollerhead et al. 2017). a) female distribution in spring, b) female distribution in fall, c) male distribution in spring, d) male distribution in fall, e) juvenile distribution in spring and f) juvenile distribution in fall. The Labrador Sea Frontier Area is indicated by the red line.

### Species and/or Habitats of Interest

The Labrador Sea represents a portion of the known range for a variety of listed species including Northern Bottlenose Whales (Scotian Shelf population listed as Endangered;

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Lawson et al. 2017) and Bowhead Whales (Special Concern). Fin Whales, one of the top 10 most sighted cetaceans in the LSFA, are currently listed as Special Concern. The southern Labrador Shelf, a margin along the LSFA, has been identified as containing highly suitable habitat for this species (Lawson et al. 2017), and large feeding aggregations have been documented in the fall off nearby southwest Greenland (to the northeast of the LSFA).

Furthermore, two EBSAs adjacent to the LSFA, Northern Labrador and Hopedale Saddle, were largely implemented because they were important migratory and overwintering areas for the endangered Eastern Hudson Bay population of Beluga whales (Seiden 2016).

The paucity of information for marine mammals in the LSFA often limits the precise delineation of important habitats for some species. In some cases, available data has allowed refinement of habitats of interest. For example, aerial survey data, reports from commercial fisheries observers in the northern portion of the LSFA (J. Lawson, pers. comm. 2018), and habitat modelling indicate that the Labrador shelf break provides highly suitable habitat for Northern Bottlenose whales (Lawson et al. 2017). Similarly, the southern Labrador Shelf, a margin along the LSFA, has been identified as containing highly suitable habitat for Fin whales (Lawson et al. 2017), and large feeding aggregations have been documented in the fall near southwest Greenland (to the northeast of the LSFA).

### **Key Uncertainties and Approaches to Address Data Gaps**

During aerial surveys for cetaceans in the Labrador Sea region, many individuals were sighted at or beyond the shelf break (Lawson and Gosselin 2009, Lawson and Gosselin, unpubl. data). To capture more information regarding the extent of offshore use by cetaceans and to track implications of anthropogenic noise from activities on the shelf, it is recommended that survey track lines extend out into deeper waters in future surveys (Lawson et al. 2017). Such efforts, if possible, should be focused in the fall when more species and animals appear to occupy the adjacent shelf.

Given the spatial and temporal coverage limitations of visual surveys, it is recommended that acoustic monitoring be pursued in the LSFA (Appendix 1). Such studies have a good chance of detecting vocalizing marine mammals (at a great distance for species such as Fin and Blue Whales) as well as characterizing anthropogenic noise stressors such as shipping and seismic exploration. Complimentary techniques, such as eDNA, could provide insight on marine mammal presence in the areas as well as for other ecosystem elements (e.g., fish and plankton). Finally, marine mammal habitat modelling efforts should be extended into the LSFA. These would benefit from integration with seabird data for species with similar diets (e.g., Common murre and Minke whales), and better prey availability data collected using dedicated vessel surveys, such as in the AZMP and AZOMP studies further south.

## **ANTHROPOGENIC ACTIVITY**

### **Available information**

Human activity within the LSFA is limited due to its remote location and deep water. This area was initially highlighted for further study as a Frontier Area as per DFO's Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas (DFO 2009). The policy defines Frontier Areas as areas in Canadian waters with no history of fishing and include areas >2,000 m in depth with limited information about benthic habitat features. Although this area has had minimal anthropogenic activity, some human interaction has occurred within the LSFA or nearby, including commercial fishing, oil and gas exploration, and marine transportation.

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Fishing activities are primarily limited to the shelf/slope area adjacent to the LSFA, but they have the potential to extend into deeper water to meet quotas. The most commonly caught species in adjacent shallower slope or shelf waters are Northern Shrimp (shrimp trawl) and Greenland Halibut (longline and gillnet). Recently, interest has intensified for offshore oil and gas exploration in the Labrador Sea (C-NLOPB 2008), with oil and gas exploration licenses and calls for bids in the southern portion of the LSFA. In 2008, the C-NLOPB completed a Strategic Environmental Assessment (SEA) for an area of offshore Labrador known as the Labrador Shelf SEA Area with an update planned for early 2018. Seismic exploration of this area began in 1980 but coverage has only been significant since 2012, with additional surveys taking place within the LSFA in 2013 and 2014 ([C-NLOPB](#)). No exploration wells have been drilled inside the LSFA to date but some have occurred on the adjacent shelf.

Marine traffic density is currently low in the LSFA. Ferry service, shipping, and commercial fishing take place in coastal areas and on the continental shelf in areas less than 2,000 m. Various northern shipping routes may open to cargo shipping as warming global temperatures reduce Arctic summer sea ice. A long-term trend of reduced ice coverage may create opportunities for increased Arctic cruise ship tourism, commercial shipping and national sovereignty expeditions (BAE-Newplan Group Limited/SNC-Lavalin Inc. 2008). This could result in the Labrador Sea being more actively used for marine shipping activities as the Canadian gateway to the Arctic (Fort et al. 2013).

### **Key Uncertainties and Approaches to Address Data Gaps**

Anthropogenic activity is minimal within the LSFA primarily due to water depth (i.e. fishery) and its remoteness. Descriptions of activities such as vessel traffic (shipping/transportation) require additional investigation of existing data sources. Oil and gas exploration is likely to continue on the slope habitat adjacent to the LSFA but it is uncertain if and when exploration will be pursued within the LSFA. Indirect influences of anthropogenic activity such as climate effects on oceanographic conditions and contaminants (e.g., hydrocarbons and plastics) are difficult to distinguish for habitats and biota within the LSFA. Wherever possible, collection of data should build upon existing surveys. For example, contaminants can be measured in specimens collected during surveys of fish and benthic organisms, whereas acoustic monitoring of industrial noise/ship traffic can be accomplished with the same instruments used for marine mammal monitoring.

## **SUMMARY**

The available knowledge indicates that the Labrador Sea is characterized by important physical and ecological components and processes that are of global significance (e.g. oxygenation of deep-water environments and carbon capture). The LSFA's ecosystem is connected to important adjacent ecosystems (e.g., slope and shelf EBSAs, *Fisheries Act* closure areas) by ocean currents and the migration of organisms (ranging from zooplankton to large marine mammals) that use the area. Such migrations also bring Labrador Sea biota to coastal peoples of Labrador, who have depended on these species as a food source for generations.

The Labrador Sea contains a gyre that likely collects and retains passively transported nutrients and organisms, which in turn has the potential to attract species at higher trophic levels. Existing ecological data confirm that the Labrador Sea supports year round use by migratory marine mammals, seabirds, and fish; several species of which migrate from beyond the region (temperate and tropical latitudes, the Northeast Atlantic and Hudson Bay). Nevertheless, many aspects of the LSFA's ecosystem remain poorly understood and important ecosystem characterization must occur prior to recommending conservation objectives.

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Data gaps are most prominent for some ecological processes (productivity, connectivity, temporal variability) and broad taxa groups (benthos and fish), where the most basic information (community composition, life history information and trophic relationships) is unavailable. Such a broad array of data gaps will require a prioritized research plan. It is suggested that in the short-term, science initiatives focus on better characterization of the following three ecosystem elements:

- Mesopelagic fish,
- Demersal fish, and
- Benthic community (particularly echinoderms, corals, sponges and infauna).

Addressing these areas of focus in the challenging Labrador Sea environment with a finite budget will require a combination of conventional tools (e.g., ROVs, benthic dredges and pelagic trawls), developing techniques (e.g., towed video sledges and eDNA) and partnerships.

General areas of research beyond characterizing community composition should focus on processes of connectivity (drift models, genetics), productivity, trophic links (fatty acids, stable isotopes, stomach contents) and habitat-faunal relationships (e.g., currents, sea bottom).

Although it is recommended to focus resources on the above priority ecosystem elements, sampling of other low-cost/high-value data from other research areas should be augmented where feasible (e.g., adding additional sensors to moorings (Appendix 1), including marine mammal and seabird observers on all research missions).

Finally, the following principles are recommended when undertaking research in the Labrador Sea:

- Involve the Nunatsiavut Government and the NunatuKavut Community Council in research activities, incorporate ITK, and build collective capacity through these partnerships;
- Seek collaboration opportunities with other research institutions to maximize knowledge transfer and share research costs;
- Design studies according to the scales of relevant ecological processes (do not artificially confine questions to the LSFA);
- Consider the larger context of the Labrador Sea (i.e. connectivity) when characterizing the LSFA;
- Where possible, conduct research across gradients of depth, bottom types, and primary productivity;
- Use standardized techniques to leverage data sets with small sample sizes and enable comparison of results to other regions;
- Archive as much material as possible to facilitate future study of these rare samples; and
- Where possible, use less intrusive survey methods to limit damage to vulnerable benthic fauna.

A better ecological understanding of the LSFA will facilitate stakeholder engagement during the MPA establishment process, enable optimized placement of MPA boundaries and informed management upon establishment. The research initiatives also provide an opportunity for understanding a globally significant region and enhancing collaborations with other deep sea researchers and indigenous communities.



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### **APPENDIX 1: POTENTIAL SAMPLING DEVICES FOR MOORING DEPLOYMENTS IN THE LABRADOR SEA FRONTIER AREA**

<b>Device</b>	<b>Function and measurements</b>
Kongsberg Wideband Autonomous Transceiver	Autonomous wideband echo-sounding technology transmits on frequencies from 35 to 500 kHz to discriminate between plankton and different fish species.
Long Ranger Acoustic Doppler Current Profiler (ADCP)	Emits high-frequency sound in pulses to measure speed of currents using the principles of the Doppler effect.
Conductivity-Temperature-Depth (CTD) meter	Obtains information on salinity and temperature and depth. The CTD may also have sensors that measures dissolved oxygen, pH, turbidity, fluorescence.
Moored CTD Profiler	A CTD (as above) that includes an apparatus to move the unit up and down the water column on a sub-surface cable. Provides full water column measurements.
Fluorometer	Measures photosynthetic efficiency of phytoplankton.
Settlement plate	Creating a substrate for pelagic larvae and other organisms such as bacteria to settle on.
Autonomous Marine Acoustic Recorder (AMAR)	Listening station used to detect vocalizing marine mammals and noise from vessels
Sediment trap	Containers used to collect particles sinking towards the sea floor. Can be used to estimate energy flow from the surface to the bottom.



## APPENDIX 2: DISTRIBUTIONS OF MARINE MAMMALS IN AND ADJACENT TO THE LABRADOR SEA FRONTIER AREA

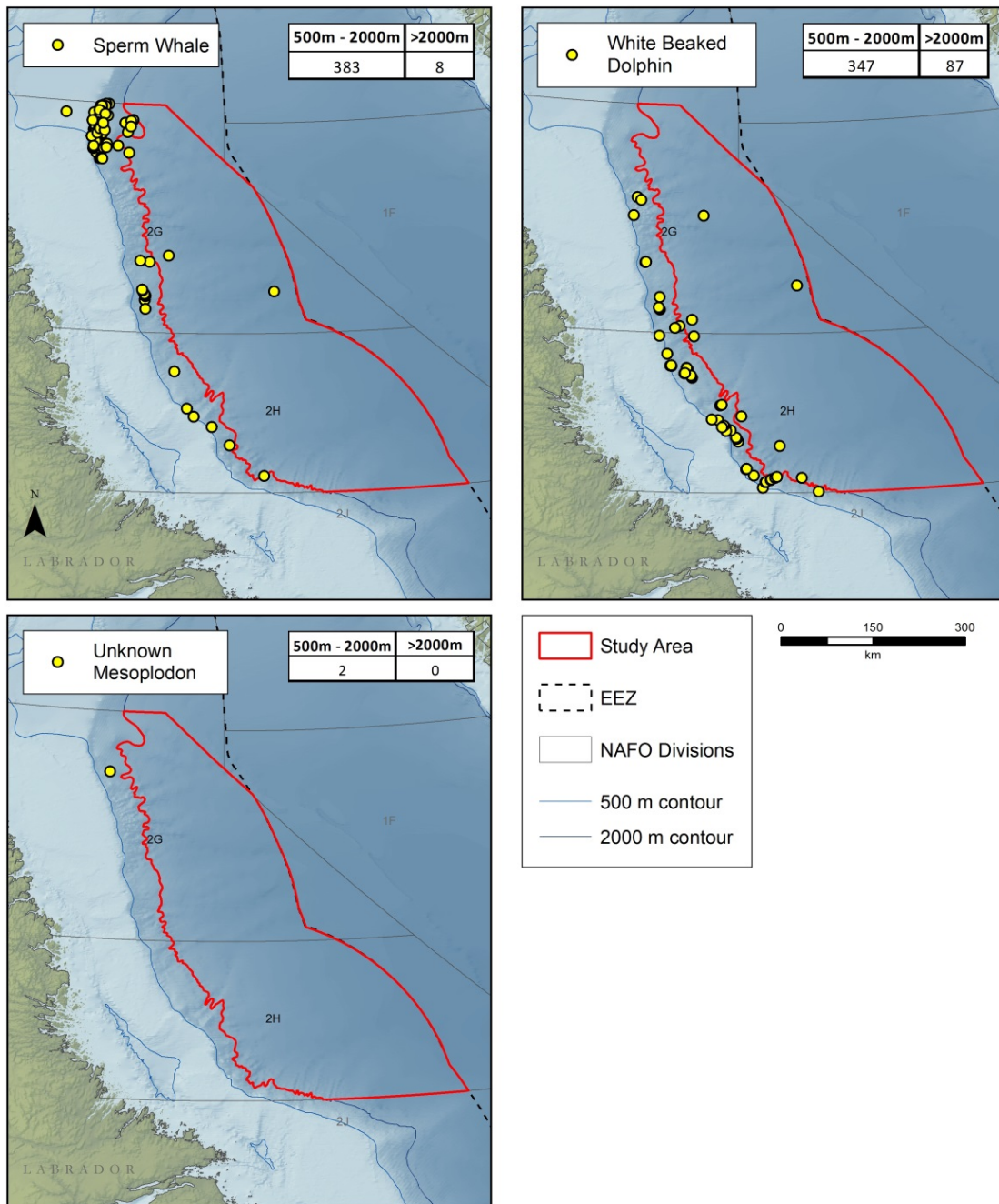


Figure A2-1a: Marine Mammal sightings from vessel and aerial surveys Labrador Sea in water depths greater than 500 m in NAFO zones 2G and 2H.

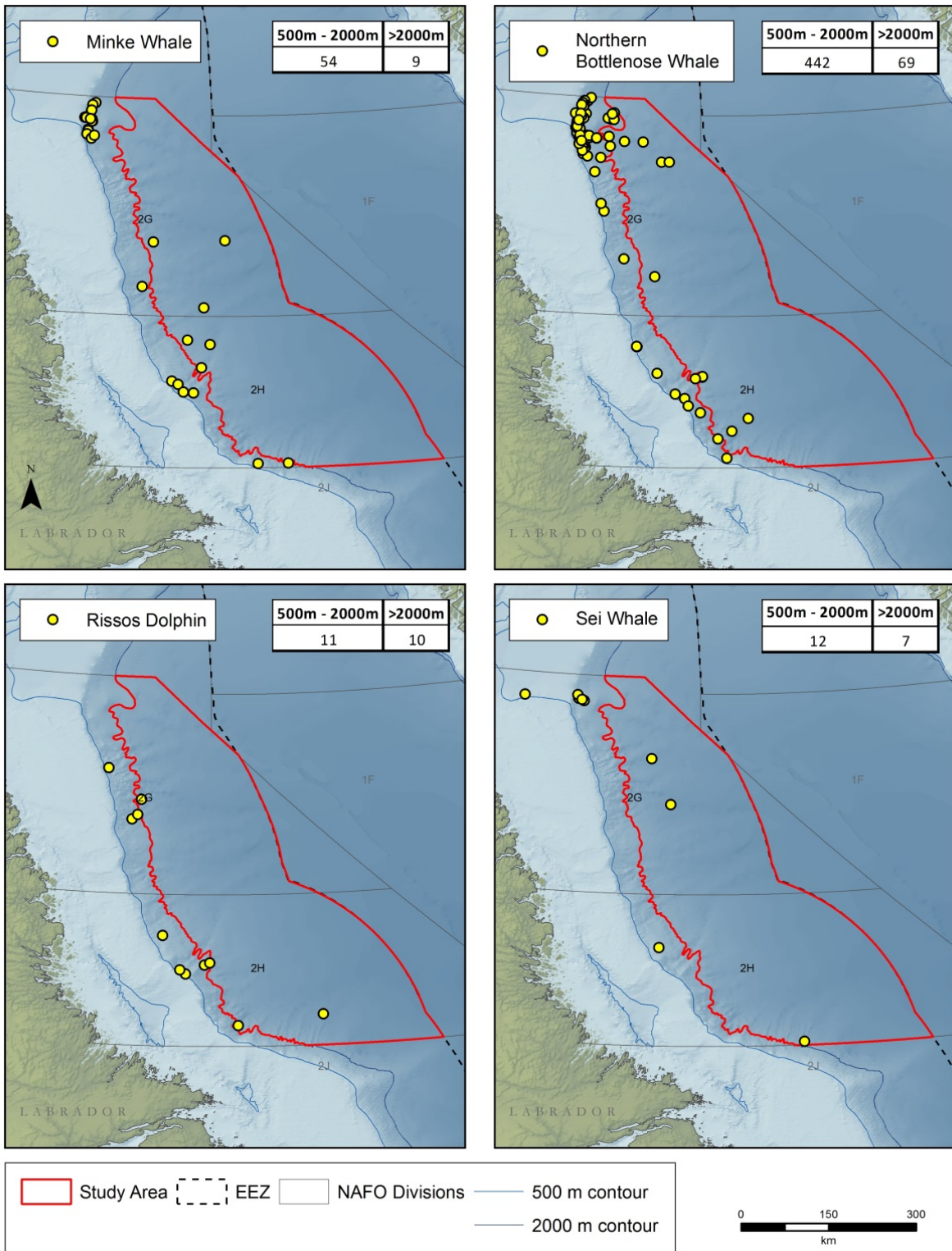


Figure A2-1b: Marine Mammal sightings from vessel and aerial surveys conducted in the Labrador Sea in water depths greater than 500 m in NAFO zones 2G and 2H.



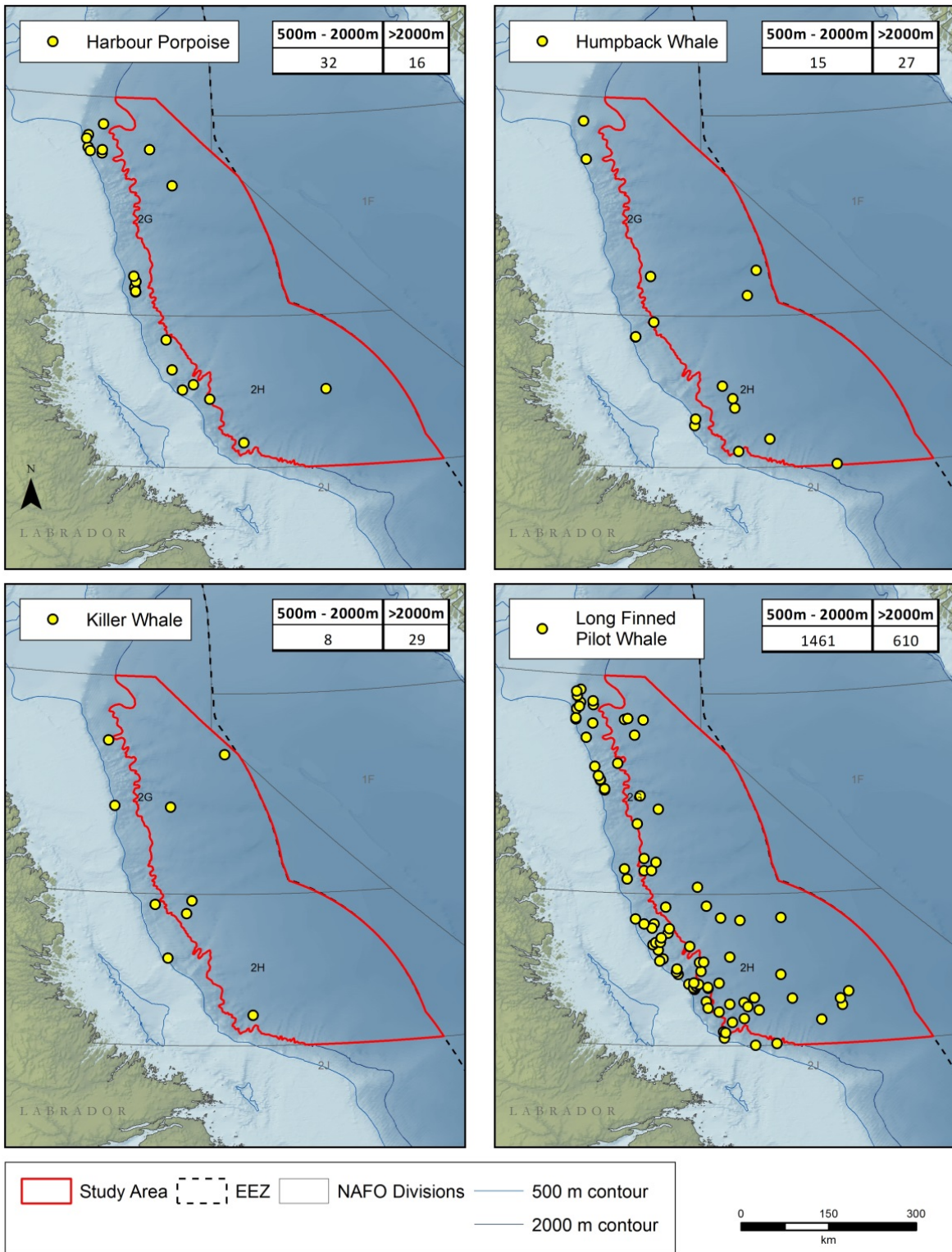


Figure A2-1c: Marine Mammal sightings from vessel and aerial surveys conducted in the Labrador Sea in water depths greater than 500 m in NAFO zones 2G and 2H.

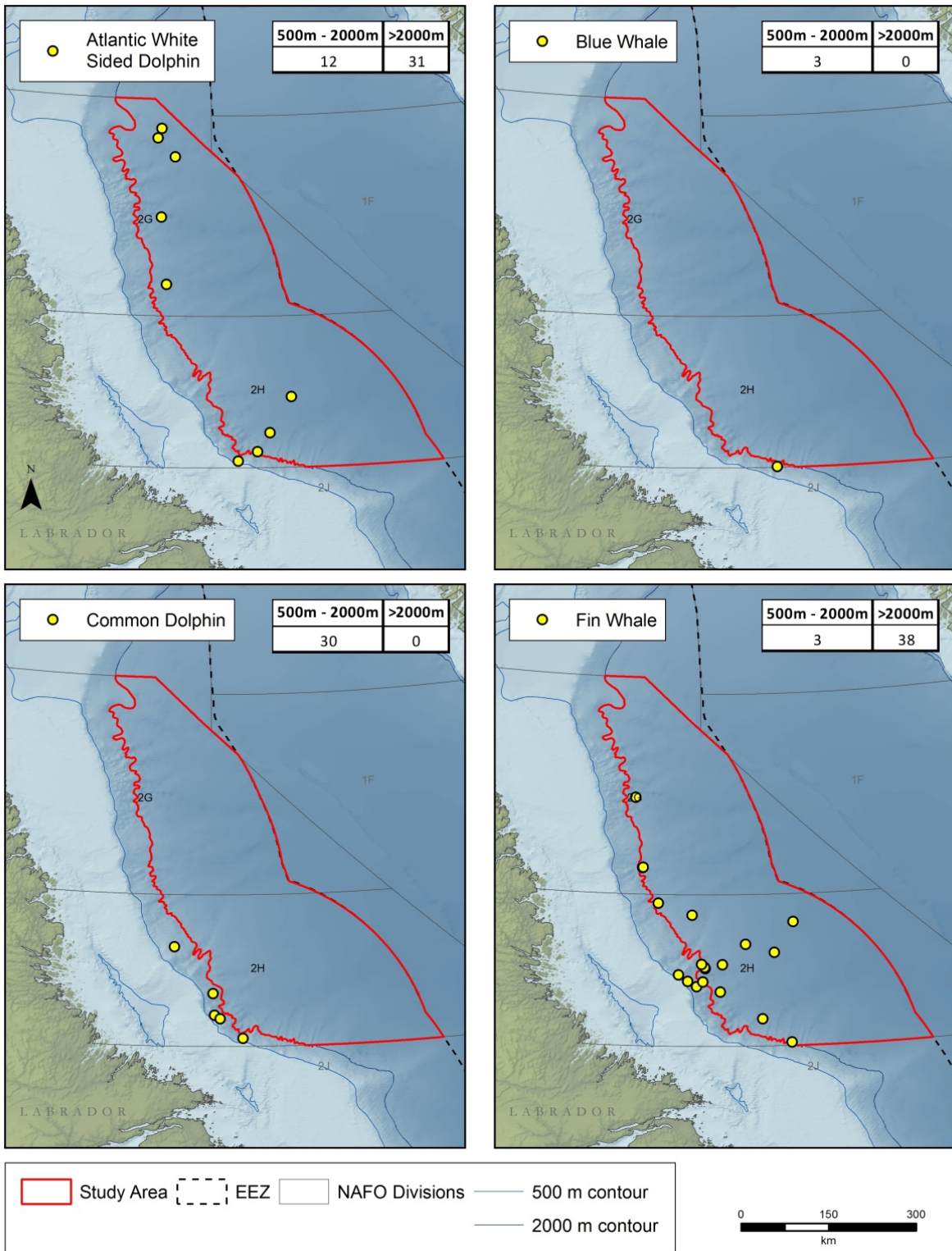


Figure A2-1d: Marine Mammal sightings from vessel and aerial surveys conducted in the Labrador Sea in water depths greater than 500 m, in NAFO zones 2G and 2H.