Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2026/042

Newfoundland and Labrador Region

Identification of Reference Sites and a Scientific Monitoring Approach for the Laurentian Channel Marine Protected Area

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May 2026

Canada

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-99883-1 Cat. No. Fs70-5/2026-042E-PDF

Correct citation for this publication:

Warren, M., Neves, B.M., Cote, D., Lawson, J.W., Morris, C., Simpson, M., Konecny, C., Cyr, F., Novaczek, E., Pretty, C., Power, A., Bélanger, D., Hayes, V.E., Miri, C., and Desforges, J. 2026. Identification of Reference Sites and a Scientific Monitoring Approach for the Laurentian Channel Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2026/042. iv + 97 p.

Aussi disponible en français :

Warren, M., Neves, B.M., Cote, D., Lawson, J.W., Morris, C., Simpson, M., Konecny, C., Cyr, F., Novaczek, E., Pretty, C., Power, A., Bélanger, D., Hayes, V.E., Miri, C., et Desforges, J. 2026. Détermination des sites de référence et d'une approche de surveillance scientifique pour la zone de protection marine du chenal Laurentien. Secr. can. des avis sci. du MPO. Doc. de rech. 2026/042. iv + 109 p.

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ABSTRACT

Canada has committed to increasing protection of our oceans, up to 30% by 2030. As part of that overall plan, the Laurentian Channel Marine Protected Area (MPA) was established under the *Oceans Act* in 2019. The Laurentian Channel MPA is a relatively large area covering approximately 11,580 km^2, and hosts a wide range of species and habitats. In order to effectively manage such a large area and allow for adaptive management, monitoring should occur; therefore the establishment of a scientific monitoring program is an important component of the overall management plan. The focus of the scientific monitoring program will be to collect data to assess and interpret the status and trends of the Conservation Objective (CO) priority species/taxa (sea pens, Black Dogfish *(Centroscyllium fabricii*), Smooth Skate (*Malacoraja senta*), Porbeagle Shark (*Lamna nasus*), Northern Wolffish (*Anarhichas denticulatus*), and Leatherback Sea Turtles (*Dermochelys coriacea*)), as well as overall biodiversity for the Laurentian Channel MPA. Building on previous national and regional guidance, we develop a scientific monitoring approach that strategically supplements existing regional programs (Complementary Monitoring) with additional practical, and feasible monitoring (Core Monitoring and Targeted Research) while maintaining a scientifically robust monitoring program. The four elements of that approach are

1. reference, or monitoring sites,
2. survey methods and strategies,
3. indicators, and
4. study design.

It is intended that this approach can also be used as a template for other marine conservation areas in the Newfoundland and Labrador (NL) region, enabling the possibility of integrated regional conservation area assessments for common indicators. Many unknowns remain and this program will require re-evaluation and refinement (particularly after field trials) to assess whether MPA objectives will be achieved over the long term.

INTRODUCTION

Protected areas contribute to healthy marine environments by prohibiting or restricting certain human activities that may negatively impact their respective conservation objectives (COs). Fisheries and Oceans Canada (DFO) currently uses two tools to create protected areas in the ocean:

1. *Oceans Act* Marine Protected Areas (MPAs); and
2. Fisheries closures known as Marine Refuges (MRs), which are a type of Other Effective Area-Based Conservation Measure (OECM).

Marine conservation has been a priority of the Government of Canada, which has committed to expanding its marine conservation areas from 14% to 30% by 2030 (Government of Canada 2019a), and to support monitoring of existing conservation areas, under the Marine Conservation Targets (MCT) Program. The latter is considered an essential pillar of effective management of these conservation areas, as the resulting data are useful in evaluating whether COs are being achieved and how management can be adapted to enhance outcomes.

The Laurentian Channel MPA was established in 2019 to protect an area of complex oceanography and relatively intact habitats (Templeman 2007). While some scientific activities have been conducted in the area, a formal MPA monitoring plan has yet to be developed. A previous Canadian Science Advisory Secretariat (CSAS) process (DFO 2015) developed recommendations for identifying monitoring indicators, protocols, and strategies for the Laurentian Channel MPA focusing on the six priority species (or taxa) from the COs (sea pens, Black Dogfish (*Centroscyllium fabricii*), Smooth Skate (*Malacoraja senta*), Northern Wolffish (*Anarhichas denticulatus*), Porbeagle Shark (*Lamna nasus*), and Leatherback Sea Turtles (*Dermochelys coriacea*)). To support Government of Canada objectives in relation to establishing a scientific monitoring program for the Laurentian Channel MPA, this CSAS process was initiated to:

- Identify direct or indirect indicators and reference sites, where possible, that could be used to monitor the status and trends of the priority species listed as part of the six COs, as well as overall biodiversity for the Laurentian Channel MPA.
- Develop a scientific monitoring approach for the Laurentian Channel MPA based on proposed indicators, survey methods, and strategies identified by Lewis et al. (2016). Each of the priority species identified in the COs will be considered when developing indicators, survey types, and study design considerations.
- Investigate the ability to assess MPA conservation priority species metrics using existing Research Vessel (RV) trawl survey data and seafloor imagery data.

Our approach to achieving these objectives was to build on, and update, the recommendations of Lewis et al. (2016) with the goal of creating an approach to monitoring that is scientifically robust, practical and feasible, and useful to support management decisions. The first two objectives are addressed in the present document and for the third objective see Morris et al. (2024). Our recommendations may require adjustments following field trials to ensure program objectives are met.

Advice provided here pertains only to scientific monitoring even though there are several other components that will make up the overall monitoring plan for this MPA. For example, enforcement of the regulations, i.e., compliance monitoring activities, are undertaken by DFO - Conservation and Protection Branch.

LAURENTIAN CHANNEL MPA

MPA Establishment and Regulations

The Laurentian Channel includes an area identified as an Ecologically and Biologically Significant Area (EBSA) (Templeman 2007; Wells et al. 2019). EBSAs are special areas that provide important services to one or more species/populations of an ecosystem or to the ecosystem as a whole, but have no management or protection measures. A portion of the Laurentian Channel EBSA was announced as an Area of Interest (AOI) for potential designation as an MPA under the *Oceans Act* in 2010 (DFO 2015; Lewis et al. 2016). After completing a biophysical overview, socio-economic review, risk assessments, and consultations with stakeholders, the MPA boundary was modified to exclude important fishing grounds so as to reduce impacts on harvesters. The resulting area (11,580 km^2) was officially announced as an MPA in April 2019 (Government of Canada 2019b) (Figure 1). The MPA's primary goal is to conserve biodiversity through the protection of the conservation priority species and their habitats, ecosystem structure and function, and through scientific research. It is an ecologically important area with uniquely intact habitats, and complex circulation and oceanographic conditions (Templeman 2007). The priority species of conservation interest selected for the Laurentian Channel MPA range from sessile species such as corals, in particular significant concentrations of sea pens, to highly mobile species like the Porbeagle Shark and Leatherback Sea Turtle. Several of these species were selected based on information provided from the EBSA identification process (see Templeman 2007). The regulations for the MPA prohibit any activity that disturbs, damages, destroys, or removes a living marine organism or any part of its habitat (Government of Canada 2019b). Therefore, this area is considered a no-take MPA, where all fisheries and extractive activities, except aboriginal food and ceremonial fisheries, are not permitted in the MPA. Certain activities deemed compatible with the COs can continue. These activities include navigation of vessels (no anchoring in Zones 1a and 1b; see Figure 1), submarine cable installation, repair and maintenance (only in Zones 2a and 2b), scientific research, monitoring and educational activities (in some cases, subject to approval of an activity plan), and any other activities related to safety and security (Government of Canada 2019b).

In 2010 a biophysical overview was completed for the AOI to compile all available information on the various biological and physical components of the study area (DFO 2011). Baseline information related to ecological conditions, species and habitat including knowledge gaps were compiled. Based on the findings of the biophysical overview, six COs for the Laurentian Channel were selected. These COs are as follows (Government of Canada 2019b):

1. Protect corals, particularly significant concentrations of sea pens, from harm due to human activities (e.g., fishing, oil and gas exploratory drilling, submarine cable installation and anchoring) in the Laurentian Channel MPA.
2. Protect Black Dogfish from human induced mortality (e.g., bycatch in the commercial fishery) in the Laurentian Channel MPA.
3. Protect Smooth Skate from human induced mortality (e.g., bycatch in the commercial fishery) in the Laurentian Channel MPA.
4. Protect Porbeagle Sharks from human induced mortality (e.g., bycatch in the commercial fishery, seismic activities) in the Laurentian Channel MPA.
5. Promote the survival and recovery of Northern Wolffish by minimizing risk of harm from human activities (e.g., bycatch in the commercial fishery) in the Laurentian Channel MPA.

6. Promote the survival and recovery of Leatherback Sea Turtles by minimizing risk of harm from human activities (e.g., entanglement in commercial fishing gear, seismic activities) in the Laurentian Channel MPA.

Site Characterization

The Laurentian Channel MPA is located off the southwest coast of Newfoundland and Labrador (NL) in Northwest Atlantic Fisheries Organization (NAFO) Division 3P. It covers approximately 11,580 km^2 including the water column, seabed, and subsoil to a depth of five meters (Lewis et al., 2016). The MPA is named after the long submerged glacial valley that runs across the Gulf of St. Lawrence, over 1,000 km from the continental slope (the mouth) to the Lower St. Lawrence Estuary where it ends abruptly near Tadoussac (i.e., the head of the Laurentian Channel), the natural division between the Lower and Higher St. Lawrence Estuary. The Laurentian Channel MPA is located at the mouth of the Laurentian Channel near the continental slope (Figure 2).

Depths in the MPA range from 100-200 m in the northwest corner along the Burgeo and St. Pierre Banks to the basin of the Laurentian Channel. The depth varies from close to 500 m on the northwest extremity to about 400 m in the southeast extremity (DFO 2015). The Laurentian Channel MPA has a large, relatively undisturbed benthic habitat compared to nearby areas such as Burgeo Bank, which has higher historical fishing effort (Koen-Alonso et al. 2018). The area has several different habitat types, but mud and clay generally characterize deeper areas and sand and gravel occur mainly on the banks, however the boundary only runs along the edge of banks and so the majority of the MPA is predominantly mud or clay (DFO 2015; Lacharité et al. 2020). A combination of previous multibeam sonar, sediment, infauna, and epifauna from seafloor imagery data has led to the identification of eight benthoscapes in the MPA (Lacharité et al. 2020). Benthoscapes can be compared to landscapes in terrestrial environments that describe biophysical features of the seafloor (Lacharité et al. 2020). These benthoscapes mostly vary in terms of depth, slope, presence/absence of iceberg scours and pockmarks/pits, and predominant surficial sediment. The largest benthoscape in the Laurentian Channel MPA occupies 34% of the MPA and is characterized by relatively deep-water (>400 m), low relief slope, abundant iceberg scours but sparse pockmarks/pits, and sandy mud with traces of gravel as the main surficial sediment (Lacharité et al. 2020).

A large part of the Laurentian Channel is located inside the Gulf of St. Lawrence, considered one of the largest estuaries in the world (El-Sabh and Silverberg 1990). The residual ocean circulation in the Gulf, and thus in the Laurentian Channel, can therefore be classified as *estuarine* in that the deep waters are advected inland, while the surface and mid-water column waters are advected seaward. In the MPA, the surface waters are generally influenced by river runoff from the St. Lawrence and other tributaries of the Gulf, while the deep waters flowing into the Laurentian Channel are a mixture of subtropical and sub-arctic waters. The two water masses entering the Laurentian Channel from the Atlantic are the warm, salty, and oxygen-poor North Atlantic Central Waters (NACW), and the cold, oxygen-rich Labrador Current Waters (LCW) originating from the Labrador Current system (Figure 2). These two water masses mix on the continental shelf to form the cold slope water before entering the Laurentian Channel proximal to the MPA (Gatien 1976; Bugden 1991; Gilbert et al. 2005). The NACW mainly consists of waters from the nearby passing Gulf Stream, while the LCW originates from the Labrador Current system (Labrador Current and Labrador Coastal Current) waters that flow southward along the shelf break and along the Labrador slope. While the main (offshore) branch of the Labrador Current rounds the Grand Banks from the east (after passing through the Flemish Pass or around the Flemish Cap), the shallower Coastal Labrador Current reaches the

mouth of the Laurentian Channel after passing through the Avalon Channel near the Island of Newfoundland (Figure 2).

As the deep waters entering the Laurentian Channel are advected inland, they are slowly depleted of oxygen by microbial degradation and remineralization processes. Near the head of the Laurentian Channel, in the Lower St. Lawrence Estuary, the bottom waters suffer severe hypoxia, which has been worsening over the recent years (DFO 2022a). It has long been suggested that the relative proportion of oxygen-poor NACW vs oxygen-rich LCW entering the mouth of the Laurentian Channel is a key driver controlling the oxygen concentration in the deep Laurentian Channel, and therefore the hypoxia in the St. Lawrence Estuary. For example, between the early 1930s and 2003, about one-half to two thirds of the observed oxygen decline at the head of the Laurentian Channel was attributed to an increase in the relative contribution of NACW to the deep waters of the Laurentian Channel, while the remainder was attributed to eutrophication (Gilbert et al. 2005). As the relative proportion of LCW entering the Laurentian Channel is mainly driven by the strength of the Scotian Shelf-break current carrying the cold slope water across the mouth of the Laurentian Channel, it appears the Labrador Current and the ocean circulation in the northwest Atlantic are key drivers determining the oxygen concentration in the Laurentian Channel (Jutras et al. 2020). Since 2008, however, the reduced inflow of highly oxygenated LCW to the deep waters of the Laurentian Channel in favor of low-oxygenated NACW has led to recent record-low oxygen levels in the St. Lawrence system (Jutras et al. 2020). Being located at the mouth of the Laurentian Channel, the MPA can be seen as a barometer of the conditions entering the Gulf of St. Lawrence, and its monitoring is essential to provide an early signal of future Gulf of St. Lawrence conditions.

Stressors

Ecosystem stressors and cumulative impact assessments are an important consideration in the development of COs for MPAs. The relevance of ecosystem stressors depends upon the regulatory objectives of the MPA in question. With respect to the Laurentian Channel MPA, the primary threat identified in the MPA regulations is commercial fishing, which resulted in six regulatory COs to guide MPA assessment and evaluation. However, the historic exposure of the Laurentian Channel MPA to fishing is low (Muntoni et al. 2019). Vulnerability metrics have not been formally identified to quantify the impact of various stressors (e.g., fishing, shipping lanes, submarine cables) on habitats in the Laurentian Channel MPA, however, other human activities inside the MPA, such as shipping and related noise may create different added stressors to the marine environment. For example, discharges into the water (e.g., wastewater, oil spills, marine litter, invasive species), physical impacts (e.g., noise, collisions with wildlife, anchoring damage), or air emissions (Jägerbrand et al. 2019; Hannah et al. 2020). Shipping lanes through the Laurentian Channel MPA can pose risks to several of the priority species. For example, anchoring can damage or destroy coral species, such as sea pens, and Leatherback Sea Turtles may be susceptible to ship strikes in the area. The extent of localized effects from climate change on the Laurentian Channel MPA are still unknown, however, it should be considered as a potential stressor for the ecosystem in general and for the CO priority species.

BIODIVERSITY AND PRIORITY SPECIES OF CONSERVATION INTEREST

Biodiversity

The Laurentian Channel MPA represents a large marine area minimally impacted by fishing activities relative to adjacent areas (Muntoni et al. 2019). The area serves as habitat to a multitude of commercially, culturally, and ecologically important taxa, which can provide important ecosystem services (e.g., carbon sequestration). The Laurentian Channel MPA is the

largest no-take MPA in Eastern Canada and is a part of Canada's marine conservation network that collectively seeks to safeguard biodiversity from human induced stressors such as resource extraction, and pollution. DFO research vessel (RV) multispecies trawl survey (hereafter referred to as 'RV trawl survey') data from the annual Spring survey indicate the Laurentian Channel MPA has elevated taxonomic richness and diversity (Shannon-Wiener) using standardized abundance and biomass per trawl set, relative to many other areas of the region (NAFO Divisions 3LNOP) (Figure 3 to Figure 5). Moreover, the biodiversity of the Laurentian Channel MPA may create a more resilient ecosystem that will help support the following CO priority species and the socio-economic benefits that arise from protecting this area. As conserving biodiversity is the primary goal of this MPA, it is important to ensure indicators to measure various aspects of biodiversity are included in the scientific monitoring approach as well.

Sea Pens

Sea pens are colonial octocorals in the cnidarian superfamily Pennatuloidea (Williams 2011). A sea pen colony is an organism composed of several individual polyps (i.e., feeding/reproductive units). They are mostly distinguished by the presence of a muscular peduncle that anchors them into soft sediment, although a few species have a modified peduncle that can attach to hard bottoms (Williams and Alderslade 2011). There are over 200 species of sea pens worldwide (Williams 2011) and at least 14 species are found in the Northwest Atlantic, 9 of them in the Laurentian Channel MPA (Hayes et al. In prep[1]). Sea pens are adapted to life on soft sediments, with some species (e.g., *Pennatula aculeata*) often forming fields that are several kilometers in length, and can be the dominant benthic megafauna taxa (e.g., Baker et al. 2012).

The few studies to date on longevity and growth rates of sea pens indicate that they have decadal longevities and average linear (vertical) growth rates ranging between 1.9-4.5 mm yr^{-1} (Neves et al. 2015, 2018b; Murillo et al. 2018). Sea pens are suspension feeders and feed mainly on particulate organic matter (Sherwood et al. 2008; Salvo et al. 2018). They are predated by nudibranchs and sea stars (Birkeland 1974; Weightman and Arsenault 2002; Gale et al. 2013), but more studies are required to investigate the specific nature of these dynamics. To better understand the health of sea pen populations in the MPA, it may be important to consider the potential role that predator abundance and distribution might have in the area.

A few studies on reproductive biology of sea pen species that occur in the MPA (e.g., *Anthoptilum* spp., *Balticina finmarchica*) indicate that they are gonochoric (separate sexes) broadcast spawners that release gametes annually (Baillon et al. 2014b, 2015). *Pennatula aculeata* was initially thought to spawn continuously (Eckelbarger et al. 1998), but a recent study showed that females appear to release gametes only every two years (Couillard et al. 2021), which contradicts information on the related species *P. phosphorea* from Scotland, in which gametogenesis for both sexes is continuous (Edwards and Moore 2008). This information is relevant because it indicates that the species might be more vulnerable than initially thought. It also highlights the importance of species-specific and regional studies to understand local dynamics, which might be different elsewhere. Reproductive strategies may explain why sea pens form fields. Since sea pens like *P. aculeata* (and other taxa) have separate sexes, their presence in large abundances might significantly increase their chances of reproductive success (Langton et al. 1990).

[1] Hayes, V.W., Neves, B.M., Pretty, C. In prep. Cold Water Coral Field Guide: Eastern Canada, Northwest Atlantic. For submission to Canadian Technical Report of Fisheries and Aquatic Sciences.

In NAFO Subdivision 3Ps, sea pens have been reported at biomasses of >28 kg/set for the relatively heavy sea pen *Anthoptilum grandiflorum,* as well as for the smaller/lighter species *Pennatula aculeata*. For instance, abundances of *A. grandiflorum* with a total catch weight of 9.6 kg had 353 colonies/set, while 10.7 kg/set of *P. aculeata* yielded 3,987 colonies/set (V. Hayes, DFO-NL, pers. comm.). Catchability, the ability of research trawls to capture specimens within the cod-end of the net, can vary by species, indicating that sea pen abundance data from research trawls, especially for small species (e.g., *P. aculeata*, *K. stelliferum*, *P. carpenterii*), are likely an underrepresentation of real impacts on sea pen communities. In fact, Kenchington et al. (2011) estimated that catchability of Campelen trawls for sea pens is only ~5.2% but further studies are required to further assess this estimation in various areas (see section 0).

Sea pens have also been visually assessed through camera surveys, where taxa commonly not reported in RV trawl surveys have been observed. For example, the sea pen *K. stelliferum* can be the dominant sea pen taxon in some regions of the Laurentian Channel MPA, as seen during a 2017 expedition using the Remotely Operated Platform for Ocean Science (ROPOS) (e.g., de Mendonça and Metaxas 2021). Another species, *Protoptilum carpenterii,* was commonly observed during the same expedition, even though it is rarely reported in RV trawl surveys (V. Hayes, DFO-NL, pers. comm.). In the case of *K. stelliferum*, low reporting in trawl samples might be due to the fact that this sea pen has a large part of its body buried in the sediment, with a smaller portion exposed. In the case of *P. carpenteri*, withdrawal behavior might contribute to trawl avoidance. For example, during a 2007 ROPOS expedition to the Southwest Grand Banks region, this species exhibited the ability to quickly withdraw into the sediment upon contact with the Remotely Operated Vehicle (ROV) arm, a behavior also documented elsewhere (Ambroso et al. 2021). Based on multispecies trawl and video data, the most common sea pen taxa in the Laurentian Channel are *Pennatula aculeata*, *Anthoptilum* spp., and *Kophobelemnon* spp.

The Laurentian Channel MPA is mostly dominated by soft sediments (Lacharité et al. 2020), which is a key requirement for the presence of high sea pen densities. In addition, Gullage et al. (2017) identified bottom temperature as a variable significantly contributing to habitat suitability models for sea pens in the Northwest Atlantic. Other studies have identified bottom temperature as a variable influencing the distribution of sea pens (Yesson et al. 2012; Downie et al. 2021). Seasonal analyses showed a higher diversity of invertebrate species associated with *A. grandiflorum* in spring/summer, when temperatures are warmer (Baillon et al. 2014a). In addition to bottom temperature, wave and current velocities, as well as particulate organic matter concentration, have been identified as important variables for these organisms (e.g., Downie et al. 2021). The study by Downie et al. (2021), which was focused on United Kingdom sites, indicated that although some variables were important for sea pens overall, different sea pen species do have different environmental requirements. For instance, particulate matter was a more important variable for the sea pens *Funiculina quadrangularis* (also present in the Laurentian Channel) and *Pennatula phosphorea,* while current velocity was more important for *Virgularia mirabilis*.

Sea pens are sedentary benthic organisms, with limited or no mobility which makes them particularly vulnerable to mechanical contact. The high sea pen biomass found in trawl bycatch is evidence that these organisms are susceptible to removal through the mechanical contact of bottom trawls, even if catchability is low. Little is known about sea pen potential for recovery from mechanical damage that does not result in removal. One study on a shallow-water population of the cold-water sea pen *Balticina willemoesi* identified that colonies were capable of reburying themselves in the sediment after displacement through simulated trawling (Malecha and Stone 2009). However, mortality was still observed and those which survived were more

vulnerable to predation by nudibranchs (Malecha and Stone 2009). The long-term survivability of those sea pens after the end of the experiment was not assessed.

Sea pens have two main calcium carbonate components in their bodies. In most taxa, their tissues are packed with sclerites, which are calcite structures of varied sizes and shapes. In addition to providing skeletal support, sclerites can also be a predation-deterrent in some octocorals. Most sea pens also have an internal skeletal structure called an axis, which is also composed of calcium carbonate, in the form of calcite (Neves et al. 2018a). The axis runs through the entire sea pen body, from the proximal to distal extremities, and it provides support to the colony. There are few studies on the calcium carbonate composition of sea pens. As with other corals with calcium carbonate structures, ocean acidification is a stressor that could have direct impacts on the health of sea pen populations. Information on current sea pen calcium carbonate composition and other metrics would be important to assist with monitoring and the interpretation of changes resulting from acidified conditions.

Black Dogfish

Black Dogfish is a deepwater shark, found at depths ranging from 200 m to about 1,100 m. This species is distributed across most of the North Atlantic, in the Northwest Atlantic from Virginia (United States of America), north along the coast of Canada to Baffin Island, in the waters off west and east Greenland, throughout the Eastern Atlantic, and south along the coasts of Europe and Africa (Compagno 1984). Shallow portions of the Laurentian Channel (<400 m) are potentially unique nursery areas for Black Dogfish, based on seasonal occurrences of substantial proportions of mature females and young-of-the-year (Kulka et al. 2022; Boag 2014). This species' life history is characterized by low fecundity (litter size: ages 4–40 live young), slow growth, maximum length of approximately 85 cm, and late sexual maturity. Black Dogfish live and feed on or near the seafloor, consuming mainly crustaceans, squids, cephalopods, jellyfish, and bony fishes. Kulka (2006) noted that Black Dogfish distribution is highly influenced by water temperature, depth, body length, and sex. Moreover, Kulka (2006) noted that large (pregnant) females migrate to shallow portions of the Laurentian Channel where pupping occurs. As the young mature, they move into deeper waters and, ultimately, out of the Laurentian Channel and into deeper slope waters as they grow. There are no directed fisheries for Black Dogfish; however, it is a common bycatch species in North Atlantic otter trawl fisheries (M. Simpson, DFO-NL, pers. comm.), which makes it vulnerable to human exploitation. Black Dogfish has no status under Canada's (Species at Risk Act) *SARA.* Changes in Black Dogfish biomass are monitored by DFO using RV trawl surveys over a large portion of this species' Canadian range in the NL Region. In NAFO Subdivision 3Ps (including the Laurentian Channel MPA), biomass of Black Dogfish has been generally stable since 2004; following a modest decline from levels observed in 1996–97 (Figure 6). The highest biomass caught in the RV trawl surveys from 1996–2021 is found in the northeast portion of the MPA (Figure 7). In NAFO Divisions 2J3K and 3LNO, the biomass of Black Dogfish has been variable, but relatively stable.

Smooth Skate

Smooth Skate is a bottom-dwelling cartilaginous fish distributed throughout the Northwest Atlantic Ocean from waters off New Jersey, the Scotian Shelf, the Gulf of St. Lawrence, south of Newfoundland, as well as the banks and shelf waters of Newfoundland and Labrador. Smooth Skates are generally distributed at depths between 50 and 500 m and at bottom temperatures of 4–7°C. Smooth Skate is one of the smaller skate species in the Northwest Atlantic, growing up to 70 cm in length, and consuming primarily small crustaceans; becoming piscivorous only at larger body sizes (Kulka et al. 2006). Both adult and immature Smooth Skates are distributed within the Laurentian Channel MPA. There are no directed fisheries for Smooth Skate; however,

it is a common bycatch species in gillnet and otter trawl fisheries that target Thorny Skate (COSEWIC 2012), thereby making it vulnerable to human exploitation. Smooth Skate has no status under Canada's *SARA*. However, (The Committee on the Status of Endangered Wildlife in Canada) COSEWIC has assessed the Laurentian-Scotian designatable unit of Smooth Skate as Special Concern (COSEWIC 2012). Changes in Smooth Skate biomass are monitored by DFO using RV trawl surveys which cover a large portion of this species' Canadian range in the NL Region. In NAFO Subdivision 3Ps (including the Laurentian Channel MPA), biomass of Smooth Skate generally increased from 1996–2005, and has since remained stable; with the exception of recent years of the Spring survey index (Figure 8, Figure 9). In NAFO Divisions 2J3K and 3LNO, the biomass of Smooth Skate has been variable, but relatively stable.

Porbeagle Shark

Porbeagle Sharks are widely distributed throughout the North Atlantic, from the Labrador Sea in the North to the Sargasso Sea in the Southwestern Atlantic, and from Iceland and the western Barents Sea to Morocco in the Eastern Atlantic (Campana et al. 2013). Overall, the seasonal distribution of this wide-ranging shark is highly influenced by water depth and temperature. Porbeagles travel northeast along the Scotian Shelf through the spring, and then appear off the south coast of Newfoundland and in the Gulf of St. Lawrence in the summer and fall (Campana et al. 2013). Unlike the previous fish species, Porbeagle Sharks are not often captured by the DFO RV trawl survey. Of significance to the Laurentian Channel MPA, Campana et al. (2013) established that one of only two known Porbeagle mating grounds occurs at the entrance to the Gulf of St. Lawrence, however it is not within the boundary of the MPA (Figure 10). Porbeagles, like other sharks and skates, have low fecundity and a late age of sexual maturation. Porbeagle diet is composed of a wide variety of species (groundfish, cephalopods), and is influenced by prey availability and shark body size (Joyce et al. 2002). There is no current directed fishery for Porbeagle in Canada; however, bycatch in longline, gillnet, and otter trawl fisheries is a threat to the Northwest Atlantic population (Simpson and Miri 2014). Porbeagle has no status under Canada's *SARA*, however, COSEWIC has assessed the Atlantic designatable unit of Porbeagle Shark as Endangered (COSEWIC 2014). Based on the International Commission for the Conservation of Atlantic Tunas (ICCAT) 2020 assessment, the Northwest Atlantic stock of Porbeagle Sharks, which overlaps the Laurentian Channel MPA, has been slowly rebuilding since 2001, but remains well below abundance levels observed in the 1960s.

Northern Wolffish

Northern Wolffish is widely distributed in Atlantic and Arctic waters, as are the Spotted Wolffish (*A. minor*), and the Atlantic Wolffish (*A. lupus*). Northern Wolffish are generally distributed from the Davis Strait/west Greenland along the edge of the Labrador Shelf, the Grand Banks, and into the Laurentian Channel. The highest concentrations of Northern Wolffish in the NL Region are found along the slope of the northern Grand Banks to the outer edge of the Labrador Shelf. Overall, Northern Wolffish distribution appears to be mainly influenced by water temperature (preferably 1.6–4°C; DFO 2010). Northern Wolffish mainly consume jellyfish and comb-jellies (sea gooseberries), pelagic fishes, shrimp, and occasionally echinoderms (Simpson et al. 2013). There are no directed fisheries for Northern Wolffish; however, it is a common bycatch species in numerous other North Atlantic fisheries (Simpson and Kulka 2002), which makes it vulnerable to human exploitation. The Arctic Ocean/Atlantic Ocean designatable unit of Northern Wolffish is listed as Threatened under Canada's *SARA*. Changes in Northern Wolffish biomass are monitored by DFO using RV trawl surveys, which have been conducted in NAFO Subdivision 3Ps, and cover a large portion of this species' Canadian range in the NL Region. In NAFO Subdivision 3Ps, Northern Wolffish biomass has been stable at very low densities along

the deep edges of the banks (Figure 11, Figure 12). In more northern areas, the biomass of Northern Wolffish has also been relatively stable since 1995 with the exception of NAFO Divisions 2J3KL, where the Fall survey index has detected significant increases since 2004 (DFO 2024).

Leatherback Sea Turtles

Leatherback Sea Turtles are the largest living sea turtle species, reaching weights of 900 kg and lengths up to 2 m. Leatherback Sea Turtles in Atlantic Canada belong to the Northwest Atlantic subpopulation. In 2017, this population was re-listed under Canada's *SARA* as Endangered (Atlantic Leatherback Turtle Recovery Team 2006), characterized by decreasing abundance (NMFS-USFWS 2013). The current recovery goal for the Northwest Atlantic Leatherback Sea Turtle population is a stable or increasing abundance trend.

Leatherback Sea Turtles migrate long distances between tropical nesting sites and temperate foraging habitats (Bailey et al. 2012). In the Northwest Atlantic, Leatherback Sea Turtles use Canadian waters seasonally in the summer and early fall months (James et al. 2007) to feed on gelatinous zooplankton (such as jellyfish and siphonophores), which are their main prey.

Leatherback Sea Turtles have important habitat areas (or broad areas of seasonal residency), and the amount of time spent in them is positively correlated with foraging habitat quality. Features of good foraging habitat include high seasonal primary production, upwelling, retention areas and oceanographic frontal systems (Mosnier et al. 2019; DFO 2020a) - all variables which influence the availability of food resources. It is difficult to delineate Leatherback Sea Turtle habitat, whether migratory or foraging-related, due to large inter-individual variability with respect to migration routes and feeding concentrations (e.g., Eckert 2006). This variability in habitat use also makes it difficult to determine population size as well. A recent habitat modelling study by DFO, using both opportunistic sightings and systematic aerial survey data, (Mosnier et al. 2019) revealed a progressive shift, from south to north, of the concentration of Leatherback Sea Turtles in Atlantic Canada, with them appearing first south and west of the Scotian Shelf in June, then off southern Newfoundland in August to September (Figure 13). Predicted probability of occurrence reached a minimum value in October, after which the probability of sighting a Leatherback Sea Turtle became zero. This model identified 15°C as a sea surface temperature (SST) threshold for the potential occurrence of Leatherback Sea Turtles, and within regions meeting this criterion, Leatherback Sea Turtles are likely to aggregate to forage in areas of highest jellyfish density (e.g., Houghton et al. 2006).

Throughout their range, Leatherback Sea Turtles encounter a variety of natural and anthropogenic stressors (see DFO 2020b), with incidental fishery interactions (which can result in entanglement) identified as a leading cause of mortality for this species in Atlantic Canada. Vessel encounters, during which vessels can strike Leatherback Sea Turtles that are at or near the sea surface, are also known to cause injury or mortality.

In addition to these direct stressors, in Atlantic Canada Leatherback Sea Turtles are subject to processes that could affect the availability of their prey. Climate change impacts the distribution and seasonality of planktonic organisms, including the jellyfish upon which Leatherback Sea Turtles feed (e.g., Purcell 2005; Smith et al. 2016). If Leatherback Sea Turtle foraging habitat expands or shifts northward due to climate change, we could expect an increase in residency times at higher latitudes (see McMahon & Hays 2006) and in places such as the Laurentian Channel; such a change could expose these turtles to higher levels of risk from stressors such as bycatch in areas outside the MPA.

Marine pollution in the form of oil spills, contaminants, marine debris, or agricultural runoff can negatively impact the prey of Leatherback Sea Turtles (DFO 2020b; Blais and Wells 2022). It is

likely that jellyfish and oil concentrate in convergence zones, where Leatherback Sea Turtles preferentially feed, potentially leading to physiological impacts.

A jellyfish fishery, such as has been trialed previously in northern Newfoundland, and particularly one operating in Leatherback Sea Turtle high use areas, could diminish the available food supply and threaten the quality of foraging habitat. Finally, although less understood, underwater noise from sources such as seismic exploration or large vessel traffic could displace Leatherback Sea Turtles from their preferred habitat.

The Laurentian Channel is important for the Leatherback Sea Turtle as it is a known feeding area and transit zone for this species. Given that southern Newfoundland represents the main and current northern edge of this turtle's foraging range in the Northwest Atlantic, abundance and residence times in this area could be important indicators for this species as climate change affects the distribution and abundance of their gelatinous prey. This area represents an important last feeding area that the Leatherback Sea Turtles occupy before they head back to southern latitudes to breed (James et al. 2007).

In addition to being an important location where Leatherback Sea Turtles obtain the energy stores for their southward migration and breeding, the Laurentian Channel and nearby areas also represent an area of risk exposure, to stressors such as underwater noise, vessel strikes, and oil spills such as from bilges, for these turtles in Canadian waters.

SCIENTIFIC MONITORING APPROACH

DFO-NL Region initiated a regional working group to develop a monitoring program for NL MPAs and MRs, which includes the development of a scientific monitoring approach for the Laurentian Channel MPA. The NL Monitoring Working Group ('NL Monitoring WG') consists of members from DFO-NL's Science, Marine Planning and Conservation, and Resource Management Branches as well as the Marine Institute, as part of an ongoing collaborative project for monitoring marine conservation areas in the NL region. The NL Monitoring WG has been identifying suitable surveys and indicators for each of the conservation areas since September 2021.

One of the first steps taken by the NL Monitoring WG was the development of a detailed list of potential indicators and survey types by CO within each of the NL Region MPAs and MRs, including considerations about timing and frequency of surveys per site. Applying the same overall monitoring approach in several of the conservation areas (MPAs and MRs) will allow for more consistent, comparable data collection across the region, and is the most efficient way to test survey methods and strategies, invest in capacity, and implement the program regionally.

The approach agreed upon by the NL Monitoring WG described here will be applied to all NL Region MPAs and MRs, excluding those with well-established monitoring programs (i.e., Gilbert Bay MPA and Eastport MPA). While the approach will be consistent across areas, several of its elements will be specific to the conservation areas and their COs. The approach is described below as follows:

1. Core Monitoring,
2. Targeted Research, and
3. Complementary Monitoring.

Core Monitoring will focus on efficient and co-located sampling of several key indicators, which can be done annually in all, or most areas. A high sampling frequency will be important, particularly in the first years of the monitoring program's establishment, and may be adjusted as

the program develops. Core Monitoring will aim to use techniques that are minimally or non-invasive, provide cost-effective data collection on most or all COs, and be comparable across conservation areas, generating a long-term regional dataset. Core Monitoring will include operations such as Conductivity, Temperature, and Depth (CTD) casts (i.e., oceanographic data), water sampling (e.g., for collection of samples for environmental deoxyribonucleic acid (eDNA) and physico-chemical parameters), camera systems (e.g., drop cameras), and moorings. The complete list of survey types to be completed is still under discussion within the NL Monitoring WG. Core Monitoring sites might include stations along lines crossing the MPA, such as those described in Site Selection Methods, or be chosen randomly as required (e.g., opportunistic sampling). The protocols will be standardized to facilitate comparison and collaborations with monitoring partners (e.g., Marine Institute).

Targeted Research will include shorter term, research-oriented programs, aiming to gather more detailed information on the COs/priority species, to test equipment and methods (field testing), improve rigor or understanding of the assumptions of the monitoring program, as well as to collect additional information to understand observed trends. Studies aiming to improve/add to monitoring design should be planned and conducted as soon as possible.

The last part of the approach will focus on utilizing complementary data (Complementary Monitoring) from varied sources, whose surveys have not been specifically designed as part of the monitoring program (e.g., Atlantic Zone Monitoring Program (AZMP), RV trawl surveys, satellite imagery, At-Sea Observers, etc.) but which have been and/or will be continuing to collect data in the MPA. These data can be used to complement and/or assist the interpretation of data collected as part of the Targeted Research and Core Monitoring. There may be limitations to how these datasets can be applied together to inform monitoring, as multiple sampling tools and spatial scales (i.e., the footprint of each sample, coverage across the MPA, and co-location) can be challenging to integrate.

Table 1 shows a proposed timeline for monitoring activities in the Laurentian Channel MPA by survey method for 2022–26, and provides a good starting point for discussion. The table includes survey methods and protocols described in Survey Methods and Strategies and are categorized based on the approach described above. In addition to the proposed annual Core Monitoring, Complementary Monitoring is, in most cases, carried out annually (e.g., DFO RV trawl surveys, AZMP, At-Sea Observers), whereas Targeted Research will likely be conducted at longer time intervals (e.g., 2–5 years for an ROV survey, but shorter and more immediate for testing equipment and methods), or they might be intensive surveys for only a few years at a time (e.g., satellite tagging/telemetry surveys) (Table 1). The table also provides information on the platform used to carry out the surveys. For example, rather than relying on ship time with Canadian Coast Guard vessels, chartered vessels may be used to carry out much of the work including camera deployments, water (eDNA) and sediment sampling (see Table 1).

While described here as three separate data streams, data collection from each will likely overlap or occur coincidentally in some cases. This program will be evaluated and adjusted as necessary after the first few years. The scientific monitoring approach described in this document focuses on four main elements:

1. reference sites,
2. survey methods and strategies,
3. indicators, and
4. study design.

The next sections will describe each of these four elements, with a focus on the Laurentian Channel MPA.

ELEMENTS OF THE MONITORING APPROACH

The proposed monitoring approach for the Laurentian Channel MPA aims to collect data on which to assess and interpret the status and trends of the CO priority species. While a significant component of the program will target data on priority species, information on important environmental drivers such as temperature, salinity, and productivity will also be included where feasible as these data will be useful to interpret the status and trends of COs. As indicated in Lewis et al. (2016), there are several data gaps in the Laurentian Channel and addressing some of these with Targeted Research or baseline data collection will be necessary prior to committing to a final set of long-term monitoring protocols.

The framework for the identification of monitoring indicators, protocols, and strategies developed by Lewis et al. (2016) was used as the basis for selecting appropriate scientific monitoring indicators and survey methods for the six COs. Another guidance document, more specific to monitoring corals and sponges, provides much of the basis for indicators and surveys for the sea pens CO (DFO 2021a). Using these documents as a starting point, several discussions with subject matter experts were carried out, as part of NL Monitoring WG meetings, to determine the most appropriate, or effective, indicators and survey methods that could be used over the next few years of the monitoring program. Each CO/priority species was investigated, and the most relevant monitoring indicators were identified. Survey methods and strategies were also proposed for each indicator. Details on other survey considerations including suggested frequency and/or seasonality of the survey, as well as any caveats or additional details were discussed and recorded as part of these discussions.

The long-term regional monitoring approach will take time to establish. The initial years will be focused on testing proposed survey methods and strategies, gathering baseline data, and investigating the appropriateness of the pre-selected indicators to monitor status and trends of the priority species and biodiversity. Therefore the NL Monitoring WG will continue to evaluate and refine these elements, as necessary.

Reference Sites

Evaluating effectiveness is an important part of MPA management since it can inform adjustments to management approaches. Effectiveness is often measured by making comparisons to reference sites that lack the benefit of MPA protection, as these locations allow managers to isolate the effects of MPA protection from broader regional trends or natural variability. However, finding inside-outside reference sites for large-scale, complex ecosystems is difficult and imperfect in the best of circumstances (Underwood 1992), since, unlike laboratory environments, confounding factors are prevalent in field conditions (Fraschetti et al. 2002). In the case of the Laurentian Channel MPA, these concerns are elevated since the MPA establishment process resulted in a protected area that was not easily comparable to adjacent habitats. Specifically, the original area targeted for protection was characterized by large swaths of habitat that were largely unfished (Muntoni et al. 2019). Prior to finalizing the MPA boundaries, a cost-benefit analysis was used to further reduce impacts to harvesters by removing the few areas that were frequently fished (Government of Canada 2019b). The MPA now represents an area that is uniquely characterized by historically low levels of exposure to fishing stressors such as bottom trawling. While this means that the Laurentian Channel MPA represents a relatively intact ecosystem compared to surrounding areas, particularly for fauna sensitive to fishing impacts (e.g., sea pens), finding appropriate inside-outside reference sites, as was requested in the stated objectives for this CSAS process, is inherently challenging

(DFO 2015; Stanley et al. 2015). Therefore, assessing MPA effectiveness within a formal hypothesis testing framework will likely be very difficult to achieve for this area.

Another difficulty in identifying reference sites for the Laurentian Channel MPA is that two of the priority species of conservation interest in the MPA, the Leatherback Sea Turtle and the Porbeagle Shark, are highly migratory and do not reside solely within the MPA. Therefore, creating reference sites for these two species may not be possible and it may be difficult to detect noticeable changes in what is a relatively small portion of these species' ranges (Lewis et al. 2016). The design and monitoring of an MPA must consider the movement patterns of important species. The adult home range or 'neighborhood' of a species can vary greatly, leading to gaps in protection (Stanley et al. 2015). Therefore, it may be difficult to detect changes in measures of these highly migratory species, and it may take an extended period of time in order to see a detectable signal of the 'promotion of the survival and recovery' of them (James et al. 2005). In these two cases, any declines in the population over time cannot be fully attributed to the failure of the MPA to meet its objectives as, either the species spends a significant amount of its life outside the protection of the MPA, or there may be interannual variation in their occupancy of the Laurentian Channel MPA. For example, Leatherback Sea Turtles have been found to transit through the Laurentian Channel MPA, based on satellite data (DFO 2020a), but are rarely documented inside. The selection methods used for other monitoring sites for collecting information on the other monitoring indicators are discussed below.

Site Selection Methods

The Terms of Reference for this CSAS process requested the identification of reference sites where possible. Given the circumstances described above, our approach focused more heavily on identifying potential monitoring sites to monitor trends within the MPA, rather than inside-outside reference sites. If questions regarding inside-outside comparisons are made, a small selection of paired sites were chosen for future Targeted Research. This approach makes more resources available to improve precision on estimates of the priority species' status and trends. Nevertheless, data collection at outside sites, where feasible, can be useful to provide baseline information for future Targeted Research studies and context, should broad-scale changes affect the ecosystem. For example, RV trawl survey data outside the MPA will continue to be collected as part of a long time series of multispecies data (e.g., Complementary Monitoring) and will be useful for providing context on regional trends of some priority species. We therefore identify monitoring sites for Core Monitoring within the MPA (method 1), areas of comparable environmental conditions outside the MPA delineated with unsupervised habitat mapping (method 2) and strata-based community analysis (method 3).

Method 1 - Core Monitoring Areas within the MPA

Method 1 provides fixed stations for Core Monitoring within the MPA. The Core Monitoring program aims to be cost-effective, co-located, and representative of habitats within the MPA. The selection of monitoring areas considered the following main criteria as a first step:

- include different areas of the MPA representing available bottom types and benthoscapes (Figure 14; Lacharité et al. 2020). Although benthoscape transitions are gradual and their true boundaries not fixed by a polygon, they were produced using diverse types of data (e.g., multibeam, seafloor imagery, sediment samples) and by covering different benthoscapes we are likely to cover a wide range of habitats.
- include representative depths: within the MPA, depths range between 116–491 m, with most of the variation being northeast to southwest (shallower to deeper). Areas <150 m are concentrated along a thin sleeve on the eastern side of the MPA, outside of the large sea

pen Significant Benthic Area (SiBA), and the large majority (69%) of the MPA is deeper than 400 m (Figure 14). Therefore, monitoring sites should include stations both at the western and eastern sides of the MPA to account for the variability in depth.

- include sites within the sea pen SiBA polygons: sea pen SiBAs are, by definition, areas of high sea pen concentrations. Given that the protection of sea pens is one of the COs of this MPA, sufficient stations within the SiBAs are needed to support interpretation of the status of the MPAs sea pens.

In addition to the above criteria, survey efficiency/feasibility was considered to optimize survey time (e.g., time spent collecting data) and cost. Given the large size of the Laurentian Channel MPA (~300 km from north to south), travel time between stations might be considerable, which could be better invested in collecting data. For context, if a vessel is travelling at a speed of eight knots (depending on vessel), it could take ~20 hours to travel across the entire MPA.

Based on the above considerations, we propose four main sets of stations along four lines crossing the MPA from west to east. These monitoring stations cover different depths and represent six of the eight benthoscapes. The proposed four lines across the MPA are equally spaced 60 km from one another (Figure 15), with an estimated distance of ~35 km (19 nautical miles) between the first and last stations in a line. This design allows for sampling the benthoscapes that cover the majority of the MPA, however, benthoscapes in the northern part of the MPA (C1 and B1) will not have any Core Monitoring stations.

- Line 1 would be the northernmost line, outside of the sea pen SiBA, crossing benthoscape A1 (predominantly mud) and some of TZ1 (mixed sediment). Depth is very consistent for most of this line (440–460 m), but it reaches 350 m at the eastern side of the MPA.
- Line 2 is inside the large sea pen SiBA, and crosses four different benthoscapes including the two in line 1, but also TZ2 (fine sediment) and A2 (mixed sediment) not covered in line 1. This line crosses depths of 250–450 m (east-west).
- Line 3 is also inside the large sea pen SiBA, and crosses four different benthoscapes including A2 and TZ1, but also C2 (sandy mud) and a little bit of B2 (muddy, gravelly sand), not covered in the previous lines. This line crosses depths of 250–450 m (east-west).
- Line 4 is partially inside the large sea pen SiBA, and crosses the same benthoscapes as line 3, except for B2. This line would also have stations close to an AZMP mooring deployed at this site (see also section Oceanographic Data). This line crosses depths of 280–430 m.

The final number of stations per line, number of seafloor imagery transects per station, their length, and the method (e.g., photos/videos) have not yet been determined. However, the power analysis conducted by Morris et al. (2024) using data on transects ~1 km in length indicates that at least 30 transects (for the whole MPA) may be required to detect changes in sea pen abundance (see further discussion in section Sea Pens and Other Benthic/Habitat Surveys). Therefore, for this exercise we illustrate the time budget needed to collect imagery for sea pens using survey lines with eight equally spaced stations per line.

Travel time between lines 1 and 4 is estimated at 12 hours (at a speed of eight knots), and travel time between two neighboring lines is estimated at four hours. If a total of two hours is spent at each station within a line, and assuming a total of eight transects per line and 32 transects per survey, that would require a minimum of 16 operational hours per line, plus transit time between stations. This could mean that a minimum of ~100 hours (roughly 4.5 days, assuming 24 hour operations) of ship-time would be required (plus travel to and from MPA) to carry out this survey. For the purposes of this example, this does not include time needed to conduct other Core Monitoring program activities or contingency time related to bad weather,

which would also need to be considered. While these preliminary numbers likely represent a reasonable approach, if the four lines cannot be surveyed in the same year, the possibility of alternating lines/years could be considered. Since statistical power remains unknown for other Core Monitoring methods, we propose that they should be co-located with sea pen sampling. However, once preliminary data allows for power analysis, sample allocations for other methods can be refined.

While we refrained from identifying inside-outside reference sites as part of the Core Monitoring of this MPA, we recognize that small pockets of historical fishing activity can be identified inside the MPA compared to outside areas. It is possible that we might expect to see recovery of sessile CO taxa like sea pens in some of these areas. Therefore, in addition to the Core Monitoring lines, we suggest the creation of inside-outside reference stations, which would be sampled as part of Targeted Research. This would require further discussion and planning (outside the scope of this document) and would not be considered as Core Monitoring stations, for reasons described in the previous section. Areas with some fishing effort are mostly concentrated along the eastern and western edges of the MPA boundaries (Figure 15). These reference stations would include paired inside-outside stations, both of which have experienced comparable levels of commercial fishing prior to the establishment of the Laurentian Channel MPA (Figure 15).

We also suggest that all areas selected for monitoring sea pens in the MPA have a buffered exclusion zone around them to avoid impacts from bottom-contact scientific surveys that could influence sea pen metrics. For instance, the DFO RV trawl surveys will continue to take place inside the MPA boundaries (DFO 2022b), and bottom trawling directly in areas being monitored specifically for sea pens will influence sea pen metrics. Bottom trawling near these areas could also influence the health of sea pen populations being monitored (e.g., due to creation of sediment plumes), but there have been no studies to confirm this yet. While DFO RV trawl survey set locations are random-stratified, the selection of alternate sets falling outside of the monitoring buffer is strongly recommended. Alternatively, the assessment of alternate set locations could be considered during the activity plan approval process, which is carried out each year. Finally, line names used here are only for discussion and should not be interpreted as final names, which will be defined at a later time.

Method 2 - Unsupervised Habitat Mapping

Habitat mapping (HM) with abiotic variables was initially carried out to identify areas within NAFO Divisions 3P and 3O (HM study area; Figure 16**Error! Reference source not found.**) with similar environmental conditions that could be used to identify potential reference sites. While inside-outside reference sites may not be used in the Core Monitoring program of the Laurentian Channel MPA, defining areas of comparable environmental conditions may potentially be of value for Targeted Research to help understand regional trends in indicators.

Habitats within the HM study area were characterized using a dimensionality reduction approach (e.g., Principal Component Analysis [PCA]) followed by an unsupervised cluster analysis using the methods described in Van Audenhaege et al. (2021). Eleven abiotic variables (Table 2) were used to broadly characterize habitats within the study area describing the bathymetry, seabed terrain, commercial fishing effort (proxy for habitat disturbance/intactness), surface and bottom temperature, salinity, and current velocity. Prior to all analyses, the input variables were resampled (i.e., layers were aggregated using the mean value of original input cells) to the same spatial resolution based on the coarsest resolution of the original layers (i.e., 8.7 km).

Principal Component Analysis

Principal Component Analysis is a dimensionality reduction technique that transforms a set of potentially correlated variables into a smaller set of independent variables while retaining the variance between observations. A PCA was run on the selected abiotic variables, reducing the multicollinearity between them through the computation of Principal Components (PCs). The PCA was run in R (v. 4.0.2) using the *prcomp* function with variables centered and scaled to have a mean of zero and a unit-variance. This scaling prior to analysis gives equal weight to variables measured on different scales (e.g., bathymetry vs. fishing effort). In PCA, most of the variance in the input data can be explained by the first few PCs after which the additional variance explained diminishes with each additional PC. To determine the number of PCs to retain for further analysis, we used the Kaiser-Guttman criterion (Legendre 2018) which suggests the retention of PCs with an eigenvalue >1 (see Table 3 for PCA results). A varimax rotation was performed on retained PCs. Varimax rotation maximizes the sum of the variance of the squared loadings through an orthogonal rotation of the axes. This results in absolute factor weights that are close to zero or one, increasing the interpretability of the factor loadings associated with each PC. The rotated components (RCs; Table 4) were used as the input variables for the k-means clustering analysis.

Following the PCA, four principal components were retained explaining a total of 66.3% of the variance. Factor loadings were used to determine which variables are most strongly associated with each RC. Factor loadings are correlations (positive or negative) of the variables with each RC where higher absolute values indicate a stronger correlation. While some variables had high correlations with multiple RCs, bathymetry, northness, slope, salinity, and surface temperature were most highly correlated with RC1, eastward current velocity and bottom temperature with RC2, eastness and fishing effort with RC3, and Relative Deviation from Mean Value (RDMV) and northward current velocity with RC4 (Table 5).

K-means Clustering

K-means is an iterative algorithm that classifies the input observations into an optimal number of clusters while maximizing the variation between clusters and minimizing the variation within clusters. To perform k-means clustering, an optimal number of clusters must first be determined for the classification. Two common methods used to determine the number of clusters (k) are the elbow method and the Caliński-Harabasz (CH) index. For both methods, k-means clustering was used to classify the data for a range of values of k (2–15). For the elbow method the within-cluster sum of squares (WSS) is plotted against the number of clusters and the optimal number of clusters is identified by locating a sharp bend or “elbow” in the curve (Legendre 2018). Beyond this number of clusters, there are small decreases in the WSS. The CH index is a ratio of the sum of the inter-cluster dispersion and the sum on the intra-cluster dispersion for clusters across all values of k (Caliński and Harabasz 1974). The optimal number of clusters is selected by identifying the value of k with the greatest CH index. K-means clustering was run on the RCs with the number of clusters (k) set to the optimal number of clusters identified by the above indicators. Both the elbow method and the CH index indicated that the optimal number of clusters for the k-means clustering analysis was five (Figure 17). The distribution of values for each variable across the five clusters is presented as a series of boxplots (Figure 18). These demonstrate the similarities and differences in the abiotic conditions between clusters.

The resulting clusters were plotted by abiotic variable to visualize differences in environmental conditions between clusters and to visualize where the different clusters are located within the study area (Figure 16). Plotting these clusters spatially indicates that much of the area within the Laurentian Channel MPA boundary belongs to Cluster 2. Cluster 2 is characterized by a mean depth of 280 m, slope of 0.4 degrees, salinity of 34.4 psu, surface temperature of 2.2°C, and

bottom temperature of 5.4°C (relatively high compared to other clusters; Table 5). The mean RDMV is close to zero indicating few peaks or pits in the topography within the area and the cluster is generally south-west facing (northness value of -0.39 and an eastness value of -0.53). In addition to the Laurentian Channel, Burgeo Bank, Hermitage Channel, and the south-west edge of the Grand Banks are assigned to Cluster 2 and likely share similar environmental conditions. These results show similar patterns to those in a larger-scale modelling of demersal and benthic invertebrate assemblage analysis done by O'Brien et al. (2022). A potential next-step for this analysis could look for clusters within the MPA boundaries to detect any within-site variation.

Method 3 - Strata-based Community Analysis

Identifying reference sites using a strata-based community analysis of DFO RV trawl survey data can be useful for comparative baseline information and to understand larger ecosystem level changes. In fact, strata-based community analysis has been used to assist the selection of reference sites elsewhere (Shackell et al. 2021). For instance, these authors selected reference sites based on comparable community dominance structures, species biomass, and depth profiles. To examine community structure in and around the Laurentian Channel MPA, our approach focuses on fish functional groups, which are based on the species general size characteristics and known feeding habits (M. Koen-Alonso, DFO-NL, pers. comm.). For a complete list of species considered in each functional group, see Appendix A:

- Small benthivores – small fish (maximum mean size <45 cm) that feed primarily on benthic organisms
- Medium benthivores – medium sized fish (maximum mean size >45 cm and <80 cm) that feed primarily on benthic organisms
- Large benthivores – large fish (maximum mean size >80 cm) that feed primarily on benthic organisms
- Piscivores (fish that primarily feed on other fish)
- Plankpiscivores (planktivores/piscivores, fish that feed on both plankton and fish or primarily on plankton during early life stages and fish during later stages)
- Planktivores (fish that feed primarily on plankton)

The DFO multispecies survey uses a stratified random survey design and occurs every spring (April-June) in NAFO Divisions 3LNOPs (Figure 1). The strata are used here to group similar depth profiles. For this analysis, only survey sets from Subdivisions 3Ps and Division 3O were used to limit the extent of the study area and only five years of data were included (2015–19) to reduce the number of data points (maximum of n = 1,070). Survey sets that did not include any species from the functional group were removed from the analysis. An additional grouping for all species was included to provide a single holistic analysis and to ensure all species were represented. Biomass (kg/tow), standardized for tow length, for each set was square root transformed to help balance out the dominant species. Communities among trawl sets were compared using a Bray-Curtis similarity index. The volume of data was further reduced by generating a single centroid, a measure of central tendency in multivariate space, for each stratum rather than including all data points. In addition, strata that crossed the boundary of the MPA were split into two parts and a centroid was calculated for each portion. Each group was then evaluated using cluster analysis (Figure 19A to Figure 25A) in PRIMER v7. Based on the cluster analysis, groupings of strata with a dissimilarity value of 50 or greater were used to identify unique 'clusters' of similar functional group community structure (Figure 19B to Figure 25B).

With all species included in the analysis, the Laurentian Channel MPA falls into Community Cluster 3 (Figure 19B). Areas with similar community structure include Hermitage Channel, north of the MPA, and areas along the edge of the shelf to the southeast at similar depths. These areas align closely with those in the unsupervised habitat analysis results (Figure 16).

There were only two clusters for the large benthivore functional group (Figure 20B). These two clusters appear to be driven by water depth, where Community Cluster 1 consists of shallow bank areas and All Species Cluster 2 consists of shelf edge or channel habitat.

The medium benthivore analysis resulted in the most clusters (7) of all the species groupings (Figure 21B. Even so, the cluster that contains the Laurentian Channel MPA is similar to other fish functional groups where the Hermitage Channel and areas of similar bathymetry along the southwest slope of the Grand Banks are similar in community structure. Medium Benthivore Clusters 1–3 are more similar compared to Clusters 4–7 as well.

The piscivore functional group was somewhat different with the northern half of the MPA having a different community structure than the southern half (Figure 22B). Of note here is that the southern cluster (Piscivore Cluster 2) has similar community structure to the same areas in the Hermitage Channel and along the southwest slope of the Grand Banks, similar to most of the other fish functional groups.

The planktivore clusters show a bit more differentiation on the shelf but once again, the MPA is similar to the southwest slope of the bank with the Hermitage Channel having insufficient data for that functional group (Figure 23B).

The plank-piscivore (Figure 24B) and small benthivore (Figure 25B) functional groups show similar patterns as well, with the MPA having similar community structure to the north (Hermitage Channel) and southeast along the shelf edge. However, the small benthivores show some differences along the shallow portion of the southwest slope of the Grand Bank when compared to the plank-piscivores.

Tracking trends in the community structure over time using this strata-based analysis is a good way to incorporate the RV trawl survey data into the monitoring approach and will provide useful context for understanding whether potential community shifts in the MPA are driven by larger-scale ecosystem processes. There is also the potential to use this methodology with lower dissimilarity values or at the scale of each strata to determine finer scale clusters or within site variation. Further discussion on the application of this method will be required before using in the scientific monitoring approach.

Survey Methods and Strategies

This section describes survey methods and strategies that are proposed for the Laurentian Channel MPA monitoring program. Table 1 identifies which part of the approach (Core and Complementary Monitoring, or Targeted Research) each survey belongs to. In some cases, a single survey may be used in multiple sampling approaches, as is indicated in the table (e.g., CTD casts are carried out as part of the AZMP survey [Complementary] and will likely be used as part of the Core Monitoring as well). It is broken down into different categories starting with the sea pens and other benthic surveys, moving onto emerging non-invasive techniques like eDNA, and baited underwater video. Next are other surveys that DFO carries out like aerial surveys for marine mammals, acoustic surveys, other tagging surveys, the DFO multispecies trawl survey, and oceanographic cruises as well as other data collection methods or non-DFO-NL surveys that may be leveraged for our monitoring purposes.

Sea Pens and Other Benthic/Habitat Surveys

Tools, techniques, and methodologies for the development of benthic surveys as part of the monitoring of corals in Canadian waters have been described in Neves et al. (2026) in detail (and references therein) as part of a national CSAS process on monitoring of corals and sponges in Canadian OECMs and will not be further detailed here. Instead, from that list we outline specific surveys considered suitable to study sea pens and benthic habitats in the Laurentian Channel MPA and nearby vicinities, which include seafloor imagery, acoustic, and sediment surveys. Tool selection for the completion of those surveys is described here as to provide options once indicator selection has been fully evaluated and finalized (i.e., feasibility of using certain indicators assessed). It should be noted that tools described for the survey of sea pens and benthic/habitat surveys can also be used to survey general benthic biodiversity.

Seafloor Imagery Surveys

Images of the seafloor can be used to collect data on sea pen metrics/indicators like numerical abundance, diversity, and potentially size structure (see section Indicators). Many modern camera systems allow for minimally invasive data collection, in comparison with bottom trawls, and are therefore a preferred method for the monitoring of sensitive habitats. Several seafloor imagery tools are available (Neves et al. 2026), but for a long-term monitoring program it will be important to consider factors that will allow consistent sampling within realistic resources (e.g., budget, human resources, equipment availability). Seafloor imagery data have been shown to yield more accurate abundance data for benthic taxa in comparison to bottom trawls (Ayma et al. 2016; Chimienti et al. 2018; de Mendonça and Metaxas 2021).

Types of deep-water seafloor imagery systems

Some of the most common seafloor imagery systems include drop cameras, towed cameras, and ROVs. Stationary systems such as baited cameras are not covered here because they are not ideal for surveying sea pens (see section Emerging non-invasive techniques to monitor ecological communities).

Drop-camera systems generally refer to systems composed of a camera(s) and lights mounted on a frame, which is tethered (Smith and Rumohr 2013). There are many different types of drop-cameras, with some collecting imagery while being suspended above the seafloor, and others touching the seafloor at multiple instances through a survey line. Some drop-camera systems allow for a real-time view of the seafloor, which allows for obstacle avoidance and more control of the survey, but many systems do not, as that increases their complexity and associated cost.

Towed camera systems are designed to collect continuous imagery throughout a survey (Smith and Rumohr 2013) as they are towed in contact with the seafloor or at a relatively consistent altitude above the seafloor during most of their deployment. Tow cameras are generally designed to collect imagery with a live view of the seafloor, which is crucial, given their frequent contact with the seafloor. Some systems might represent a blend of drop and tow camera systems, depending on the desired survey type.

ROVs are the most complex of these systems, as they tend to be large and require more specialized expertise to deploy and maintain. They tend to be more costly to deploy and require larger vessels than most drop/tow camera systems. But as described in the following subsections, the system selected for the collection of seafloor imagery in this MPA will need to consider several factors including, but not limited to, vessel fitting and availability, system availability, survey objectives and design, budget to acquire, deploy, and maintain, human resources and budget for field work, and data analysis.

Seafloor imagery in the Laurentian Channel

In past years, seafloor images have been collected in the Laurentian Channel MPA using different imagery systems. In 2014, McGregor GeoScience Limited was contracted by DFO to conduct seafloor imagery surveys at 40 locations of the Laurentian Channel MPA. Transects were 200–500 m long and collected between 40–60 georeferenced images. The system was a custom-made drop-camera providing real-time observations of the seafloor. There were challenges with image quality, mostly a result of high sediment turbidity in the water column (although issues with focus were also identified). These images were used for the identification of benthoscapes at the MPA (Lacharité et al. 2020). In 2015, the 4KCam and DEEPImager (Geological Survey of Canada) systems were used during an expedition co-led by DFO-NL and DFO-Maritimes Region, with the 4KCam system yielding considerably better-quality images in comparison to the 2014 imagery. Data from downward-looking images collected using the 4KCam were used in the sea pen power analysis conducted by Morris et al. (2024). In 2017, the ROV ROPOS was used to collect high-resolution imagery using both downward and forward-looking cameras, as part of a joint expedition between DFO and the Canadian Healthy Oceans Network (CHONe 2). In 2018, the Bedford Institute of Oceanography (BIO) Campod camera system was used to collect high resolution downward-looking imagery in the area through periodic photo stills and continuous video. A total of 11 stations were covered that year, with transects varying between 1–2 km in length, mostly in duplicate or triplicate at each station. Both ROPOS and Campod transects (i.e., location, length) were planned and conducted as part of CHONe 2 graduate student projects, and their surveys were designed to answer specific research questions and therefore, may not be the most suitable for carrying out a long-term monitoring program.

The collection of seafloor imagery data as part of a monitoring plan in the Laurentian Channel MPA should consider the following:

Which type of system to select?

The choice of a camera system for the monitoring of the Laurentian Channel MPA (and likely other conservation areas in the NL Region) will ultimately depend on which system is the most cost-efficient (i.e., best monetary value and able to complete monitoring objectives). A few factors to be considered include minimal impact on the benthic habitat, depth (i.e., minimum of 600 m depth for the Laurentian Channel alone), type of bottom (flat vs. steep), requirements for precise position accuracy, and scale (e.g., lasers).

Many of the available systems touch the seafloor, but often leave a small footprint (e.g., the perimeter of the system's frame). The drop camera system used in 2015 (4KCam) for example, had a trigger weight that touched the seafloor, but the system itself does not. The Campod system used in 2018 is a relatively sophisticated system that provides real-time images of the seafloor during the survey. Campod touches the seafloor at specific intervals. A large ROV such as ROPOS does not touch the seafloor (unless the pilots are requested to land it, for sampling or safety reasons, for example), as its tether is fitted with floats. Touching the seafloor in an area such as the Laurentian Channel can also represent a disadvantage due to the stirring and resuspension of sediment that it might cause, hampering image quality (e.g., 2014 imagery). However, the 2015 and 2018 images collected using systems that partially touch the seafloor have shown to be acceptable.

High positional accuracy is important, particularly if fixed stations are selected. Both McGregor's system, 4KCam and Campod generate georeferenced still photos. Therefore, efforts should be made to acquire/use systems that can count on navigation tools that allow for high position accuracy. Position accuracy for ROPOS was estimated at ±1 m, while accuracy for Campod was estimated as ±10s of meters (de Mendonça and Metaxas 2021).

Laser pointers is another requirement for the camera system planned to be used in monitoring. The 4KCam system did not have laser pointers and the size of trigger weights was used to estimate image field of view. That obviously comes with loss in precision, and it increases the time required for image post-processing work. In addition, the use of forward-looking cameras should account for scaling that might go beyond the presence of laser pointers. For instance, it might be necessary to know the height of the camera and the angle of incidence with the seafloor in order to calculate field of view area from forward-looking/oblique cameras (Long et al. 2020).

While ROVs are generally the preferred tool to conduct benthic surveys in sensitive habitats, not all ROVs are the same and having access to high-quality, dependable ROVs like ROPOS might be too challenging and costly to consider their use as part of a long-term monitoring program. We believe that ROVs should continue to be used for Targeted Research and even as part of additional baseline data collection, which is still needed for sea pens in the Laurentian Channel MPA. Also, ROVs would still be required for specimen sampling, which cannot be done with drop-cameras. In addition, de Mendonça and Metaxas (2021) showed that Campod performed better than ROPOS at capturing abundance of sea pens and general epibenthic biodiversity in the Laurentian Channel MPA. Therefore, drop camera systems seem to be the most cost-effective tool for seafloor monitoring surveys in this MPA. Specifics of which drop-camera system to be used will also depend on multiple factors, some of which are discussed here.

Downward or forward-looking?

The scale of a camera survey is a crucial parameter to be considered. For instance, downward-*versus* forward-looking images will yield different data. Downward-looking camera images will generally focus on a much smaller field of view area than forward-looking images, but the level of detail that can be seen will be higher. While the collection of both downward and forward-looking images can be simultaneously obtained with certain camera systems, from a monitoring perspective it is unlikely that images from both cameras can be timely analyzed at the current scale of Canadian MPAs and OECMs. However, the difference in the scale might make it worthwhile to collect both sets of imagery, which can be analyzed on an “as needed” basis. Particularly as we conduct preliminary surveys to assess which type of system and resulting data might be more appropriate for this MPA. Downward-looking cameras might be more useful to detect sea pen juveniles, for example, which is of interest in this MPA. On the other hand, forward-looking cameras allow a better estimation of population density, as they provide a wider field of view and in some cases a better angle for identification.

Videos or still photos?

Some camera systems collect videos, still photos, or both. The possibility of having access to videos in addition to still photos allows for the advantages of both, as they provide opportunities to observe *in situ* behavior and provide different angles of the same organism. For instance, during the process of image annotation, annotators often refer to videos to look for a better focus or morphological structure not seen in a still photo. Megafauna richness estimated from tow-camera transects surveyed at the Banc-des-Américains MPA (managed by DFO-Quebec Region) was considerably different between photos and videos collected simultaneously, with photos tending to yield higher number of taxa (i.e., higher richness) than videos, although both equipment yielded taxa only observed in videos or photos. Most taxa were more diverse and frequent in the videos. However, this was not consistent across all taxa, with smaller organisms such as bivalves and ophiuroids tending to be better represented in photos (G. Faille, DFO-Quebec Region, pers. comm.). This highlights the importance of clearly stating the objectives of such surveys beforehand. If the objective is to examine general community trends, video might be the best choice, but if the objective is to survey smaller fauna or juveniles,

photos might be more appropriate. Collecting both videos and stills represents an advantage, therefore having access to a system that collects both should be considered.

When to sample and how often?

Seasonality of seafloor imagery surveys is generally less of a concern when planning the sampling of sessile/sedentary, relatively long-lived organisms such as sea pens (i.e., decades). However, in order to better take advantage of the data for multiple purposes, relatively consistent sampling in terms of seasonality might be the best approach. Furthermore, as discussed under Sediment surveys below, seasonality does matter for benthic infauna diversity assessments and it might matter for some epifauna, and hence general biodiversity patterns and trends. Similarly, phytoplankton and zooplankton biodiversity patterns are strongly seasonality-driven. Therefore, assuming that these surveys would take place concomitantly to take advantage of ship-time, seasonality should be considered in the monitoring design and plans.

How often to sample is a more complex question, because it is unknown how long it might take for changes in sea pen patterns to be observed in the Laurentian Channel MPA. Morris et al. (2024) were able to examine this question for the fish COs considered in their study because historical trawl data are available for those species. While there are some seafloor imagery data available for sea pens in the Laurentian Channel MPA, these data have a limited temporal coverage and were not collected consistently across years (e.g., different gear). Considering that sea pens are relatively long-lived organisms, we do not expect to detect annual changes in their associated indicators as a result of the protective measures (see section Indicators). Nonetheless, we suggest that seafloor imagery surveys meant to monitor sea pens and other benthic communities in the MPA take place annually for the next five years, as we collect enough data to evaluate power (see below) and re-evaluate this frequency.

Minimum number of samples

A power analysis of sea pen abundance data from Laurentian Channel MPA seafloor imagery was performed by Morris et al. (2024). The analysis considered data on downward-looking photos of the seafloor for 13 transects ~1 km in length, for a total of 30–60 photos per transect. We refer the reader to the Morris et al. (2024) document for details. In summary, these authors identified that based on those seafloor images, in order to detect a 50% decline in sea pen abundance 80% of the time, a minimum of 40 imagery transects with 40 photos per transect would be required. This result is further discussed under Sea Pens.

Protocols

Protocols for seafloor imagery surveys will need to be developed specific to the chosen equipment and area being surveyed. Field protocols, including factors such as survey speed, altitude (distance from the seafloor), logging information, etc. will need to be developed. In terms of imagery analysis, a detailed imagery annotation protocol is currently being finalized to facilitate and standardize seafloor imagery annotation (B. M. Neves, DFO-NL, pers. comm.). In addition, an *in situ* ID guide for the Laurentian Channel benthic/demersal fauna was recently published (Command et al. 2024). Given that camera systems are the preferred method to survey sea pens in the MPA, the number of seafloor images requiring analysis in the next few years is expected to escalate quickly. For instance, surveying 30 transects with 40 photos each will yield 1,200 photos per trip for the Laurentian Channel MPA only (i.e., MRs are also expected to rely on seafloor imagery). Therefore, we recommend the implementation of techniques that can reduce imagery annotation processing time and assist with standardization, such as artificial intelligence (AI) methods (Piechaud et al. 2019; Durden et al. 2021). DFO-NL Region Science recently signed a Memorandum of Understanding (MOU) with National

Research Council of Canada to develop, test, and run a deep learning model that can detect and identify epifauna morphospecies from underwater imagery. This model may allow for the standardized processing of video libraries in a fraction of the time it would take for the same type of work to be done manually. However, it is still in its early stages of development and considerable training/calibration is expected before implementation in this monitoring program can occur.

Summary on sea pens/benthic habitat surveys

Monitoring methodologies described above represent an array of possibilities. In practice, we must first test and compare different equipment and tools (de Mendonça and Metaxas 2021) to assess which are the most cost-effective, but also which yield the data that we need for monitoring purposes. For instance, we currently do not know whether downward- or forward-looking imagery will yield the best results, or which spatial scales are more relevant (i.e., field of view area, altitude, distance between transects). The analysis of data collected without a specific experimental design focused on monitoring is far from ideal, therefore planning field surveys that aim at answering design-specific questions is needed urgently.

DFO-NL Region Science has undertaken dialogue with other DFO regions to assess whether NL Region can mirror equipment already successfully used elsewhere. For instance, the drop-camera system utilized by DFO-Pacific Region for their benthic surveys (the Bathyal Ocean Observation and Televideo System [BOOTS]) has been used successfully in sensitive deep-water seamount environments and is a system that should be considered. Similarly, Campod and the 4KCam are promising tools used primarily by DFO-Maritimes Region that can yield high-quality imagery. A comparison of possible tools and a cost-benefit analysis is needed before equipment is acquired for the long-term monitoring program. These more complex systems are not off-the-shelf items, and their fabrication, calibration, and testing will require time. Equipment selection and acquisition should be as cost-effective as possible and should consider the purchase of components that can be updated and upgraded, so that surveys can be initiated without compromising consistency in data collection. Finally, given the large amount of imagery data collected, reliable and low-cost access to cloud storage and an effective data governance structure will be paramount for the success of this monitoring program.

Multibeam/Sidescan Sonar Surveys

Multibeam sonar data can be used as part of a benthic monitoring program, but in the case of the Laurentian Channel MPA where bottom type is dominated by soft substrate, it will likely not be used as part of Core Monitoring. Ship-based multibeam bathymetry and backscatter collection in the Laurentian Channel started in 2010, as part of habitat assessment surveys conducted by an external contractor requested by DFO. In 2012 and 2013, multibeam backscatter analyses were conducted by the same contractor, leading to the production of several map layers including the backscatter raster itself and derivatives of bathymetry (e.g., slope). In 2012 and 2013, two additional multibeam/sub-bottom profiler surveys took place in the MPA, for another 6,111 km^2 and 2,531 km^2 of surveyed areas, respectively.

Even though these data were collected using different platforms and sonars, they were successfully combined and reprocessed to a multibeam raster file with a spatial resolution of 50 x 50 m (Lacharité et al. 2020). These data were useful to generate benthoscapes of the Laurentian Channel MPA in combination with seafloor imagery, but they are not at a high enough resolution to determine the presence and distribution of individual sea pens or even areas of sea pen significant concentrations (e.g., sea pen fields). Therefore, the advantage of collecting additional multibeam data in the MPA is mostly for the possibility of collecting data at higher resolutions.

More recent technologies that can collect multibeam and side-scan sonar data at centimeter-scale resolutions, such as some AUV-based applications (Steele et al. 2019), might increase the range of parameters that can be obtained from the multibeam data. High-resolution multibeam and side-scan data are expected to contribute to the monitoring of sea pens and benthic habitats in the Laurentian MPA through, for example,

1. assessment of whether sea pen fields can be identified using acoustic data, in combination with previously collected seafloor video;
2. if 1) is possible, monitoring changes in sea pen patch size and distribution,
3. monitoring changes in the habitat, and
4. assessing whether there is indication of violations of the closure (Huvenne et al. 2016).

Sediment surveys

Sediment samples are often collected as part of benthic diversity assessments. Organisms living inside (infauna) and on the sediment surface (epifauna) can be used as indicators of biological change and have been used as such in several contexts (see Clarke et al. 2014a). In benthic ecology, organisms are often classified according to their sizes (i.e., retention in specific sieve apertures), and infaunal organisms are generally classified as macrofauna (>0.5 mm) or meiofauna (<0.5–0.042 mm) (Eleftheriou and Moore 2005). Recently, Miatta and Snelgrove (2022) showed that macrofauna community composition and biological trait expression was different in sea pen fields compared to bare sediment habitats in the Laurentian Channel MPA, although it is too soon to consider benthic biodiversity a direct indicator of sea pen dynamics therein. Nonetheless, benthic macrofauna/meiofauna assessments can contribute to our understanding of benthic dynamics and potential changes in biodiversity in the MPA and might be useful in the context of sea pen-sediment interactions.

Sediment samples have been collected in the Laurentian Channel during multiple surveys through the past years (2014, 2015, and 2018). In 2014 and 2015 sediment samples were collected by a contractor using a Double van Veen grab sampler (two standard areas of the seafloor, 0.1 m^2 each) at 36 stations as part of initial surveys at the MPA (AOI at the time). In 2015, samples were also collected as part of an expedition with DFO-Maritimes Region (van Veen, 4K, DeepImager). In 2018, a large van Veen (Natural Resources Canada's) was used to collect sediment at nine stations. Samples processed for benthic community structure analysis (2014, 2015, 2018) have been submitted for analysis to the Atlantic Reference Center (ARC, New Brunswick). The ARC currently holds a collection of macrofauna specimens (and their photographs) from the Laurentian Channel MPA.

The collection of sediment samples as part of a monitoring plan at the MPA should follow a careful design (Underwood and Chapman 2013), which include the following considerations:

Sampling method: which sediment sampler to use?

The International Organization for Standardization (ISO) standard 16665 (International Standard on guidelines for sampling and sample processing of soft bottom macrofauna) recommends the use of benthic grabs (e.g., van Veen) in benthic surveys up to 750 m deep. The ISO 5667-19:2004 (Guidance on sampling of marine sediments) is more specific about deep-water and offshore settings and recommends heavier gear such as box-corers in those environments. While a grab with a sampling area of 0.1 m^2 has been suggested for benthic fauna surveys (ISO 16665), it is our experience that a single 0.1 m^2 van Veen model might not be reliable enough for the collection of deep-water samples offshore. A double van Veen (twice 0.1 m^2 maximum penetration depth of 20 cm) has been successfully used in the Laurentian Channel MPA in previous expeditions and it has proven performance in 2000 m depth (e.g., Benthic Solutions

limited); therefore, we believe that this equipment might be well suited for work in the Laurentian Channel MPA and other Canadian MPAs and MRs. With a double van Veen, sediment from one of the grabs can be used for assessing infauna diversity, while the other grab can be used for collection of sediment for physico-chemical characterization. A double van Veen can weigh 200 kg in air, and deployment requires a vessel with an A-frame or crane with at least 2 m of clearance (Mcgregor GeoScience). Holte and Buhl-Mortensen (2020) compared the performance of two van Veen grabs of different sizes (0.1 m^2 and 0.25 m^2) and found that the grabs yield comparable results in terms of fauna composition, but that the small grab often had poor performance (i.e., samples rejected).

The International Seabed Authority (ISA) recommends the use of a box-corer for their benthic surveys, which generally occur in very deep water and might require heavier equipment (ISA 2002). A Usnel box-corer can sample an area of 0.25 m^2, with a penetration depth of up to 65 cm. A box-corer is also useful for non-biological studies, as it collects undisturbed sediment and preserves the sediment stratigraphy. Another advantage of using a box-corer is that it has been used for several studies across Canada (NAFO 2013; Nephin et al. 2014; Roy et al. 2015).

While consistency of equipment is relevant, even more critical is the use of comparable mesh sizes when sieving the sediment for biological characterization. For instance, while a mesh size of 0.5 mm has been commonly used for macrofauna, deep-sea organisms tend to be smaller and mesh sizes might need to be adjusted (Eleftheriou and Moore 2005). Miatta and Snelgrove (2022) used a mesh size of 0.42 mm for their macrofauna analysis of infauna in the Laurentian Channel, while samples previously collected using the van Veen grab in the MPA were sieved under a 0.5 mm mesh (Lacharité et al. 2020), which is one of the mesh sizes recommended by ISO standards. In the case of long-term monitoring, standardization is key, and the chosen mesh size should be used consistently.

Although macrofauna might be less challenging to process, the use of meiofauna samples might be of interest, as Rogers et al. (2008) found a stronger statistical power for meiofauna than for macrofauna samples in their study area (i.e., considerably less samples needed for meiofauna), which is further discussed below. The use of sediment eDNA to assess both meiofauna and macrofauna from a same sample should be considered as well.

Protocols

ISO protocols (e.g., 16665, 5667:19) outline strategies, sampling methods, and sample processing protocols as well as good practices for taxon determination and quantification, as well as quality assurance and quality control of sediment sampling. We recommend that any specific sediment sampling and processing protocols (i.e., Standard Operating Procedures [SOPs]) that are developed for monitoring the MPA should follow international standards such as the ISO described here. SOPs can also be inspired from previously used SOPs such as the one used for the collection of the 2014–15 samples, which has been made available to DFO-NL. Eleftheriou (2013) and Noble-James (2018) are also excellent resources to access when developing these regionally focused protocols.

Positioning accuracy

Most of the time, sediment samplers are not deployed with the aid of a positioning system, but they can be deployed with an acoustic instrument to provide precise seafloor position. This is useful for long-term sampling, as to provide a more precise location and information on distance between samples and replicates.

When to sample and how often?

As mentioned earlier, seasonality should also be considered when planning for the collection of sediment samples in the Laurentian Channel MPA, as Miatta and Snelgrove (2022) showed that seasonality influences macrofauna diversity metrics in the area.

As for sea pens, long-term temporal changes in infauna diversity patterns have not been assessed in the Laurentian Channel MPA. However, infaunal benthic communities are generally composed of short-lived organisms and communities can change quickly (e.g., months). If there are opportunities to conduct sediment sampling at the same or shorter intervals than those requested for seafloor imagery (e.g., as part of Targeted Research), there might be a benefit to build a good baseline and assess their utility to detect change in seasonal biodiversity patterns in the MPA.

Minimum number of samples

The minimum number of samples needed to detect change should be assessed through a power analysis (e.g., Morris et al. 2024). Failure to do so will likely compromise interpretations related to efficacy of the MPA. Rogers et al. (2008) performed a power analysis to investigate the minimum number of replicate sediment samples required to detect significant trends in several ecological components (e.g., benthic diversity metrics) 80% of the time (power of 0.8). They found that intensive replicate sampling would be required to detect changes, which varied across (i.e., meiofauna, macrofauna, megafauna) and within types of fauna (e.g., abundance versus diversity metrics). For instance, their analysis indicated that over 3,600 sediment grab samples per survey would be necessary to detect significant change in macroinfauna abundance, versus 904 samples for meiofauna. While in both cases the number of required samples is not realistic, the large differences in macrofauna vs. meiofauna should be noted. In addition, these authors found that when examining diversity indices instead (e.g., Pielou's index), the number of required samples for macrofauna and meiofauna analyses considerably decreased to 10–131 and 3–20 depending on the site, respectively.

The Rogers et al. (2008) study highlights the need to seriously assess the minimum number of samples required in a program to

1. assess the feasibility and cost-benefits of such a sampling program, and
2. to guide proper sampling design, including the choice of indicators.

It will be necessary to do further sediment sampling in the Laurentian Channel MPA with the power analysis question guiding the sampling strategy, so that a suitable sediment sampling program can be planned. Taxonomic identification and quantification of infauna samples (e.g., abundance and biomass) can be costly (hundreds of dollars per sample), and specific budgets will need to be allocated for that. The potential use of eDNA to assess infauna diversity has not been evaluated for the Laurentian Channel MPA, but it could be investigated as a potential method to be used in the future.

Emerging non-invasive techniques to monitor ecological communities

Technological advancements have provided promising new tools for monitoring marine biodiversity. Like more conventional approaches, the following methods have features that are attractive for use in conservation areas, despite some limitations.

Environmental DNA methods

Environmental DNA (eDNA) methods fall into two broad categories: methods that target specific taxa (quantitative polymerase chain reaction [qPCR] approaches) and those that sample a broad spectrum of the community (metabarcoding techniques). Both methods rely on collection

of DNA fragments that have been shed by animals into the environment (e.g., water column or sediment). The collections of eDNA can be done through water samples or sediment grabs, are non-lethal, and relatively unintrusive to sensitive habitats compared to many other methods (e.g., trawls) (Stoeckle et al. 2020; Valsecchi et al. 2021). This makes it relatively easy to collect along with other water samples for physical and biological oceanographic data (i.e., niskin bottles, rosettes). Moreover, the method can be applied across different habitat types, making it a strong candidate for comparison across protected areas. eDNA samples are typically filtered and preserved in the field and sent to a laboratory for analysis where targeted genetic material is isolated and replicated. For qPCR methods, only material from a target taxon is retained for analysis, whereas metabarcoding markers will retain genetic material from more broad taxonomic groups. Targeting of genetic material is accomplished using markers, which can cover very broad taxonomic groups or be more specialized for certain taxa. The resulting genetic material is sequenced and for metabarcoding, assigned to known taxa by matching the sequences to those in genetic databases. While qPCR is restricted to individual taxa, it has the advantage of being more amenable to estimating indices of abundance and has more accessible laboratory equipment requirements(i.e., generally less expensive). Metabarcoding has the advantage that it provides simultaneous data on a multitude of taxa and therefore a more holistic picture of the faunal community. While efforts are being made to incorporate estimates of abundance into metabarcoding (e.g., He et al. 2022), most practitioners restrict their analyses to presence-absence. Like many methods, the results obtained from eDNA approaches will depend on several factors, most notably marker selection, but also bioinformatic techniques, field protocols, etc. Therefore, using these approaches will require standardization to use successfully within a monitoring framework. The approach is also limited by the fact that no specimens are collected and therefore supplementary information that may be useful for interpretation (e.g., life stage, growth, biomass, etc.) would have to be collected with Complementary Monitoring. Finally, molecular databases such as GenBank are still lacking sequence information for many species, which in some cases can limit sequence matches to high taxonomic levels (e.g., family, order). On the other hand, sequence data can be reassessed once databases improve and generate higher resolution taxonomic information. Depending on the question being asked, estimation of biodiversity patterns at high taxonomic levels (if lower levels are not available) might be enough, but biological information will be more limited (e.g., functional traits). Nevertheless, such approaches have great promise as they can be collected in a variety of habitats, on various research platforms, and can provide information on a wide variety of taxa or whole communities. Research on the utility, cost-benefit, and development of protocols for using eDNA to assess biological communities in the Laurentian Channel MPA should be considered as part of a monitoring plan.

Baited Cameras

Baited camera systems can be used to monitor biological communities in the Laurentian Channel MPA. As with eDNA, baited cameras have minimal effects on habitat and can be deployed in a variety of environments (i.e., depths, substrates, etc.). Stationary cameras outfitted with lights are soaked for a variable number of hours, and videos are later used to observe fish and invertebrates that are attracted to bait (e.g., squid). Previous use of this method in the NL region shows a broad community of fish (including Laurentian Channel MPA CO taxa like Black Dogfish, Smooth Skate, and Northern Wolffish) to visit these systems. Given the reliance on bait, the species observed are biased to piscivores and scavengers, nevertheless these data have been useful for differentiating fish communities (Sutton et al. in

prep.[2]) and have potential to detect change in CO taxa in the Laurentian Channel MPA. Some previous limitations of baited cameras are being mitigated with technological advancements. For example, analyzing video data is time consuming – even for modest sample sizes, but new AI methods show great promise for reliable and standardized analysis (Morris et al. 2021). Similarly, deep water camera systems have traditionally been relatively expensive, limiting the sample sizes (and resulting statistical power) associated with this technique. But recent designs developed by DFO-NL have greatly reduced costs allowing cameras to be deployed on fleets of modified crab pots (Morris et al. 2021). Because baited camera videos have not been previously collected in the Laurentian Channel MPA, baseline data collection will be essential to assess their utility as part of the Core Monitoring program. Particularly if coupled with the automated video analyses, the approach has promise for ecological monitoring.

Underwater Vision Profiler

Similar to baited cameras, the Underwater Vision Profiler (UVP) uses advanced imaging systems in combination with machine learning to capture and classify images of fauna. Unlike baited cameras, the UVP targets zooplankton and is lowered through the water column taking 1,000s of photos as plankton pass through its sensors. The machine learning algorithms identify the plankton using established databases and provide taxa specific counts of various plankton by depth throughout the water column. Unlike conventional nets, the UVP can collect data on the full water column and identify important zones of productivity (Forest et al. 2012). The UVP can also be deployed on an oceanographic rosette and therefore can sample plankton communities while data are collected for other program objectives (e.g., eDNA, CTD casts, etc.). A disadvantage of the UVP compared to conventional nets is that the level of taxonomic identification is coarser (e.g., it can identify copepods, but not to species level). While plankton are not explicitly identified as a CO in Laurentian Channel MPA, their important role in the food web makes information on these taxa important to interpreting observed changes in CO taxa.

Aerial Surveys

A standard approach to study near-surface marine species, such as Leatherback Sea Turtles and endangered baleen whales, over large areas is aerial surveys. Between 2014 and 2021, DFO has conducted low-level aerial transects that includes flight lines that cross the Laurentian Channel MPA and adjacent areas (example of transects flown in and near the Laurentian Channel AOI in 2014 are shown in Figure 26; see Lewis et al. 2016). These surveys will continue for the foreseeable future as the Department continues its multispecies aerial monitoring of Atlantic Canada. The DeHavilland Twin Otter 300 aircraft was equipped with four large bubble windows at which trained DFO observers were stationed, with a fifth team member acting as data recorder and flight navigator. Sightings and meteorological data were recorded using specialized survey software, and subsequently analyzed using Distance sampling and geographic information system (GIS)-based habitat modelling techniques. All near-surface marine megafauna were recorded and included marine mammals, seabirds, large sharks, sea turtles, sunfish, and jellyfish swarms.

These surveys were minimally invasive as they invoked little or no reaction from animals near the trackline, and covered the large survey area in a short period of time. Limitations of the surveys include low transect coverage relative to the size of the study area, and speed of aircraft passage which would lead to underestimates of the presence of deep-diving cetaceans.

[2] Sutton, J., Côté, D., Fisher, J. A. D., and Priede, I. G. 2026. The Distribution of Atlantic Ocean Deep-Sea Demersal Fish Assemblages across Environmental Gradients. Deep-Sea Research. In Preparation

Acoustic and Satellite Tagging

Acoustic telemetry provides a method for tracking movement and behaviour in aquatic environments without recapture. More simply, telemetry is the automatic measurement and transmission of data. This research relies on a two-part system: small, animal-mounted transmitters that each emit a unique acoustic signal and a network of receivers that record the time and date when the tagged animal is within range. Additional sensors can be added to the transmitters to record environmental and biological data, including but not limited to depth, temperature, and/or predation events (Halfyard et al. 2017; Bangley et al. 2020). While there are no current plans to initiate targeted telemetry studies in the Laurentian Channel MPA, some suggested applications are described here for future consideration. Further discussion on the specific indicators to be measured and their value to the monitoring program will have to occur prior to initiation.

A comprehensive, overlapping acoustic receiver array for the entire 11,908 km^2 of the Laurentian Channel MPA would be prohibitively expensive to install and maintain. To mitigate cost and maintenance effort, Renshaw (2019) recommends a non-overlapping grid array, with receivers spaced up to 20 km apart. In the NL Region, ongoing DFO telemetry studies for cod and flatfish have opted for receiver gates targeting key habitats instead of a broad grid pattern. Depending on the specific goals of a potential Laurentian Channel MPA telemetry program, either of these approaches or a combination may be appropriate. Collaboration with neighbouring acoustic telemetry programs (e.g., DFO-NL, DFO-Maritimes, DFO-Gulf, Ocean Tracking Network) may also alleviate cost and better leverage investment in acoustic transmitter deployments.

Satellite-linked tags allow tracking of aquatic animals without requiring recapture or relying on detection range of moored receivers. For aquatic animals that surface frequently, like Leatherback Sea Turtles, satellite tagging can provide near-real time monitoring of movements and diving/feeding behaviour (Hoover et al. 2019). In addition to location, the sensors on these tags can include swim depth, speed, depth, salinity, and water temperature. Such tags have been applied to Leatherback Sea Turtles in Maritimes waters by DFO researchers for some time (e.g., James et al. 2005, 2007), and some of these tagged turtles have passed through the Laurentian Channel MPA. Alternately, pop-off satellite-linked archival tags can be used to record depth and temperature for species that do not spend time at the surface, such as sharks, in addition to the position on a scheduled pop-off date (Hussey et al. 2018; James et al. 2020).

MPAs are excellent candidates for acoustic and satellite tagging studies for some marine species. Movement across MPA boundaries, residency within or timing of migration through conservation areas are all important questions that are well served by installation of acoustic receivers and deployment of transmitters and/or satellite tags in key species of conservation concern (Crossin et al. 2017). For example, acoustic telemetry was used to measure MPA efficacy for conservation of turtle and shark species in the Seychelles, leading to recommendations on boundary adjustments that increased protection of the species movements by 34% (Lea et al. 2016). In cases where species of conservation concern have high site fidelity, telemetry can also be used to assess MPA efficacy by quantifying the proportion of important home-range habitat that falls within the protected area (Lippi et al. 2022).

The COs for the Laurentian Channel MPA include several species that are candidates for telemetry-based monitoring (Black Dogfish, Smooth Skate, Porbeagle Shark, and Northern Wolffish), in addition to several other species that may also derive benefit from the closed area (Renshaw 2019). Renshaw describes potential telemetry programs for monitoring elasmobranchs within the Laurentian Channel MPA. Additional biological sampling (e.g., weight, length, sex, genetic sampling) is easily incorporated into tagging efforts. For species like the

Black Dogfish and Porbeagle Sharks, reproductive monitoring, including ultrasound studies, non-lethal hormone sampling and/or intra-uterine satellite tags may help to determine reproductive status of tagged individuals and inform on use of the Laurentian Channel MPA for mating or nursery habitat (Penfold and Wyffels 2019).

Passive Acoustic Receivers

Passive acoustics instruments (e.g., hydrophones = underwater microphones) also have the potential to be used for the monitoring of indirect Biodiversity Conservation Benefits (BCBs). For instance, Archer et al. (2018) found that soundscapes in glass sponge reefs differ from soft sediment areas (non-reef) and identified fish sounds within the reef area. Furthermore, Lin et al. (2019) suggested that soundscapes might be important settlement cues for deep-sea benthic larvae (i.e., to detect their habitats). Therefore, the use of soundscapes has been argued as a potential new conservation tool, particularly useful in deep-sea habitats (Lin et al. 2019).

DFO has deployed autonomous, bottom-mounted acoustic recorders, in addition to directed underwater sound measurements, to address questions related to underwater soundscapes in areas of southern Newfoundland. The autonomous recorders (Autonomous Underwater Recorder for Acoustic Listening (AURALs), Autonomous Multichannel Acoustic Recorder (AMARs), and SoundTraps; Figure 27) can be deployed to the seafloor at locations as deep as the center of the Laurentian Channel MPA. They record sounds using a single hydrophone and store them digitally. The recorders are retrieved from the bottom after a period of months to a year, and the recorded sound files are downloaded. The three systems have different sampling rates, so sounds up to 256 kHz can be recorded by the AMARs and SoundTraps, where a lower frequency capability of 16 kHz is provided by the AURAL recorders. DFO uses automated software (Low-Frequency Detection and Classification System (LFDCS); Baumgartner and Mussoline 2011) and manual validation by experienced acousticians to detect and identify a wide range of natural ambient, cetacean, and anthropogenic sounds.

Cominelli et al. (2020) used data from DFO recorders in and near the Cabot Strait to assess the amplitude and frequency characteristics of shipping noise in this area. Similarly, Lawson (pers. comm.) measured and modelled the underwater sound characteristics (as broadband received sound pressure level in dB and frequency-specific sound amplitude) at the northern edge of the Laurentian Channel MPA in 2009 during a seismic exploration project in the Laurentian Channel. These acoustic data and modelling processes allow DFO to detect and identify vocalizing marine mammals in the Laurentian Channel MPA, assess the scope of anthropogenic sounds in the study area, and draw conclusions as to the potential impacts such sound exposures could have on animals in the Laurentian Channel MPA.

RV Trawl Surveys

Multispecies RV trawl surveys provide fishery-independent sampling of commercial and non-commercial species. In the NL Region, the Spring DFO RV trawl survey has been conducted on an annual basis from April to June since 1982. The trawl gear was changed from an Engel Hi-Lift Otter Trawl to a Campelen shrimp trawl in 1995 (McCallum and Walsh 1997). These two gear types differ in their characteristics (i.e., catchability) and conversion factors only exist for a small group of commercial species. Therefore, Engel data cannot be scaled to comparable Campelen catches meaning that community and some species-specific analyses based on RV trawl survey data have to be performed using the two datasets separately. Further to that, the current RV trawl surveys are undergoing another change as two new vessels were recently added to the Canadian Coast Guard (CCG) fleet, meaning comparative fishing is currently underway. Nonetheless, the plan is to continue the time series into the foreseeable future based on the current random stratified design. Although Porbeagle Sharks and Leatherback Sea Turtles are not often caught in these surveys, data are collected on the other CO priority species

which can be used to assess biomass, abundance, and spatial distribution trends, as well as other species-specific biological indicators. While trawl gear is not recommended as part of specific surveys to monitor sea pens or the fish species COs (Morris et al. 2024), data from these surveys can still be used to increase our general knowledge about the area and are included under Complementary Monitoring. Further details on the DFO RV trawl survey can be found in Lewis et al. (2016).

Fisheries Related

Various Canadian programs exist which monitor fisheries catches or landings in the NL Region (e.g., Dockside Monitors, At-Sea Fisheries Observers (ASOs), Logbooks, and Vessel Monitoring System (VMS)), and data relating to some of the COs (i.e., to protect Black Dogfish, Northern Wolffish, and Smooth Skate from human-induced mortality) are collected for these demersal fish species. Two of these programs, Dockside monitoring and Logbooks, are less useful for the Laurentian Channel monitoring program. As part of the Dockside monitoring program, Northern Wolffish, Smooth Skate, and Black Dogfish are almost always discarded at sea due to no commercial value and, if landed, these species are grouped at a generic level (i.e., wolffish [catfish], skates, dogfish), which eliminates dockside monitoring as a source of data by species. *SARA* Fishing Logbooks are required by law to be completed by all fish harvesters for recording the capture and condition of Northern Wolffish. To date, harvesters' compliance rates of *SARA* Logbook returns have not been assessed; however, data on other logbook requirements indicated that rates of return are usually very low, and thus inadequate to capture actual impacts of harvesting on non-target species (M. Simpson, DFO-NL, pers. comm.).

Only Canadian At-Sea Observers provide speciated catch and discard data on wolffish, skates, and dogfish in Canadian commercial fisheries. In addition, At-Sea Observers also measure length/weight/sex of individuals from target species and bycatch, and collect standardized non-lethal (e.g., fin clips for eDNA) and lethal (fish otoliths for ageing; stomach contents) samples for subsequent scientific analyses. Furthermore, they collect set-by-set data and samples of marine species caught at locations, water depths, and times of year never fished by DFO RV trawl surveys. Unfortunately, in recent years, Canada's At-Sea Observer program had very little coverage of the majority of fisheries: e.g., less than one percent in many cases, which is grossly inadequate to estimate the actual negative impacts of commercial fishing on bycatch and species at risk.

Even with the caveats listed above, the COs for Northern Wolffish, Smooth Skate, and Black Dogfish is to reduce bycatch in commercial fisheries (i.e., human-induced mortality within the Laurentian Channel MPA), so Canadian At-Sea Observers (catches and discards by species) and VMS (vessels reporting their geographic position, speed, course, and activity every hour), will help monitor whether commercial fishing occurs within the Laurentian Channel MPA. Given that regulations for this MPA prohibit all commercial and recreational fishing in every zone within its boundaries, these fisheries monitoring tools can support DFO-Conservation & Protection to enforce those prohibitions in the specific spatial area of this large MPA.

Oceanographic Data

The Atlantic Zone Monitoring Program (AZMP) collects physical and biogeochemical oceanographic data in the NL Region along cross-shelf oceanographic sections. Two of these sections are located to the northeast of the Laurentian Channel MPA – southeast (SESPB) and southwest St. Pierre Bank (SWSPB) – are sampled during the spring (April-May) and fall (November-December). Although most stations along these two sections are located outside of the Laurentian Channel MPA, the two southernmost stations on SWSPB fall within the MPA boundaries. At each station, a rosette-mounted CTD equipped with additional sensors (pH, O_2, PAR, chlorophyll-*a* and coloured dissolved organic matter [CDOM] fluorimeters,

transmissometer) is used to profile the entire water column. Water samples collected with Niskin bottles at selected depths during CTD casts are used to quantify the distribution of nutrients (nitrate, ammonia, silicate, phosphate), chlorophyll-*a*, particulate organic carbon and nitrogen (POC, PON), and carbonates across the water column. In addition, vertical plankton net tows are carried out to characterize the mesozooplankton community (abundance, biomass, diversity). The different sampling protocols used by the AZMP are described in Mitchell et al. (2002), and the most recent physical and biogeochemical observations are presented respectively in Cyr et al. (2022) and Maillet et al. (2022). AZMP oceanographic databases in the Laurentian Channel MPA region extend back to the fall of 2008. Similar procedures can be applied to complement the AZMP databases by expanding the spatial and temporal coverage of oceanographic data collection within the Laurentian Channel MPA.

As of 2022, DFO has also been collecting near bottom physical information (current, temperature and salinity) using two moorings deployed in the MPA since 2015. The mooring LC-AOI-01 is located at (45.70°N, 57.25°W) and the mooring LC-AOI-02 is located at (45.51°N, 56.67°W) (Figure 14). These moorings are annually maintained as part of the AZMP and can be augmented with more instruments for a better characterisation of the sites and to further contribute data to the MPA monitoring program (e.g., addition of passive or active acoustics, sediment traps, oxygen sensors, etc.). This sampling is planned to be augmented in the future.

Other Data Collection/Non-DFO-NL Surveys

Large Pelagic shark commercial longline survey (DFO-Maritimes)

In 2007, DFO in conjunction with Canadian fish harvesters conducted a fishery-independent survey of Porbeagle Shark in Atlantic Canada, which extended through the Laurentian Channel MPA (Campana et al. 2015). This survey was established as a baseline for monitoring the health and abundance of the Porbeagle Shark population in Atlantic Canada. A second survey occurred in 2009, and a subsequent survey was conducted in 2017 using the same survey design (to allow year-to-year comparisons). Future plans for this survey are unknown, however, expectations for changes to the status of large migratory species, like Porbeagle Sharks, are not likely to occur over the short term and so this survey may provide valuable information on the species.

Sightings (Opportunistic)

The Marine Mammal Section of DFO-NL has maintained a database of marine megafauna detections collected through a variety of means, including dedicated aircraft- and vessel-based surveys, acoustic monitoring, and opportunistic submissions. For the latter, hundreds of records of sightings of Leatherback Sea Turtles have been submitted to DFO through mail, email, and social media. While these data are usually limited in the metadata they contain (such as observer effort), they can be useful for presence-only distribution and habitat mapping, such as MaxEnt, after careful investigation of the source of the data to ascertain the likelihood of observer error/bias and whether there was confirmatory imagery.

Redfish survey

The Atlantic Groundfish Council (formerly the Groundfish Enterprise Allocation Council; GEAC) has conducted biennial stratified random redfish trawl surveys covering offshore areas in NAFO Divisions 3P and 4V since 2000. This survey is industry-led but falls under a collaborative agreement with DFO. Tows are conducted using a Campelen trawl for 15 minutes, following the same protocol as DFO RV trawl surveys (Kulka and Atkinson 2016). One difference between these surveys, however, is that trawls in the Redfish surveys do not have a cod-end liner in the net, which has implications for sea pen catchability, which is already low for this type of trawl

(Kenchington et al. 2011). Nonetheless, this does not imply less impact on sea pen habitat, but rather less bycatch retention.

Trawl sets do take place within the Laurentian Channel MPA, subject to activity plan approval. In 2020, 23 sets were approved under the activity plan, carried out between August 15-September 15. A total of 28 trawl sets in the eight strata that overlap the MPA have been proposed for the 2022 survey. Catch data as well as some coral bycatch samples collected during these surveys have been provided to DFO-NL Science by GEAC. Alongside the trawl sets, this survey also aims to develop an acoustic index of redfish that would help validate and refine the trawl survey index. Acoustic data are collected via a hull-mounted transducer during tows and when transiting between sites both inside and outside MPA boundaries.

Halibut longline survey

The Atlantic Halibut Longline Survey is a collaborative effort between industry and DFO established in 1998 to provide an index of abundance for assessment of Atlantic Halibut in NAFO Divisions 3NOPs4VWX5Zc. In 2017, stratified random survey stations were incorporated into this survey extending the depth range and spatial distribution of the original fixed-station design (Cox et al. 2019; DFO 2021b). In recent years, 4–6 sets have been within LC MPA boundaries annually, including both fixed stations and new randomly stratified sets. Like redfish trawl surveys, Halibut longline survey sets also fall inside the MPA and are also subject to activity plan approval. Sea pens have not been reported as longline bycatch resulting from this survey in the Laurentian Channel MPA (DFO, unpublished data).

Winter Groundfish Survey

The Winter Groundfish survey is a new program carried out by DFO-Gulf Region, based on a random sampling design and using a Campelen 1800 survey trawl. This survey is planned to run for three years starting in 2022 with annual sampling between Feb 1-March 31. A total of five trawl sets were allocated within the Laurentian Channel MPA in 2022. The purpose is to gather information on the distribution and overlap of multiple species of groundfish species in the Laurentian Channel and to contribute to better understanding of the potential impacts of an expanding redfish fishery on other species as bycatch.

The utility of these groundfish surveys in the monitoring program are yet to be determined but they are described here as a means to keep them for future consideration as they do overlap with the Laurentian Channel MPA and may provide additional context for changes in the overall ecosystem.

Satellite Imagery

Satellite observations can be used to monitor past and present SST and surface chlorophyll-*a* concentration in the Laurentian Channel MPA. Surface chlorophyll-*a* data extends back to 1997. The Operational Remote Sensing Group at BIO has developed user-friendly interfaces including the *PhytoFit* application (Clay et al. 2021) that can be used to retrieve raw data, data products such as SST, chlorophyll-*a,* and anomaly maps, and other useful information on the phenology of the spring and fall phytoplankton blooms (e.g., bloom timing, duration, and intensity).

Because of the high temporal resolution of satellite data (e.g., as frequent as daily), such information can be used to monitor seasonal and interannual changes in the physical (e.g., temperature) and biogeochemical (e.g., phytoplankton) environment of the region. Linkages can further be made between the presence and/or development of certain species (e.g., SST are used in the development of habitat suitability models for Leatherback Sea Turtles) or to monitor threats to the ecosystem (e.g., marine heat waves or harmful algal blooms).

External Collaborations

Another valuable source of data for monitoring will come from external collaborations with institutions such as Memorial University of Newfoundland through its Fisheries and Marine Institute (MI). In early 2022, a contribution agreement under the Ocean Management Contribution Program, was signed between DFO and MI. The project will advance collaborative methods of monitoring marine conservation areas in the NL Region over the next four years (2022–26). The collaborative nature of the agreement will allow for new research partnerships between DFO and academia and increase capacity to monitor not only the Laurentian Channel MPA but the other Marine Refuges in the NL Region as well. It will be important, moving forward, to ensure that certain data collection protocols are standardized between groups to maintain a reasonable level of data quality assurance (DFO 2015).

Indicators

It is often difficult to measure the impact of MPA management decisions, thus indicators are used to help identify change and the impacts on the ecosystem (Pomeroy et al. 2005). The selection of appropriate indicators is crucial, and they can be either qualitative or quantitative, based on the objectives of the MPA (Pelletier et al. 2005). As part of the framework for identifying monitoring indicators, protocols and strategies for the Laurentian Channel MPA (Lewis et al. 2016), several potential indicators were identified for each CO as well as indirect indicators and other ecosystem and habitat characterization indicators. To keep our approach practical and feasible for the next few years a subset of those indicators was selected based on several steps outlined in DFO (2013). These steps are:

1. Identify the operational conservation objectives
2. Identify suitable indicators
3. Identify selection criteria
4. Evaluate indicators
5. Assess whether there is redundancy
6. Agree on a final suite of indicators
7. Estimate limit reference levels and target levels.

Several bilateral meetings were held with members of the NL Monitoring WG, and other subject matter experts, to go through the list of potential indicators and identify suitable ones. Eight selection criteria from Step 3 above helped to guide the discussion: theoretical basis, measurement, historical data, sensitivity, responsiveness, specificity, public awareness and cost-effectiveness. Further detail on these criteria can be found in DFO (2013). Each indicator was evaluated for how it would be used in the context of monitoring and the final list of indicators was agreed upon by all members of the NL Monitoring WG. Step 7 was not considered in this process as it was outside of the scope of the request, however, developing thresholds for each indicator should be a priority in the future. Aside from the indicators specific to the COs and the overall goal of biodiversity, indicators for physical and biological oceanography were included to provide context for larger scale changes in the environment. In total, 29 indicators (Table 6) along with corresponding survey methods and strategies (Table 7) were identified; these indicators will be described in the following sections.

Biodiversity

Biodiversity assessments can be conducted using data from several sampling methods, all of which specialize in certain taxa due to their associated biases. Emerging methods (e.g., eDNA

and baited cameras), like conventional surveys (e.g., RV and drop camera surveys), capture a broad spectrum of taxa. Each can provide data on CO priority species or the communities of which they are part of and rely on. Common indicators for biodiversity are taxa richness and evenness, with higher values representing a system with more biodiversity. But more sophisticated measures that incorporate function and taxonomic diversity could also be explored with these data (also see section Infauna and non-sea pen epifauna below). Other approaches include food web complexity, which can be estimated using taxa traits of the species lists generated. Beyond RV trawl surveys, there are few datasets with which to evaluate biodiversity in the Laurentian Channel MPA, so the datasets used will depend on cost-effectiveness determined from field trials.

Infauna and non-sea pen epifauna

While the protection of benthic infauna and non-sea pen epifauna is not specifically listed as one of the COs of this MPA, other epifauna and infaunal organisms are also vulnerable to bottom trawling and should be considered as part of monitoring approaches used in this program (De Juan et al. 2007).

Assessments of benthic community patterns and species diversity have often focused on analysis of common metrics such as richness, numerical abundance, biomass and diversity indices (e.g., Shannon-Wiener) (Clarke et al. 2014a). But more recently, studies that take an extra step to incorporate biological information (e.g., biological traits related to life history or functional roles) have become more common (Tillin et al. 2006; Parzanini et al. 2018; Lins et al. 2021) and suggested to be considered as part of design and planning of conservation areas (Miatta et al. 2021). Functional diversity has been considered an indicator of bottom trawling disturbance (Tillin et al. 2006; De Juan et al. 2007), which is the main threat associated with the Laurentian Channel COs.

Functional diversity provides more information than species diversity alone because it can incorporate the different ecosystem roles and functions played by living organisms (e.g., filter-feeder vs. predator), as well as some of their sensitivities (e.g., life span) in the analyses. High diversity in biological traits is generally associated with higher species diversity and higher resilience to disturbances (Danovaro et al. 2008), and this type of data can be highly informative when trying to detect and understand change. Functional diversity of sediment macrofauna in the Laurentian Channel has been recently assessed (Miatta and Snelgrove 2022) and provides baseline information that could be used as part of this MPA's monitoring plan. For example, these authors have compiled a database of six functional traits for macrofauna taxa found in the MPA, which can be adjusted over time to assess potential changes in the structure of these benthic communities from a functional perspective. While compilation of functional traits can be time consuming, there are multiple databases available online that can be used to assist with this work, and traits for species published in Miatta and Snelgrove (2022) are already publicly available.

As previously mentioned in this document, determining which variables might be practical to detect change is still to be fully assessed. Biomass, functional traits, and trophic markers have been suggested for the monitoring of areas under the impact of polymetallic nodules mining (Lins et al. 2021) for example, but our preliminary list of metrics for infauna and non-sea pen epifauna currently includes numerical abundance, biomass, and functional traits. Derivative variables such as diversity indices should also be included in such assessments.

Soundscape

Most natural soundscapes are unique and differ depending on a variety of environmental factors (biota, depth, substrate type, ice-cover, etc.). These natural soundscapes are an important part

of the habitat for many marine animals who use sound to understand their environment and to communicate. However, climate change and other anthropogenic activities can alter the functionality of MPAs, including its soundscape. Anthropogenic noise is a pollutant that is recognized to negatively affect some marine animals, particularly marine mammals, although the ecological impact of noise on the vast majority of other marine life is poorly understood. Large MPAs with limited shipping activity, such as the Laurentian Channel MPA, could reduce the potential effects of noise on marine life; however, the propagation characteristics of low frequency noise mean that it can travel exceptionally long distances and therefore even the largest MPAs are not free of anthropogenic sounds. Therefore, having a method to detect signs of major issues is useful for marine resource managers; quantitively monitoring marine soundscapes of an area being protected provides a direct indicator of anthropogenic noise, regardless of our understanding of its ecological impacts upon animals within a given area.

Soundscape monitoring can inform scientists and management decisions regarding the potential effects of such noise within MPAs (e.g., Weiss et al. 2021; McKenna et al. 2021). Several common acoustic metrics are used to quantify underwater sound, including; root-mean square sound pressure level (rms SPL; expressed in decibels (dB) re 1 µPa), power spectral density (PSD) level (expressed in dB re 1 $\mu Pa^2/Hz$), daily sound exposure levels (daily SELs) commonly used as surrogate for the received energy, and daily equivalent continuous sound level (daily L_{eq}) that is equivalent to the rms SPL computed over an averaging period of 24 h. Ideally, multiple measures of the MPA's acoustic environment would be integrated into a soundscape to provide a superior description of the composite acoustic environment since characterizing a marine soundscape through single sound level measures provides an incomplete description, reduces our understanding of distinctive acoustic features, and can hinder comparisons with adjacent areas or other MPAs.

There are many types of acoustic sensors that can be used to collect soundscape information (see section Passive Acoustic Receivers), and the analyses of the large amounts of acoustic data they collect, using computer-based AI approaches, is a growing field of research (e.g., Liu et al. 2020).

Sea Pens

Examples of potential indicators for the monitoring of cold-water corals in Canadian OECMs were listed and described as part of a 2020 CSAS process (DFO 2021a). In that process, indicators were classified as state (ecosystem and environmental) and pressure (stressor) indicators (OSPAR 2012). Indicators were described and evaluated based on steps listed above from DFO (2013) however, only steps 1–4 were evaluated in that CSAS process. The final list included 15 suitable state indicators, plus indirect BCBs, and stressor indicators. The list of indicators was based on previous publications with a focus on corals in Canada, including Lewis et al. (2016). Four of these state indicators were related to reef-forming corals (e.g., *Lophelia pertusa* = *Desmophyllum pertusum*), which are not found in the Laurentian Channel MPA. The remaining 11 state indicators were:

- Numerical abundance
- Biomass
- Distribution
- Diversity indices
- Size structure
- Live: dead ratio and condition

- % Corals with zoanthids
- Patch area and density
- Patch isolation/proximity
- Patch connectivity
- Contagion index

Indicators “Live:dead ratio and condition” and “% corals with zoanthids” are unlikely to be suitable for sea pens, as dead sea pens are not often observed during *in situ* surveys, and to our knowledge there are no records of sea pen infestation by zoanthids. However, sea pens can be infested with endoparasitic copepods (Baillon et al. 2014a; Penney et al. 2021). Baillon et al. (2014a) documented two distinct endoparasitic copepods (Families Lamippidae and Corallovexiidae) in the polyps of *A. grandiflorum* (Penney et al. 2021) and *B. finmarchica* (=*Halipteris*). *Lamippe bouligandi* is the parasitic copepod commonly observed inside the polyps of *Anthoptilum grandiflorum*. These copepopds can infest up to 19% of polyps of a single colony. In addition, infested polyps showed significantly lower fecundity than non-infested polyps, which indicates that copepod occurrence might have potential as an indicator of sea pen health.

The final selection of indicators should now consider steps 5–6 of the 2013 framework (DFO 2013): assessing redundancy and agreeing on the final suite of indicators. While not redundant, the indicators numerical abundance, distribution, and diversity indices can all be derived from the same data source. For instance, to determine numerical abundance of sea pens, it will be necessary to determine species ID, which can also inform on both distribution and diversity indices. Similarly, obtaining data on size structure can also provide information on numerical abundance, distribution, and species diversity. The geospatial indicators (i.e., patch area and density, isolation/proximity, connectivity, and contagion index) depend on specific definitions of patch. As of now, we do not have enough baseline data to develop thresholds to define sea pen patches from seafloor imagery in the Laurentian Channel MPA.

The indicator *distribution*, while relatively easy to obtain, since it is derived from other variables of interest, might prove to be problematic. Most of the historic data on sea pens in the MPA comes from DFO RV trawl surveys and changes in the distribution of sea pens might get confounded with differences in gear. For instance, as mentioned earlier, the sea pens *K. stelliferum* and *P. carpenteri* are rarely reported in trawl samples but have been commonly observed in videos. Therefore, changes in sea pen distribution ranges in the MPA might reflect changes due to other factors and may not be a result of protection by the MPA.

As a result, the following indicators are likely to be the most useful for the specific monitoring of sea pens, if further analyses indicate that they can, in practice, be collected consistently and with enough statistical power: numerical abundance, biomass, diversity indices, and size structure. Endoparasitic copepod infestation is yet to be investigated as a potential indicator of change in the MPA, but it deserves to be considered as part of the research objectives for the MPA.

- Abundance: Morris et al. (2024) did an analysis on the statistical power of sea pen abundance data obtained from seafloor imagery in the Laurentian Channel MPA. The analysis indicates that similar data might be used to detect a decline in sea pen abundance at a relatively high statistical power and realistic sample size. However, as described by those authors, the threshold at which a decline in sea pen abundance might cause irreversible damage to their populations is unknown at this point, and whether the decline

modelled in those analyses is biologically relevant. We suggest that collection of sea pen abundance data should use seafloor imagery as its primary source.

- Biomass: the most realistic way of obtaining biomass data for sea pens is by weighing physical samples, which generally precludes the use of seafloor images for this purpose. In practice, sea pen biomass data have been obtained in the Laurentian Channel as part of DFO's RV trawl surveys for many years. However, a power analysis has not been conducted on RV trawl survey sea pen biomass to assess whether it could be reliably used for monitoring if scientific trawling continues in the MPA at current levels. Furthermore, due to low sea pen catchability of the Campelen trawl (Kenchington et al. 2011), trawl biomass should not be considered as the main indicator for the monitoring of sea pens in this MPA. Data from these surveys can still be used to identify large catches and their locations, and to provide samples for other analyses and contribute to monitoring of the MPA, as discussed in other parts of this document. If shifts in sea pen trawl biomass are detected over the next years, Targeted Research investigating this metric might be warranted. We also suggest future research towards estimation of biomass from imagery, which although not common might be possible (De Clippele et al. 2021).
- Diversity indices: might turn out to be unsuitable for the purposes of monitoring to detect significant changes in the MPA, due to the relatively low number of sea pen taxa in the MPA but can still be informative to assess status and trends. In future iterations of power analyses using imagery data, diversity indices should be included for their evaluation. We suggest that collection of sea pen diversity data should use seafloor imagery as its primary source.
- Size structure: is a challenging indicator because sea pens are difficult to measure from images, and because we have not assessed sea pen size structure bias of the Campelen trawl method. It is known that juveniles are often not retained by the trawl and that abundance has not been consistently measured during DFO RV trawl surveys. Nonetheless, size structure constitutes a crucial variable to assess sea pen recruitment in the MPA. While precise measurements are indeed challenging, alternative approaches such as size through categories (e.g., large, medium, small) and size resulting from counts of polyp leaves (Chimienti et al. 2018) should be considered in future iterations of power analyses using imagery data.

Another consideration is that, although some of these indicators are derived from the same dataset, specific power analyses would be needed for all of them, as the number of required samples might not be the same for each one. For instance, the number of samples required to detect change in sea pen abundance might be quite different from the number required to detect change in sea pen diversity (i.e., diversity indices). Rogers et al. (2008) found that the number of samples required to observe change in megafauna metrics (e.g., biomass, abundance, diversity indices) was variable and changed depending on the gear used. The final selection of indicators also needs to consider turnover time between data collection, analysis, and reporting, as well as availability of human resources to do so. But as mentioned under Seafloor Imagery Surveys the implementation of AI techniques for use with imagery annotation might help to significantly mitigate processing time for the large amount of imagery data expected to be collected in the MPA. Nonetheless, as with other components of the monitoring program, full implementation of AI techniques in this context might require years and, in some cases, will represent a trade-off between lower processing time and lower taxonomic resolution.

In addition to the indicators listed above, environmental and stressor indicators were also suggested for the monitoring of corals and sponges in Canada (Kenchington et al. 2012; DFO 2021a). Environmental indicators are mentioned under Oceanography. Stressor indicators

suggested in DFO (2021a) include those associated with commercial fishing, oil and gas activities, and ice-related, which will not be considered here. There are currently no exploration licenses for oil and gas activities near the Laurentian Channel MPA, so impacts from these activities are not of immediate concern (e.g., transport of drilling waste), although oil spills could still happen in the area. Other stressor indicators listed in DFO (2021a) include anthropogenic sediment deposition, timing, duration, and magnitude of phytoplankton bloom, seabed litter presence, and activities related to submarine cables. These indicators were detailed in Neves et al. (2026) and will not be further detailed here. However, they will be considered in the monitoring plan as part of Targeted Research and Complementary Monitoring. While these indicators are listed here as part of coral and sponge CSAS processes and some might be more focused on benthic activities (e.g., sedimentation and submarine cables), they might also be relevant to other CO priority species and biodiversity in general (see Table 6). While climate change was not specifically detailed here, some oceanographic parameters (environmental indicators) can be used to monitor climate-change induced stressors. Shifts in sea pen carbonate content could be investigated as a potential state indicator related to ocean acidification.

Black Dogfish, Smooth Skate, Northern Wolffish

Monitoring of Black Dogfish, Northern Wolffish, and Smooth Skate relative to their COs will occur mainly through the continuation of existing DFO multispecies Spring surveys, ASO records, and fisheries landings monitoring. The collection of eDNA samples and baited camera video provide options to obtain further information on these species (e.g., presence), although these methods have not yet been tested for these taxa in this area. Multispecies surveys provide data on species distribution, biomass/abundance, length composition, sex, and maturity, and can also be used to collect additional samples (DNA, parasites, isotopes, stomach contents). Fisheries statistics, such as those collected by ASOs and through existing landings monitoring tools (logbooks, dockside monitoring), directly address the main CO of reducing human-induced mortality in the Laurentian Channel MPA. The annual ASO coverage of relevant Atlantic fisheries remains at primarily 0–5% (since 2010; with a few exceptions), while commercial landings monitoring of targeted species does not report bycatch data. Therefore, unreported commercial fisheries bycatch is likely the largest threat to CO priority species human-induced mortality in areas adjacent to the Laurentian Channel MPA.

Deployment of additional acoustic receivers within and outside the Laurentian Channel MPA boundaries can support research on seasonal distribution, movements, and habitat requirements for different life stages of acoustically-tagged Northern Wolffish, Black Dogfish, and Smooth Skates. Previously, wolffish movements and habitat selection were monitored using internal acoustic tags (Simpson et al. 2015); a study which could be repeated in and around the Laurentian Channel MPA. In addition, external acoustic tags can be attached to Black Dogfish and Smooth Skates to capitalize on this acoustic array. Alternatively, Smooth Skates could be monitored using pop-up satellite archival tags (PSAT; Knotek et al. 2020).

For all three species, these tagging studies could also investigate post-release mortality; especially given that a portion of those species inhabit deeper waters and may experience increased physiological (and potentially lethal) stresses when quickly hauled to the ocean's surface/aboard vessels by fishing gear. This is particularly important for Northern Wolffish because the primary conservation tool of its recovery strategy is the immediate live release of wolffish bycatch with the least possible harm during commercial fishing operations.

In addition to data provided by DFO multispecies Spring surveys, Canadian At-Sea Observers (ASO's) are the sole source of speciated catch and discards of wolffish and skates in commercial fisheries. When requested by DFO, ASOs also measure length/weight/sex of

individuals from target species/bycatch on Sexed/Unsexed Length Frequencies, and collect standardized non-lethal (e.g., fin clips for eDNA) and lethal (fish otoliths for ageing; stomach contents) samples for subsequent scientific analyses.

Porbeagle Shark

The main survey used for monitoring the status of the Atlantic Porbeagle population is the large pelagic shark commercial longline survey. This fishery-independent survey provides time-series data with estimates of distribution, relative abundance, trends, and life stage/size/sex composition. Ongoing tagging of Porbeagle Sharks (with external passive acoustic tags or satellite tags), conducted by DFO in NL Region waters, will provide data on individual Porbeagles and their movements.

Records of all shark encounters (lethal and non-lethal) are also important for monitoring Porbeagle Sharks, however, current fisheries related methods for collecting this information are limited, even more so due to the lack of commercial and recreational fishing in the MPA. Improvements could be made to better utilize some of these Complementary Monitoring methods. For example, logbooks are currently used to monitor only the endangered White Shark but should be expanded to include Porbeagle Sharks (and ideally all other Atlantic large pelagic sharks), along with photographic documentation. Furthermore, misidentification of large shark species by Atlantic fish harvesters is common, so a pocket-sized waterproof Sharks Species ID Guide could be distributed to all commercial License holders/fishers when applying for/renewing their Licenses. Ideally, reporting of all Atlantic shark bycatch should be made a Condition of License in Canada. As was mentioned in Fisheries Related the CO for Porbeagle Shark is to protect from human induced mortality (e.g., bycatch in the commercial fishery) and these encounters will help monitor whether commercial fishing occurs within the Laurentian Channel MPA.

Leatherback Sea Turtles

Leatherback Sea Turtles range over a large area of the Northwest Atlantic. However, they are more likely to occur in certain spaces, such as off the southern coast of Newfoundland, as evidenced by a density map produced using data from a systematic aerial survey (the 2007 Trans North Atlantic Sightings Survey [TNASS], Figure 13) (Lawson and Gosselin 2009). The density of Leatherbacks is highest closer to the Newfoundland south coast in shallower waters, but portions of the Laurentian Channel MPA also have high densities. This general distribution pattern holds true when we produce a kernel density map of Leatherback density based on a habitat model (Mosnier et al. 2019)(Figure 28).

Information on the reasons for Leatherback use of habitat in the Laurentian Channel MPA is limited. This turtle species is known to specialize on jellyfish prey (particularly Cyanea and Aurelia in Newfoundland waters), but biomass and distribution estimates for these prey are lacking. Over almost two decades of aerial survey effort, it is clear that the number and spatial extent of jellyfish swarms in Atlantic Canada are increasing (J. Lawson, DFO-NL, pers. comm.); although as a measure of biomass such observations are speculative and based on visual records with low precision – for example we would not know the vertical extent of most jellyfish swarms seen from the air. In parallel, the regional abundance of Sunfish (*Mola mola*), a fish that also specializes on jellyfish prey, has increased in recent years and could be used as an indicator of the presence of jellyfish prey for themselves and Leatherbacks.

Reporting of Leatherback Sea Turtle interactions with fishing gear and vessels (both lethal and non-lethal) is very important for monitoring this species. Fisher logbooks should be expanded to include non-landed turtle captures (since Leatherbacks are rarely brought aboard fishing vessels), along with photographic documentation of the sea turtles in gear. As with Porbeagle

Sharks, reporting of all Leatherback Sea Turtle bycatch should be a Condition of License. While most Leatherback Sea Turtle fishing gear encounters have occurred on the (predominantly southern) coastal areas of Newfoundland, there are several reports of these sea turtles being bycaught in nets off the southern coast of Labrador. Several lethal entrapments of Leatherbacks are reported in fishing gear each year around Newfoundland, but this is an underestimate of the true number; about one third of Leatherbacks entrapped in fishing gear die. Leatherback Sea Turtles are more likely to be caught in the vertical lines of fixed gear (such as whelk or crab pots), or nets (such as groundfish or bait gillnets).

Oceanography

The ocean climate of the Northwest Atlantic changes on interannual and decadal time scales (Cyr and Galbraith 2021). These changes in the climate are accompanied by fluctuations of the physical (e.g., temperature, salinity, currents, etc.) and biogeochemical (oxygen and nutrient concentrations, pH, chl-*a*, plankton composition and abundance, etc.) environments, with potential larger impacts on the ecosystem. In order to disentangle the status of the MPA's ecosystem and the changes associated with, for example, climate change, physical and biogeochemical indicators must be closely monitored. Environmental indicators (e.g., habitat-related parameters, temperature, chlorophyll-*a* concentration and zooplankton abundance) were also proposed in DFO (2021a) as part of the national monitoring framework on corals and sponges. Timing, duration, and magnitude of phytoplankton blooms, for example, have also been suggested as a stressor indicator for the monitoring of corals and sponges in Canada (Kenchington et al. 2012; DFO 2021a).

It is suggested to continue the existing monitoring of oceanographic indicators routinely collected as part of the AZMP, or with the deployment of moorings as described above. In addition to these existing indicators, other variables such as surface chlorophyll-*a c*oncentration (estimated using satellite observation of ocean color), nutrient flux to benthic habitats using sediment traps, soundscape monitoring, and fisheries acoustics (from moorings) could also be considered.

Study Design

For long-term monitoring programs, establishing a robust, and well thought out study design is essential. Guidance for developing effective study designs for monitoring have been well covered elsewhere (Quinn and Keough 2002; Parks Canada Agency 2007) and are only touched on here. DFO (2021a) also included a detailed section on methodologies/design for the monitoring of coral and sponge MRs, which can also be used as a reference. Study designs should dictate where and when (time of day, depth, season, frequency, etc.) sampling is conducted and reflect well defined questions of the monitoring program and reporting requirements. Flaws in study design can result in erroneous conclusions, loss of confidence in the program, costly corrections, disruptions of time series, and/or misalignment with program objectives.

For MPAs, monitoring questions should naturally follow COs and results should be planned to complement reporting schedules (yet to be defined). For the Laurentian Channel MPA, one monitoring question might be: Are the densities of Black Dogfish maintained within the MPA boundaries? A study design addressing this question will identify sampling locations and times that minimize bias across the area in question. Operational limitations often restrict sampling (e.g., sampling depths, substrates, seasons, etc.), which in turn limits the representation of the data and the generality of the conclusions. In other circumstances, resource limitations may require that efforts be focused on an important subset of the MPA (e.g., key habitats), to ensure sufficient sampling to detect change (see section STATISTICAL POWER AND DESIGN). These intentional restrictions to the sampling frame (i.e., temporal and spatial extent of area sampled)

are often necessary and can be accommodated if the limitations are clearly understood in the design process and articulated when reporting the results. More insidious problems with study design are those that result in unplanned biases or those that affect the independence of data. The former issue can be resolved by unbiased sample site selection techniques such as random, systematic, or random stratified sampling. Attempts to free sampling from bias can be undermined by the forced inclusion of historic sampling sites, particularly in cases where the selection criteria of those data are unknown or not aligned with program objectives (e.g., a site selected because it was particularly good habitat for an indicator or CO priority species might bias resulting analyses to misrepresent MPA status in a more positive light). The latter issue of independence among samples is a common assumption of many statistical analyses. For example, samples collected in spatial and temporal proximity are more likely to be similar than those that are less proximal (i.e., spatial and temporal autocorrelation). Datasets with high correlation can lead to falsely inflated statistical power and can cause Type-I errors (detection of statistical changes that are not there). In practice, correlation is widespread in nature and more advanced statistical methods can account for and correct such issues during the analysis stage, but these come at the expense of statistical simplicity. Moreover, not understanding correlation patterns can lead to inefficient study designs. Ideally, pilot data are used to understand the correlation that should be expected across sampling scales and to optimize sampling strategies in a way that minimizes redundant sampling.

A final important aspect of study design is establishing a program with sufficient statistical power to detect change. Power analysis is a statistical tool used to evaluate and compare design approaches, assess program feasibility, and optimize sampling intensity to meet project objectives. Statistical power is influenced by factors within (e.g., desired detectable effect size, sample size, and accepted Type I error rates, statistical test used) and beyond (inherent variability of the indicator of interest) the control of monitoring program designers. More coarse detectable effect sizes, larger samples and greater tolerance of Type I errors (i.e., false positives) all can improve statistical power. In contrast, higher intrinsic variance in the indicator negatively affects power. Often, additional variables, if included in the models used to detect change, can account for some variation and improve statistical power. Furthermore, statistical tests and supporting study designs can also differ in their efficiency (Morris et al. 2018) to detect change. As with understanding correlation structure, existing data are valuable for informing power analyses. For example, existing RV trawl survey data were used to inform a power analysis by Morris et al. (2024) as described in the next section.

POWER ANALYSIS RESULTS

One of the objectives for this CSAS process was to investigate the ability to assess MPA conservation priority species metrics using existing DFO RV trawl survey data and seafloor imagery data. Predicting and measuring changes resulting from MPAs has posed a challenge for practitioners, in part because ecosystems are complex and can change in unanticipated ways, but also due to MPA design factors (boundaries, conservation objectives, monitoring programs) that leave little chance of meeting stated goals. Morris et al. (2024) evaluated

1. whether it is realistic to expect improvements in the MPA for four of the CO priority species, and
2. whether existing scientific surveys are capable of detecting changes in these taxa should they occur.

Three CO priority species were sampled in the DFO RV trawl surveys (Black Dogfish, Smooth Skate, and Northern Wolffish) and a fourth CO, sea pen taxa, were enumerated using seafloor imagery. Simulations indicate that the trawl surveys have very little chance of detecting change

in the abundance of the three fish species examined, while seafloor imagery data had higher statistical power for sea pen taxa. This analysis highlights the inefficiencies of using RV trawl survey data to detect changes in three Laurentian Channel MPA CO priority species. In many cases, even quadrupling existing sampling intensity within the MPA would not provide sufficient power to detect catch per unit effort (CPUE) declines of 50%.

Power analysis using simulations in this way can inform us on the likelihood of determining effectiveness of the MPA COs in achieving their goals. However, the fact that the MPA was established in an area of minimal fishing pressure ensures that the newly created fishery restrictions will not generate measurable improvements in its COs. While positive change in existing COs is unlikely to be induced by the MPA, or to be detected if they occurred, this MPA could provide conservation benefits if COs (with measurable indicators) and monitoring approaches were realigned to match the unique features of this area of largely unimpacted sensitive benthic habitats. These recommendations offer monitoring program designers the opportunity to pivot to other more effective approaches or COs better aligned with monitoring programs that can generate usable results to inform decision making. For more information on this power analysis see Morris et al. (2024).

CONSIDERATIONS AND RECOMMENDATIONS

MPA SIZE AND LOCATION

Research has shown that large MPAs are advantageous as they cover more unique habitats and contain multiple species, allowing a greater potential to protect ecosystems (Sheppard et al. 2012). Although a large MPA allows for a focus on large-scale ecological processes, it also comes with monitoring challenges (Stanley et al. 2015). The Laurentian Channel MPA is a relatively large offshore MPA which results in challenges in the creation of monitoring programs. The high cost of mobilizing sampling programs to areas offshore can be prohibitive and limit the scale and types of monitoring possible (Lewis et al. 2016). Additionally, the current limited access to vessels and vessel-time for the purpose of scientific monitoring in Canada is not a negligible issue. While multiple DFO surveys depend on Canadian Coast Guard vessels, it will be important to consider access to alternative suitable vessels. Application of this monitoring approach across all MPAs and MRs in the NL Region will provide opportunities for testing of survey methods and strategies in other areas as well as more capacity building to be able to implement them in the Laurentian Channel MPA more effectively. Broad coordination (between and within DFO Regions, including with external partners) and discussions regarding prioritization of sampling sites and/or survey methods will be key when planning these surveys.

REFERENCE SITES

With only minimal historical fishing effort in the area selected for protection, potential MPA-related improvements in COs resulting from the removal of fishing activities in the Laurentian Channel MPA are expected to be limited. Rather than focusing on MPA improvements relative to outside reference sites, a more appropriate/realistic approach would be to assess biodiversity-related status and trends in the MPA. Under this scenario, more resources could be allocated toward measuring the conditions within the MPA, with the use of Complementary Monitoring data from outside the boundary of the MPA to provide regional (larger scale) context to interpreting change within. For example, data at the scale of the NAFO Division (from RV survey) or from Fishery Logbooks would help scientists understand if measured declines in CO priority species seen within the MPA are the result of local issues or broader scale stressors (e.g., widespread declines in productivity due to climate change). Analysis of such information may only be triggered following measured declines within the

Laurentian Channel MPA, provided suitable baseline data exist. Therefore, as discussed through this document, while we recommend the selection of monitoring sites for interpretation of monitoring data on some COs, we do not advocate using these sites for assessing MPA effectiveness within a formal hypothesis testing framework.

REPORTING

Little guidance has been provided on reporting requirements or reporting timelines for the Laurentian Channel MPA thus far. It is recommended that standardized annual reports be developed that include information on MPA-related surveys and data gathered each fiscal year. The use of reproducible reporting templates (e.g., R markdown files) could be produced by the NL Monitoring WG and updates fed into the templates to maintain a consistent reporting format. While the set-up of R markdown files for the different groups working on the monitoring program will require coordination and time investment, it will largely facilitate reporting in the long run. Dedicated support for database management and the automation of feeding data sources into these reproducible reports will also be essential. Specific contents of the reports will be based on the indicators described herein but the actual analyses to be completed will be dependent on available data. It is possible that, with sufficient data, a more in-depth report could be produced after several years (e.g., five years) that would aim to evaluate whether or not the current monitoring approach is providing valuable information on status and trends of the priority species and biodiversity in the area.

It is recommended that after the first five years of this monitoring approach are complete, a workshop be planned to provide both scientists and managers with an overview of lessons learned, highlighting successes and challenges associated with monitoring in the Laurentian Channel MPA. This would also be an ideal venue for providing advice and feedback for adaptive management of the MPA.

LONG-TERM MONITORING

Monitoring requires a long-term commitment to data collection (Noble-James et al. 2018). An important consideration is the continuity of data collection going forward. Ideally, once the program is started, there should be a consistent effort to maintain the Core Monitoring activities. The frequency of Core activities, as described above, may need to be adjusted based on resources available each year (i.e., financial and human resources). However, lack of consistency will negatively influence the program and careful planning should take into consideration expected limitations of those resources, without compromising scientific quality. The department will also continue to make every effort to collect samples and data using other research platforms of opportunity, and by collaborating with academia, non-government organizations, and citizen scientist researchers. Opportunities for student participation in the monitoring program should also be considered. However, clearly stated data sharing agreements will be need to be in place to facilitate the use of non-DFO data sources.

Another consideration for many long-term programs are challenges associated with climate change. For example, our current understanding of the ecosystem may no longer be valid in the future. The COs created during the MPA establishment process, which can be lengthy, may become outdated if species shift their distribution outside of the MPA boundaries. Similarly, other important species may move into the area and benefit from the MPAs protection measures. We can anticipate future stressors by using climate forecasts (e.g., low O_2, species shifts), however, building a monitoring program in a way that accounts for, and provides some value for, species replacement (e.g., biodiversity measures) may be the best approach. Maintaining a long-term monitoring approach that covers multiple marine conservation areas in the region will also help assess any changes at scales larger than just the MPA itself.

STATISTICAL POWER AND DESIGN

To ensure we have a scientifically robust monitoring program, it is recommended that various methods for increasing statistical power and improving experimental design be considered. Quinn and Keough (2002) devote an entire chapter of their book to experimental design and we emphasize some of their points in this section. Considerations regarding replication, independence, and ways to reduce unexplained variance are critical, and the use of power analysis can increase our confidence that an effect will be detected, if such an effect exists. Power analysis was previously highlighted in other parts of this document and is the focus of a Laurentian Channel case study by Morris et al. (2024). Power can be improved at the expense of increased Type 1 errors (detecting changes that do not exist), which is a common approach for environmental monitoring and impact assessments (Quinn and Keough 2002). Moreover, restricting statistical tests to detecting declines, or improvements, but not both (i.e., one-tailed statistical tests) can also enhance statistical power. Finally, inclusion of covariates can reduce unexplained variance and positively affect power.

Co-location of sampling (where possible) can reduce field costs and help leverage other datasets. For example, eDNA collections in the same place as UVP drops can help us understand the fine-scale taxonomic composition of the plankton community quantified by the UVP. Similarly, eDNA data can be ground-truthed by observations from baited and drop cameras as well as infauna sampling. In summary, there are multiple ways to increase statistical power and improve experimental design and these often require preliminary data to fully assess.

SEASONALITY

Ecosystems in temperate areas such as the Laurentian Channel experience pronounced seasonality in environmental conditions and faunal communities, particularly for migratory taxa, including CO priority species like Leatherback Turtles and Porbeagle Sharks. As it is infeasible to track all indicators through all seasons, we recommend restricting Core Monitoring activities to late summer when most CO priority species occupy the Laurentian Channel MPA, and sea state conditions are most amenable to sampling. This will maximize the efficient use of vessel time and avoid adding confounding seas-related factors to monitoring datasets. These data will be supplemented where possible with year-round autonomous data collection (e.g., remote sensing, moorings, etc.). Data sources from established external monitoring programs (i.e., Complementary Monitoring) will maintain existing seasonal timing, and in some cases fill seasonality gaps for the Core Monitoring program (e.g. RV trawl surveys are always conducted from April – June in the MPA) . Some specific considerations on seasonality were provided under the section Seafloor Imagery Surveys related to sea pens (epifauna) and other benthic habitats.

ADAPTIVE MANAGEMENT

As there are uncertainties with any marine ecosystem, adaptive management is essential so that management strategies are progressively adjusted in response to new information (Government of Canada 2019b). The monitoring program for the Laurentian Channel MPA will provide useful data for adaptive management of the MPA, triggering management action, or Targeted Research when management outcomes are not being achieved. Moreover, it may be necessary to modify the monitoring plan should new threats emerge. A future consideration for the NL Monitoring WG should be establishing those thresholds or trigger points for the monitoring indicators to provide clarity on when adaptive management measures should be considered. Ensuring ongoing dialogue with management on the status of not only the CO priority species, but also what scientific information might be required to inform potential

adaptive management actions (e.g., adjustments to monitoring priorities or modification of regulatory intent) will also be key to the monitoring program success.

CONCLUDING REMARKS

The scientific monitoring approach proposed here strategically supplements existing regional programs (Complementary Monitoring) with specific cost-effective MPA monitoring (Core Monitoring and Targeted Research) and will serve as a foundation that supports useful and scientifically robust monitoring of the Laurentian Channel MPA. We believe it can also be used as a template for other NL conservation areas, enabling the possibility of integrated regional conservation area assessments for common indicators. Many unknowns remain and this program will require re-evaluation and refinement (particularly after field trials) to ensure MPA objectives will be achieved over the long term.

ACKNOWLEDGEMENTS

The authors would like to thank all meeting participants for their valuable feedback and discussions on the two working papers during the meeting. Also, thank you to our reviewers, Ryan Stanley (DFO-Maritimes), Dan Keller (Parks Canada), Paul Snelgrove (MUN), and Mariano Koen-Alonso (DFO-NL) for reviewing one or both of the working papers.

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TABLES

Table 1. Timeline for monitoring activities in the Laurentian Channel MPA, 2022–26.Activities are colour coded as follows: red - aerial survey, grey - Redfish survey, orange - chartered vessel, purple - non-DFO led/data gathering, yellow - Halibut longline survey, light blue - DFO trawl survey, dark blue - ROV, pink - Gulf winter groundfish survey, green - AZMP/Oceanography and brown - large pelagic shark longline survey.

Survey Methods	2022/23	2023/24	2024/25	2025/26	**Sampling** (Core/ Complementary/ Targeted)	**Frequency**
DFO multispecies trawl surveys	-	-	-	-	Complementary	Annual (spring)
Aerial surveys (turtle, cetacean, jellyfish)	-	-	-	-	Complementary	Annual
Satellite imagery	-	-	-	-	Complementary	Annual (continuous)
Satellite Tags (Pop-up Archival Transmitting [PATs])	-	-	-	-	Targeted	no current plans
Acoustic Telemetry (receivers and tagging)	-	-	-	-	Targeted	no current plans
Acoustic receivers (moorings and mobile)	-	-	-	-	Targeted	no current plans
Multibeam/ sidescan sonar	*LCMPA completed (2010–13)				Targeted	no current plans
Oceanographic mooring	-	-	-	-	Complementary / Core	Annual (continuous)
CTD cast	-	-	-	-	Complementary / Core	Biannual (Core)
eDNA (water/sediment)	-	-	-	-	Core	Biannual (Core)
Sediment corer (benthic grab/ box core)	-	-	-	-	Core	Biannual (Core)
Drop and drift/tow camera (Non-ROV camera systems)	-	-	-	-	Core	Biannual (Core)
Baited Camera	-	-	-	-	Core	Biannual (Core)
ROV	-	-	-	-	Targeted	~every 5–10 years
Underwater Vision Profiler (UVP)	-	-	-	-	Core	Biannual (Core)
Observer Data	-	-	-	-	Complementary	Annual
AZMP	-	-	-	-	Complementary	Annual (spring and fall)
Sightings (opportunistic)	-	-	-	-	Complementary	Annual
VMS or logbooks	-	-	-	-	Complementary	Annual
FFAW (Fish, Food, and Allied Workers Union)	-	-	-	-	Complementary	Annual
Dockside Monitoring	-	-	-	-	Complementary	Annual
Large Pelagic Shark Commercial Longline Survey	-	-	-	-	Complementary	~every five years
Redfish Survey	-	-	-	-	Complementary	Biannual (late summer)
Halibut Longline Survey (Maritimes)	-	-	-	-	Complementary	Annual (summer)
Gulf winter groundfish survey	-	-	-	-	Complementary	Three year program

Activity	Aerial Survey	Redfish Survey	Chartered Vessel	Non-DFO led/data gathering	Halibut Longline Survey
DFO Trawl Survey	ROV	Gulf Winter groundfish Survey	AZMP/Oceanography	Large Pelagic Shark Longline Survey	

Table 2. Abiotic variables used in unsupervised habitat mapping analysis.

Name	Original spatial resolution (m)	Description	Data Source
Bathymetry (m)	450	-	GEBCO Compilation Group (2021) GEBCO 2021 Grid
Slope (degrees)	450	-	Derived from the GEBCO 2021 bathymetry data
RDMV	450	This is a measure of relative position, which identifies peaks (positive values) and pits (negative values).	
Eastness	450	Ranges between -1 (fully West) and 1 (fully East). The aspect is converted in radians, and the eastness is the sine of the aspect in radians.	
Northness	450	Ranges between -1 (fully South) and 1 (fully North). The aspect is converted in radians, and the northness is the cosine of the aspect in radians.	
Fishing effort (hours)	1,000	Total fishing effort from 2005–18 for commercial fishing vessels (all fisheries and gear types) with VMS onboard	Derived from: Fishing effort within Significant Benthic Areas in Canada's Atlantic and Eastern Arctic marine waters (2005–15) with update to 2018 from Open Data (Koen-Alonso et al. 2018)
Surface Temperature (°C)	1,500	Averaged for March, April, May from 1985-2013	Surface water temperature by satellite remote sensing. Data published on St. Lawrence Global Observatory-SLGO (Fisheries and Oceans Canada 2017).
Bottom Temperature (°C)	8,700	Averaged for March, April, May from 1993-2020	Global Ocean Physics Reanalysis. (GLORYS12 Version 1). Copernicus Monitoring Environment Marine Service (CMEMS).
Salinity (psu)	8,700	-	
Eastward ocean current velocity (m/s) (u)	8,700	-	
Northward ocean current velocity (m/s) (v)	8,700	-	

Table 3. Component matrix for the principal component analysis showing correlations between the abiotic variables and the principal components.

Abiotic variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
Bathymetry (m)	-0.41172	0.235912	-0.21693	-0.13455	0.097856	-0.41396	0.032271	-0.065	-0.34941	0.329456	0.541142
Eastness	-0.14282	-0.49445	-0.24875	0.25783	-0.18996	-0.02478	-0.70028	0.213716	-0.0005	0.178877	0.044877
Northness	-0.3056	0.166314	0.211746	-0.09729	0.086877	0.452009	-0.36739	-0.66556	0.072161	0.169675	-0.029
Slope (degrees)	0.411541	-0.17536	-0.09793	-0.03635	0.223245	0.031512	-0.12124	-0.25644	-0.78945	-0.13772	-0.12446
Relative deviation from mean value (RDMV)	-0.03027	-0.16046	-0.60447	-0.41975	-0.52921	0.175631	0.211338	-0.24743	0.041792	-0.11389	-0.0157
Salinity (psu)	0.462342	0.164036	-0.06001	0.11754	-0.04386	-0.11347	-0.26303	-0.24022	0.27957	-0.38752	0.609834
Eastward ocean current velocity (m/s) (u)	-0.10119	0.554287	-0.0963	0.291346	-0.3216	0.459964	-0.09113	0.349949	-0.32975	-0.1723	0.064671
Northward ocean current velocity (m/s) (v)	0.176807	0.17772	-0.17945	-0.64136	0.403323	0.223613	-0.30453	0.406546	0.124369	0.08404	0.019904
Surface Temperature (°C)	0.438923	-0.12891	0.126201	0.077183	-0.16638	0.336187	0.22676	0.038363	-0.01218	0.692679	0.308699
Bottom Temperature (°C)	0.303015	0.479589	-0.29753	0.146308	-0.10985	-0.36075	-0.18587	-0.16534	0.128277	0.363151	-0.46457
Fishing effort (hours)	-0.08174	-0.05795	-0.56722	0.437088	0.555981	0.272515	0.240907	-0.07672	0.169611	0.01134	0.031322
Eigenvalue	3.62	1.50	1.12	1.05	0.94	0.84	0.72	0.63	0.36	0.19	0.03

Table 4. Component matrix with correlations between the rotated components (RC) and the abiotic input variables. For each variable, the highest factor load is highlighted (grey) denoting the RC with which it is most highly correlated.

Abiotic variable	RC1	RC2	RC3	RC4
Bathymetry (m)	-0.837	0.132	0.138	0.176
Eastness	-0.054	-0.467	0.599	-0.024
Northness	-0.628	-0.017	-0.16	-0.141
Slope (degrees)	0.799	-0.02	-0.045	0.177
RDMV	-0.055	-0.126	0.244	0.748
Salinity (psu)	0.806	0.406	-0.131	0.035
Eastward ocean current velocity (m/s) (u)	-0.311	0.68	0.073	-0.179
Northward ocean current velocity (m/s) (v)	0.167	0.15	-0.421	0.633
Surface Temperature (°C)	0.846	0.008	-0.163	-0.066
Bottom Temperature (°C)	0.427	0.771	-0.005	0.149
Fishing effort (hours)	-0.046	0.179	0.743	0.073

Table 5. Mean values (± SD) of abiotic variables across clusters.

Abiotic Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Bathymetry	-80.57 ± 35.34	-280.17 ± 199.51	-250.38 ± 314.24	-120.54 ± 127.35	-2474.16 ± 983.37
Eastness	-0.01 ± 0.69	-0.53 ± 0.53	0.36 ± 0.51	-0.17 ± 0.7	-0.27 ± 0.49
Northness	-0.1 ± 0.71	-0.39 ± 0.54	-0.6 ± 0.51	0.03 ± 0.7	-0.78 ± 0.3
Slope	0.13 ± 0.19	0.4 ± 0.58	0.96 ± 1.18	0.11 ± 0.18	1.83 ± 0.92
Relative deviation from mean value	0.18 ± 0.19	0 ± 0.17	0.11 ± 0.19	-0.18 ± 0.18	-0.01 ± 0.17
Salinity	32.65 ± 0.31	34.37 ± 0.69	33.29 ± 1.36	32.75 ± 0.32	34.92 ± 0.05
uo velocity	-0.02 ± 0.03	0 ± 0.01	-0.01 ± 0.01	-0.01 ± 0.02	-0.03 ± 0.02
vo velocity	0.01 ± 0.03	0.01 ± 0.02	0 ± 0.02	-0.02 ± 0.03	0.01 ± 0.02
Surface temperature	1.54 ± 0.52	2.2 ± 1	1.87 ± 0.75	1.71 ± 0.67	4.59 ± 0.79
Bottom temperature	0.86 ± 0.89	5.36 ± 1.21	3.43 ± 2.58	0.97 ± 1.05	3.16 ± 0.71
Fishing effort	4.25 ± 10.07	3.62 ± 8.51	133.72 ± 77.97	6.17 ± 12.35	1.47 ± 3.98

Table 6. Indicators selected for each conservation objective priority species as well as biodiversity and oceanography.

Indicator	Sea Pens	Black Dogfish	Smooth Skate	Northern Wolffish	Porbeagle shark	Leatherback Sea Turtle	Biodiversity	Oceanography
Biomass	X	X	X	X	-	-	X	X
Abundance/Density	X	X	X	X	X	-		X
Species/Taxa Diversity	X[1]	-	-	-	-	-	X	X
Species/Taxa Richness	X[1]	-	-	-	-	-	X	X
Size Distribution	X	X	X	X	-	-	-	-
Occurrence/Frequency	-	X	X	X	X	X	-	-
Distribution	-	X	X	-	-	-	-	-
Fisheries Catch Weight	-	X	X	X	-	-	-	-
Length Frequencies	-		X	X	-	-	-	-
Lethal Encounters/Non-Lethal Entanglements	-	-	-	-	X	X	-	-
Size (length)	-	-	-	-	X	-	-	-
Weight	-	-	-	-	X	-	-	-
Movements	-	-	-	-	X	-	-	-
Jellyfish Aggregations (abundance and distribution)	-	-	-	-	-	X	-	-
Temperature	-	-	-	-	-	-	-	X
Chlorophyll-a	-	-	-	-	-	-	-	X
Salinity	-	-	-	-	-	-	-	X
Oxygen Concentration	-	-	-	-	-	-	-	X

Indicator	Sea Pens	Black Dogfish	Smooth Skate	Northern Wolffish	Porbeagle shark	Leatherback Sea Turtle	Biodiversity	Oceanography
Ocean Acidification (alkalinity, pH, DIC, PCO2)	-	-	-	-	-	-	-	X
Soundscape/Acoustic Features	-	-	-	-	-	-	X	X
Nutrient Flux (movement of water masses)	-	-	-	-	-	-	-	X
Currents	-	-	-	-	-	-	-	X
Infaunal and Epifaunal Composition	-	-	-	-	-	-	X	-
Trophic Flows	-	-	-	-	-	-	X	-
Energy Flows	-	-	-	-	-	-	X	-
Predator/Prey Biomass	-	-	-	-	-	-	X	-
Primary Productivity	-	-	-	-	-	-	-	X
Zooplankton Variability	-	-	-	-	-	-	X	X
Threats (e.g., sedimentation, noise, oil spills)	X	-	-	-	-	-	X	-

[1]See section Indicators for a discussion on the use of these metrics for monitoring sea pens.

*Table 7. Indicators selected for each of the survey methods and strategies. * Indicates surveys that may be used in the monitoring program but haven't been linked to a monitoring indicator.*

	Surveys and Strategies																								
	Trawl Surveys	Aerial Surveys	Acoustic and Other Tagging			Benthic / Habitat Surveys				Other Minimally Invasive Techniques			Oceanography			Fisheries Related				Other Data Collection / Non-DFO-NL Surveys					
Indicator	DFO Multispecies RV Trawl Surveys	Aerial Surveys (turtle, cetacean, jellyfish)	Acoustic Telemetry (receivers and tagging)	Acoustic Receivers (moorings and mobile)	Satellite Tags (PATs)	*Multibeam / Sidescan Sonar	Drop and Drift/Tow Camera (Non-ROV)	Sediment Corer (benthic grab / box core)	ROV	eDNA (water/sediment)	Baited Camera	UVP (Underwater Vision Profiler)	AZMP	CTD Cast	Oceanographic Mooring	Dockside Monitoring	Observer Data	FFAW	VMS or Logbooks	Satellite Imagery	Sightings (opportunistic)	*Redfish Survey	*Halibut Longline Survey (Maritimes)	Large Pelagic Shark Commercial Longline Survey	*Gulf Winter Groundfish Survey
Biomass	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Abundance / Density	X	-	-	-	-	-	X	-	X	-	X	-	X	-	-	-	-	-	-	-	-	-	-	X	-
Species/Taxa Diversity	X	-	-	-	-	-	X	-	X	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Species/Taxa Richness	X	-	-	-	-	-	X	-	X	X	X	X	X	-	-	-	-	-	-	-	-	-	-	-	-
Size Distribution	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Occurrence / Frequency	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	X	X	X	X	-	X	-	-	-	-
Distribution	X	-	-	-	-	-	X	-	X	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-
Fisheries Catch Weight	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-

	Surveys and Strategies																									
	Trawl Surveys	Aerial Surveys	Acoustic and Other Tagging			Benthic / Habitat Surveys				Other Minimally Invasive Techniques			Oceanography			Fisheries Related				Other Data Collection / Non-DFO-NL Surveys					
Indicator	DFO Multispecies RV Trawl Surveys	Aerial Surveys (turtle, cetacean, jellyfish)	Acoustic Telemetry (receivers and tagging)	Acoustic Receivers (moorings and mobile)	Satellite Tags (PATs)	*Multibeam / Sidescan Sonar	Drop and Drift/Tow Camera (Non-ROV)	Sediment Corer (benthic grab / box core)	ROV	eDNA (water/sediment)	Baited Camera	UVP (Underwater Vision Profiler)	AZMP	CTD Cast	Oceanographic Mooring	Dockside Monitoring	Observer Data	FFAW	VMS or Logbooks	Satellite Imagery	Sightings (opportunistic)	*Redfish Survey	*Halibut Longline Survey (Maritimes)	Large Pelagic Shark Commercial Longline Survey	*Gulf Winter Groundfish Survey
Length Frequencies	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		X	-	-	-	-	-	-	-	-
Lethal Encounters / Non-Lethal Entanglements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-
Size (length)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Weight	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-
Movements	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Jellyfish Aggregations - Abundance and Distribution	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	X	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	X	-	-	-	-	-
Chlorophyll-a	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	X	-	-	-	-	-
Salinity	X	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-

Indicator	Surveys and Strategies																								
	Trawl Surveys	Aerial Surveys	Acoustic and Other Tagging			Benthic / Habitat Surveys				Other Minimally Invasive Techniques			Oceanography			Fisheries Related				Other Data Collection / Non-DFO-NL Surveys					
	DFO Multispecies RV Trawl Surveys	Aerial Surveys (turtle, cetacean, jellyfish)	Acoustic Telemetry (receivers and tagging)	Acoustic Receivers (moorings and mobile)	Satellite Tags (PATs)	*Multibeam / Sidescan Sonar	Drop and Drift/Tow Camera (Non-ROV)	Sediment Corer (benthic grab / box core)	ROV	eDNA (water/sediment)	Baited Camera	UVP (Underwater Vision Profiler)	AZMP	CTD Cast	Oceanographic Mooring	Dockside Monitoring	Observer Data	FFAW	VMS or Logbooks	Satellite Imagery	Sightings (opportunistic)	*Redfish Survey	*Halibut Longline Survey (Maritimes)	Large Pelagic Shark Commercial Longline Survey	*Gulf Winter Groundfish Survey
Oxygen Concentration	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-
Ocean Acidification (alkalinity, pH, DIC, PCO2)	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-	-	-	-	-	-	-	-
Soundscape / Acoustic Features	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nutrient Flux (Movement of Water Masses)	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-
Currents	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-
Infaunal and Epifaunal Composition	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trophic Structure	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy Flows	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	Surveys and Strategies																								
	Trawl Surveys	Aerial Surveys	Acoustic and Other Tagging			Benthic / Habitat Surveys				Other Minimally Invasive Techniques			Oceanography			Fisheries Related				Other Data Collection / Non-DFO-NL Surveys					
Indicator	DFO Multispecies RV Trawl Surveys	Aerial Surveys (turtle, cetacean, jellyfish)	Acoustic Telemetry (receivers and tagging)	Acoustic Receivers (moorings and mobile)	Satellite Tags (PATs)	*Multibeam / Sidescan Sonar	Drop and Drift/Tow Camera (Non-ROV)	Sediment Corer (benthic grab / box core)	ROV	eDNA (water/sediment)	Baited Camera	UVP (Underwater Vision Profiler)	AZMP	CTD Cast	Oceanographic Mooring	Dockside Monitoring	Observer Data	FFAW	VMS or Logbooks	Satellite Imagery	Sightings (opportunistic)	*Redfish Survey	*Halibut Longline Survey (Maritimes)	Large Pelagic Shark Commercial Longline Survey	*Gulf Winter Groundfish Survey
Predator / Prey Biomass	X	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Primary Productivity	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	X	-	-	-	-	-
Zooplankton Variability	-	-	-	-	-	-	-	-	-	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-
Threats (e.g., sedimentation, noise, oil spill)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-

FIGURES

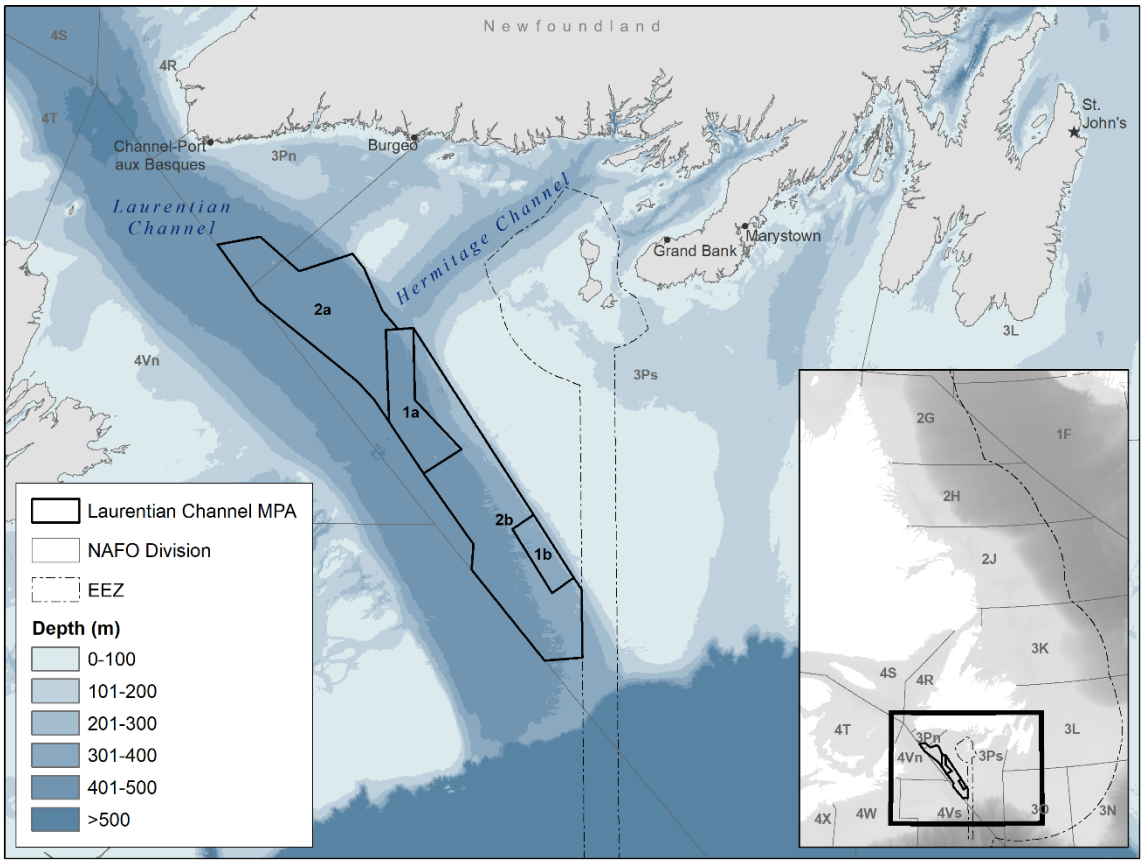

Figure 1. Location of the Laurentian Channel MPA (black outline) and its management zones (i.e., 1a, 1b, 2a, 2b) off the southwest coast of Newfoundland. The inset map shows the NAFO Divisions in and surrounding the NL Region. Darker blue represents deeper water.

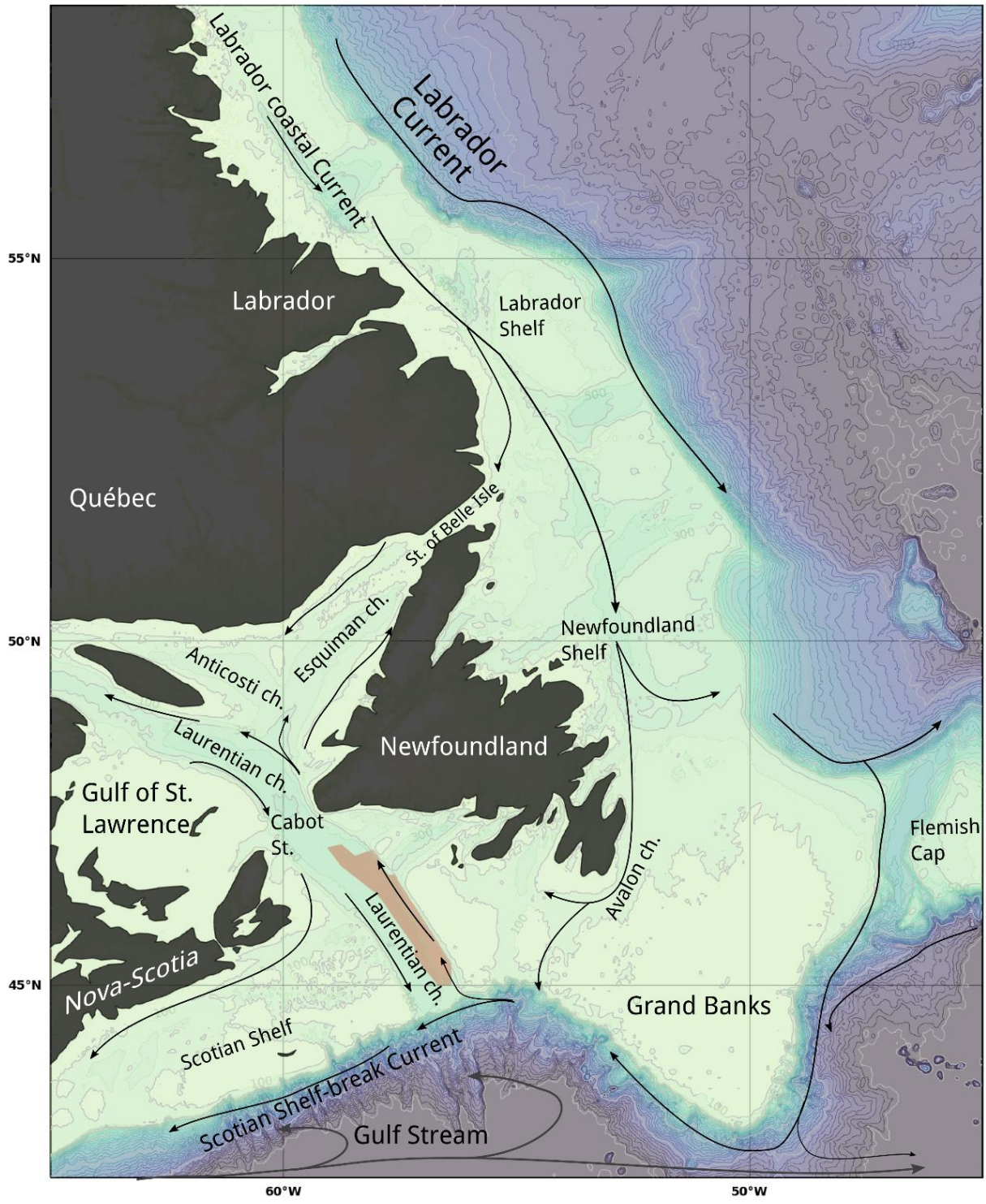

Figure 2. Bathymetric map of Atlantic Canada with a sketch of some ocean currents relevant for the discussion. The Laurentian Channel MPA is highlighted in orange. Darker colours represent deeper water.

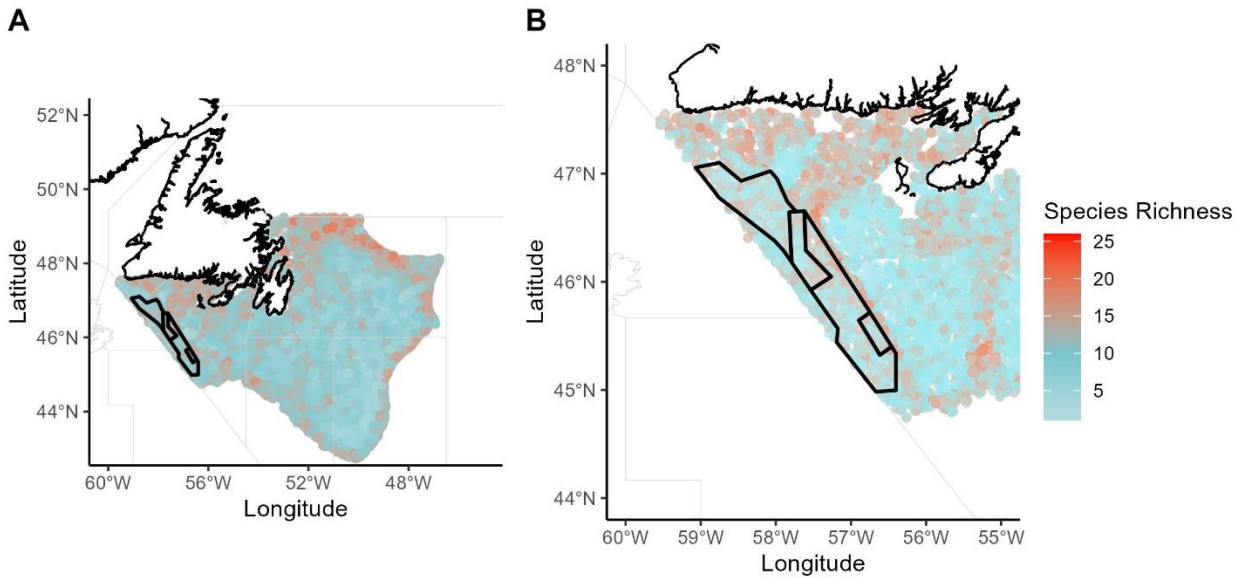

Figure 3. Species richness for all spring RV trawl survey species from 1996–2021 for NAFO Divisions 3LNOP (A) and 3P (B). Red represents higher species richness.

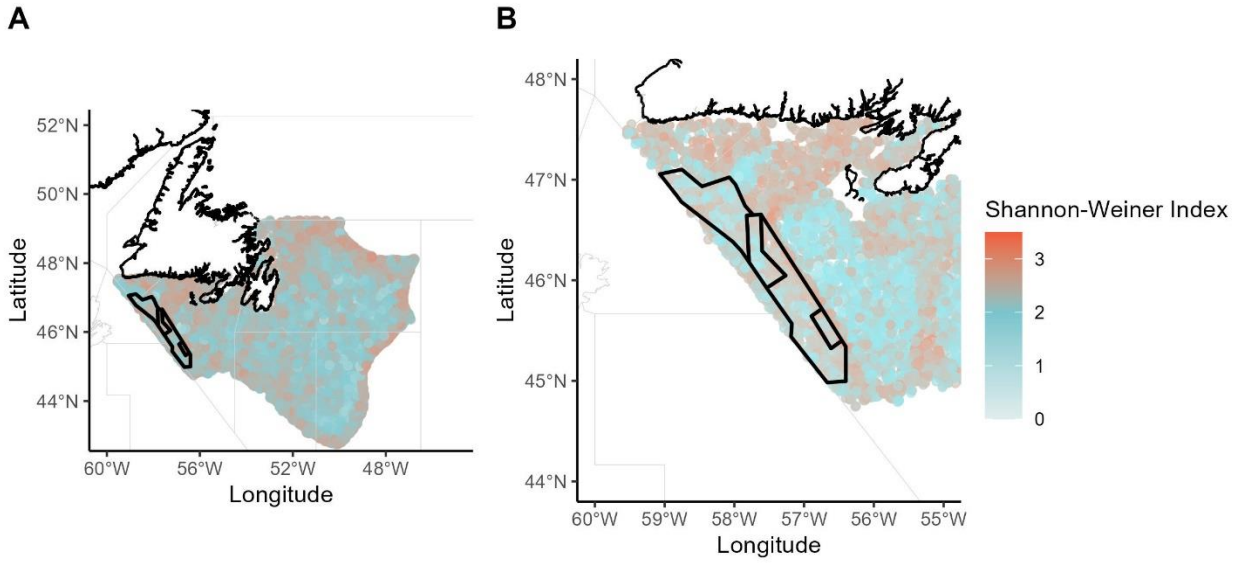

Figure 4. Shannon-Weiner diversity index for all spring RV trawl survey species from 1996–2021 for NAFO Divisions 3LNOP (A) and 3P (B). Red represents higher Shannon-Weiner Index values.

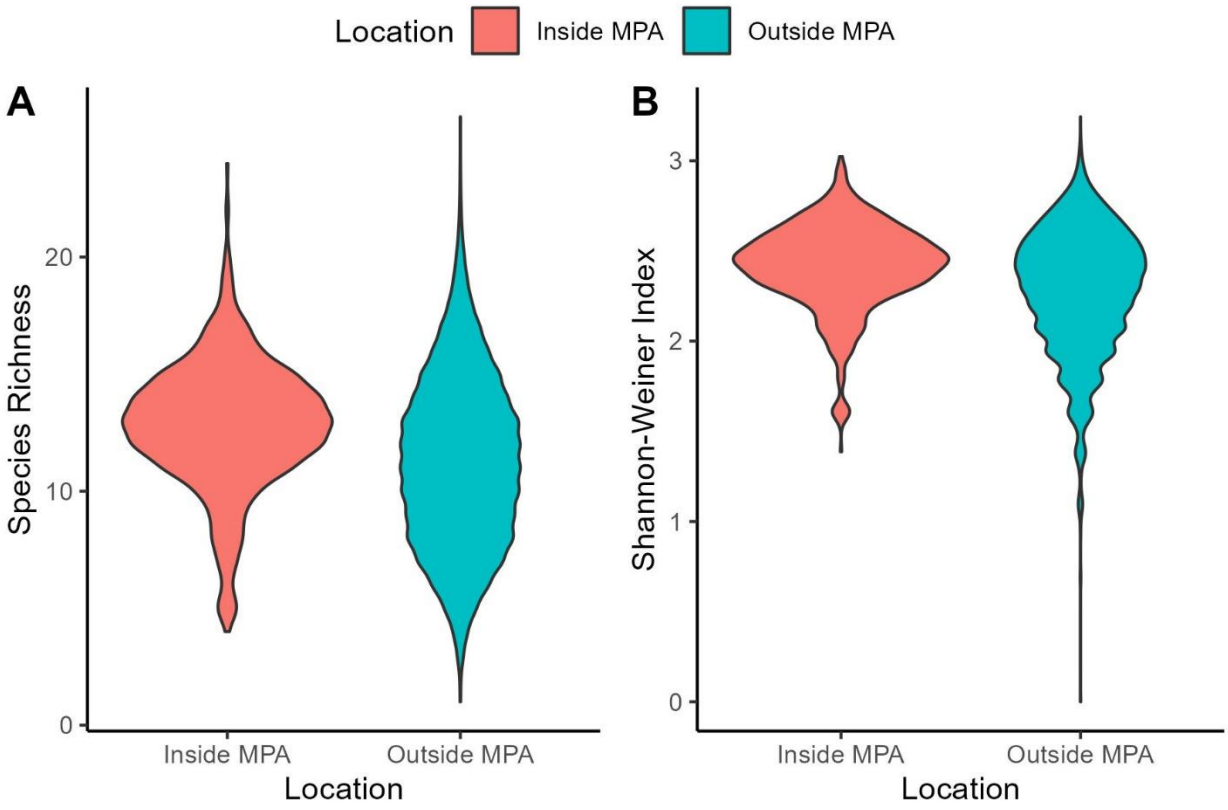

Figure 5. Species richness (A) and Shannon-Weiner Diversity Index (B) values from spring RV trawl surveys (1996–2022) for areas inside and outside the Laurentian Channel MPA (see panel B in Figure 3 and Figure 4 for spatial extents). Inside the MPA is represented by the colour pink and outside the MPA by blue.

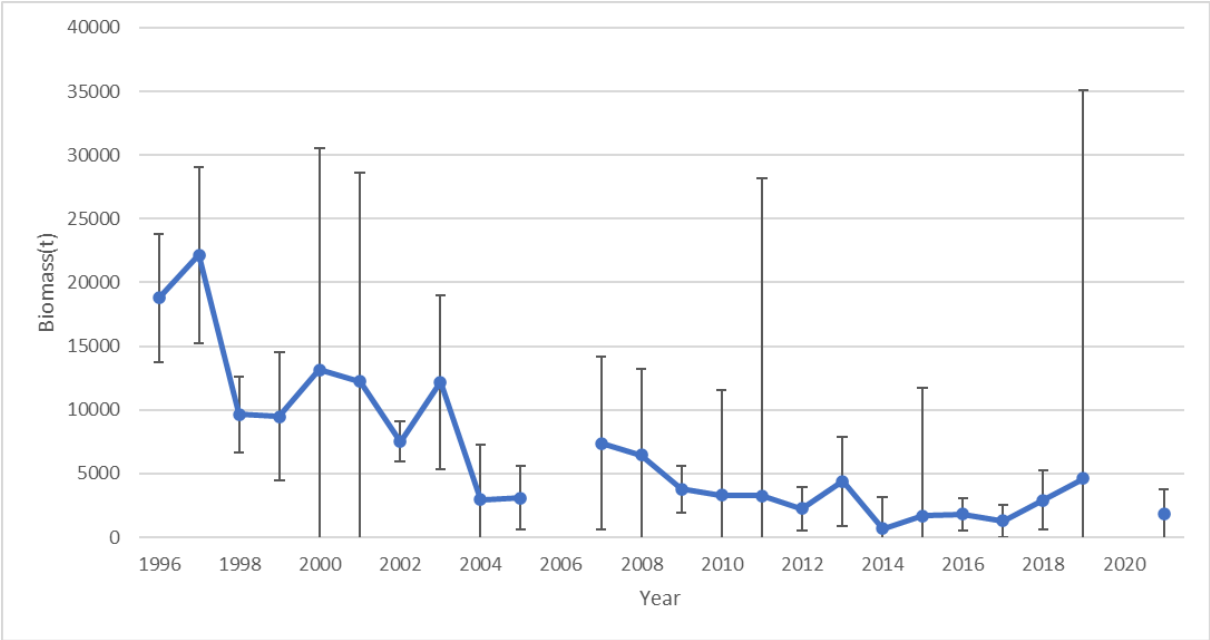

Figure 6. Biomass trends of Black Dogfish in NAFO Subdivision 3Ps from the DFO-NL spring RV trawl survey, 1996–2021.

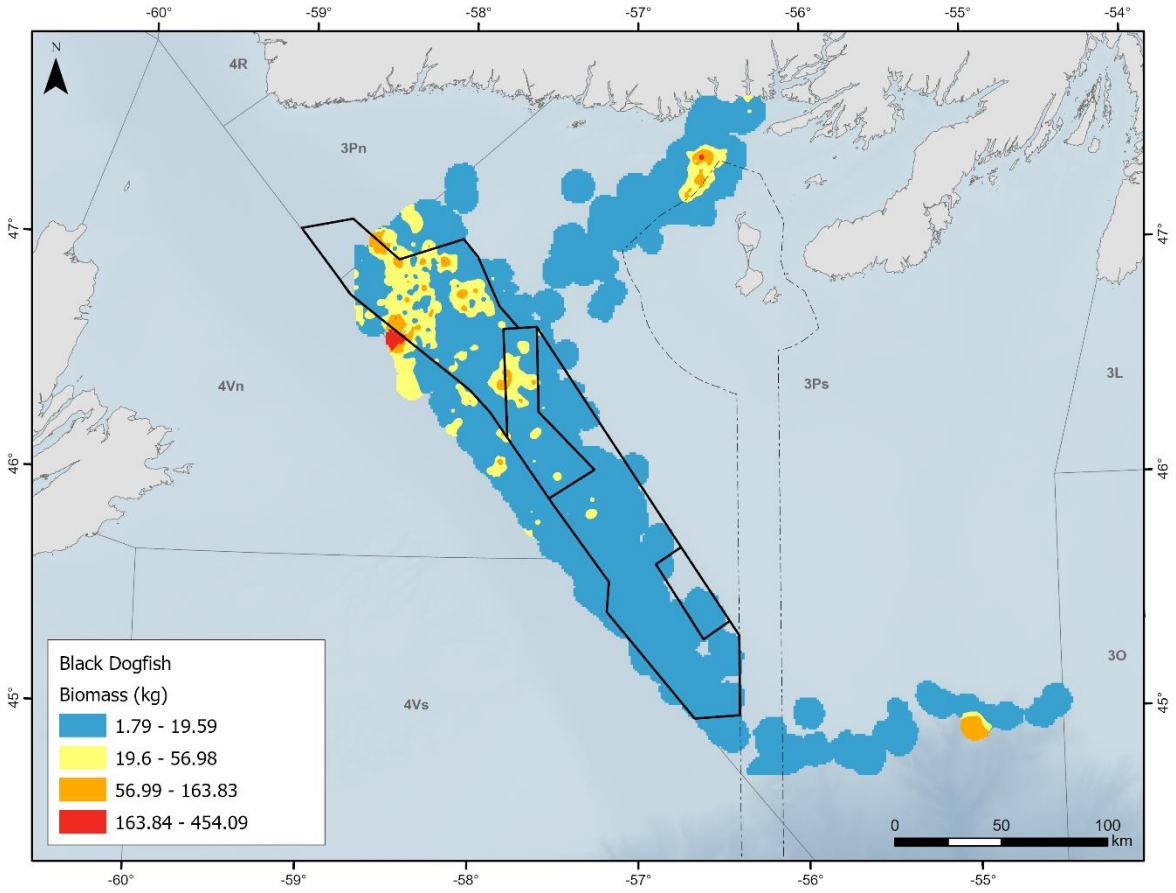

Figure 7. Inverse distance weighted (IDW) biomass of Black Dogfish, based on DFO-NL's spring RV trawl survey in NAFO Subdivision 3Ps from 1996–2021, inclusive, using a variable search radius of 10 points to a maximum distance of 7,500 m and a power of two. The layer was classified into four classes based on natural breaks (Jenks). The Laurentian Channel MPA is shown as a solid black outline. Warmer colours (red and orange) represent higher biomass.

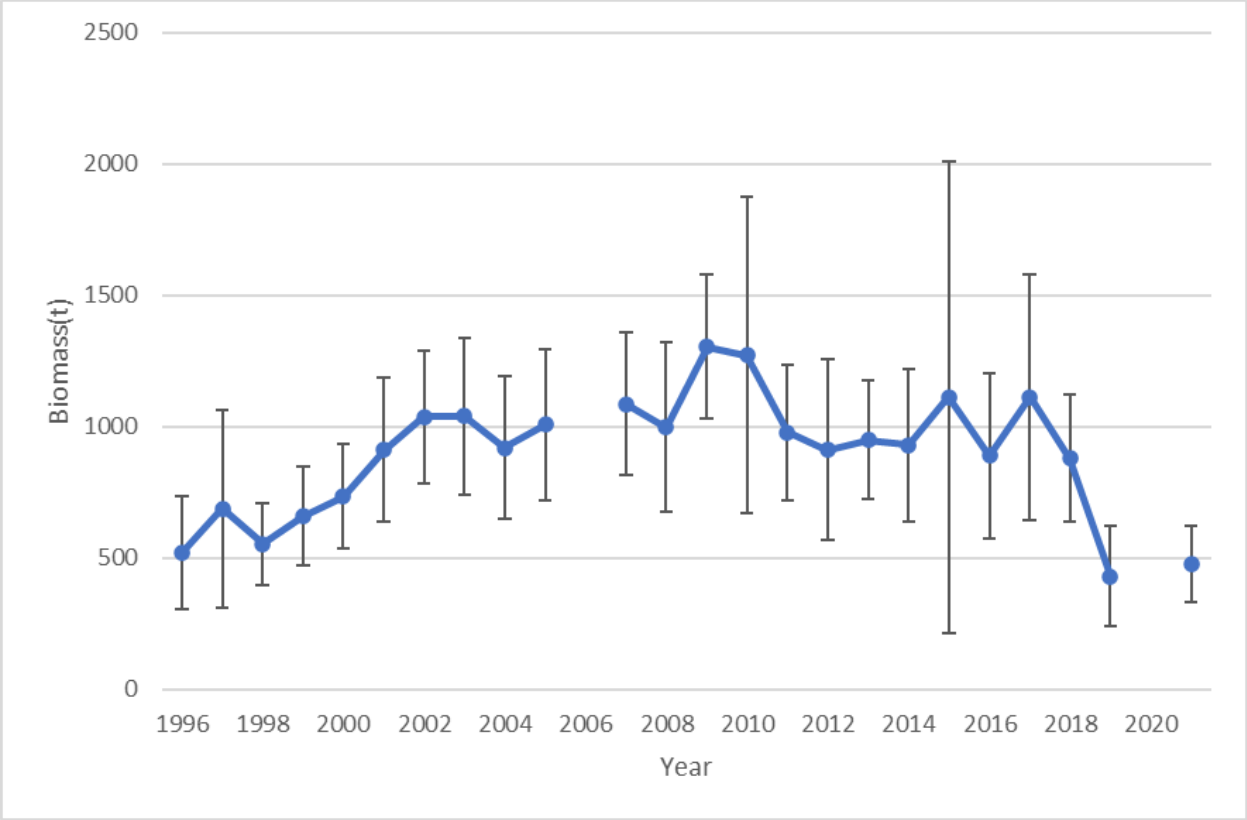

Figure 8. Biomass trends of Smooth Skate in NAFO Subdivision 3Ps from the DFO-NL spring RV trawl survey, 1996–2021.

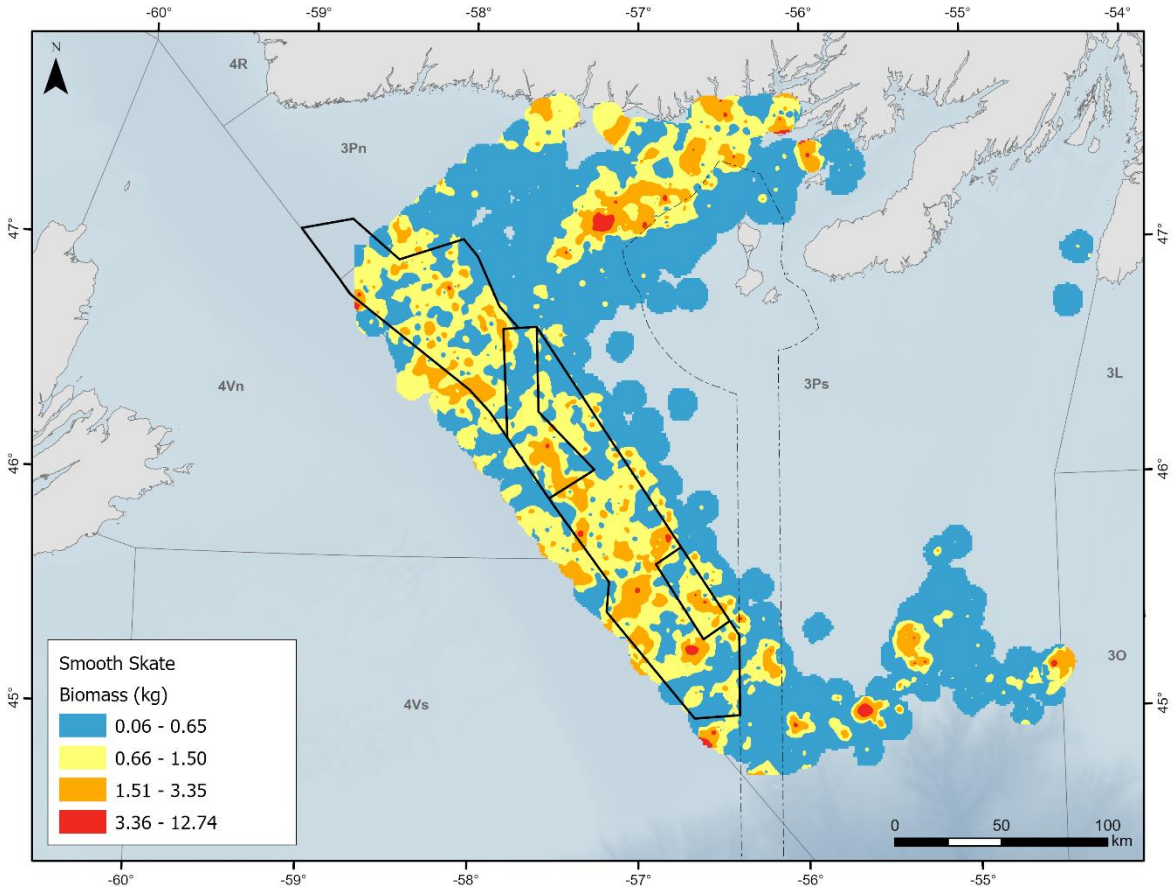

Figure 9. IDW biomass of Smooth Skate, based on DFO-NL's spring RV trawl survey in NAFO Subdivision 3Ps from 1996–2021, inclusive, using a variable search radius of 10 points to a maximum distance of 7,500 m and a power of two. The layer was classified into four classes based on natural breaks (Jenks). The Laurentian Channel MPA is shown as a solid black outline. Warmer colours (red and orange) represent higher biomass.

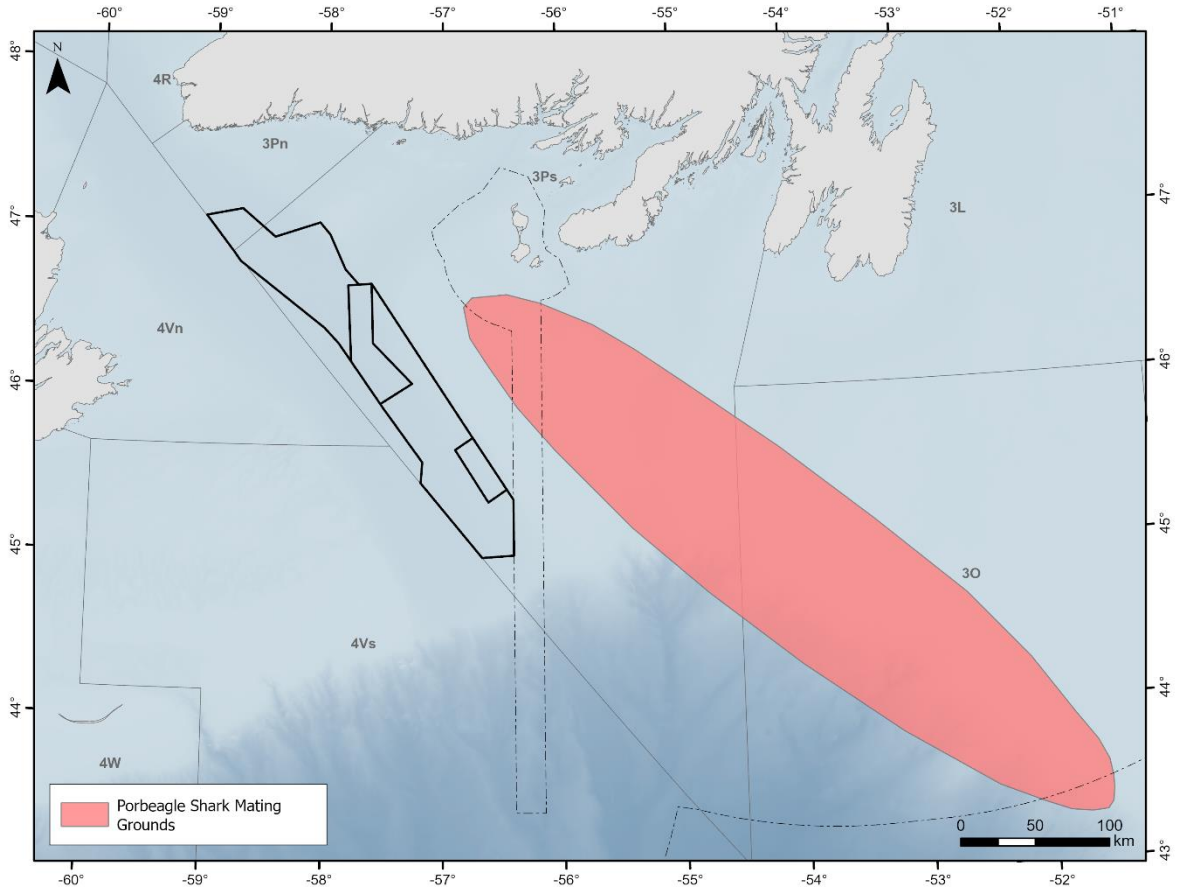

Figure 10. Porbeagle Shark mating grounds (solid pink oval shape), orthorectified from Campana et al. (2013)*, shown alongside the Laurentian Channel MPA (solid black outline).*

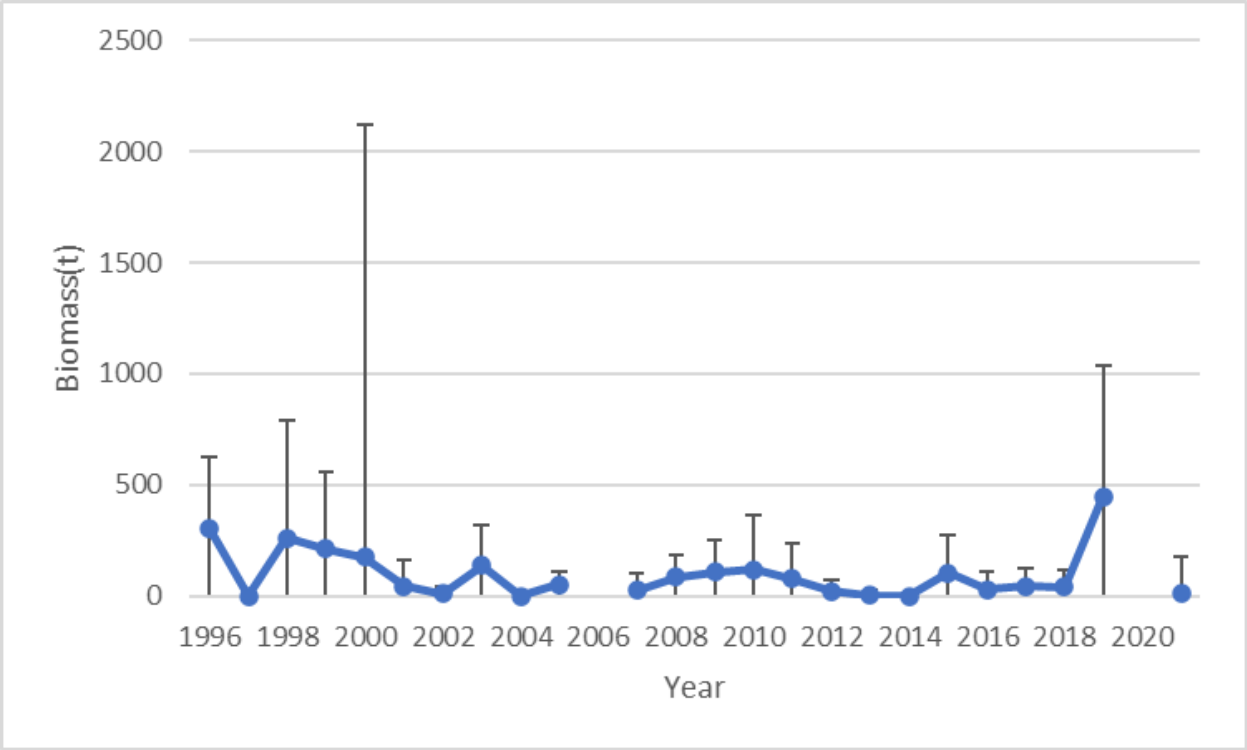

Figure 11. Biomass trends of Northern Wolffish in NAFO Subdivision 3Ps from the DFO-NL spring RV trawl survey, 1996–2021.

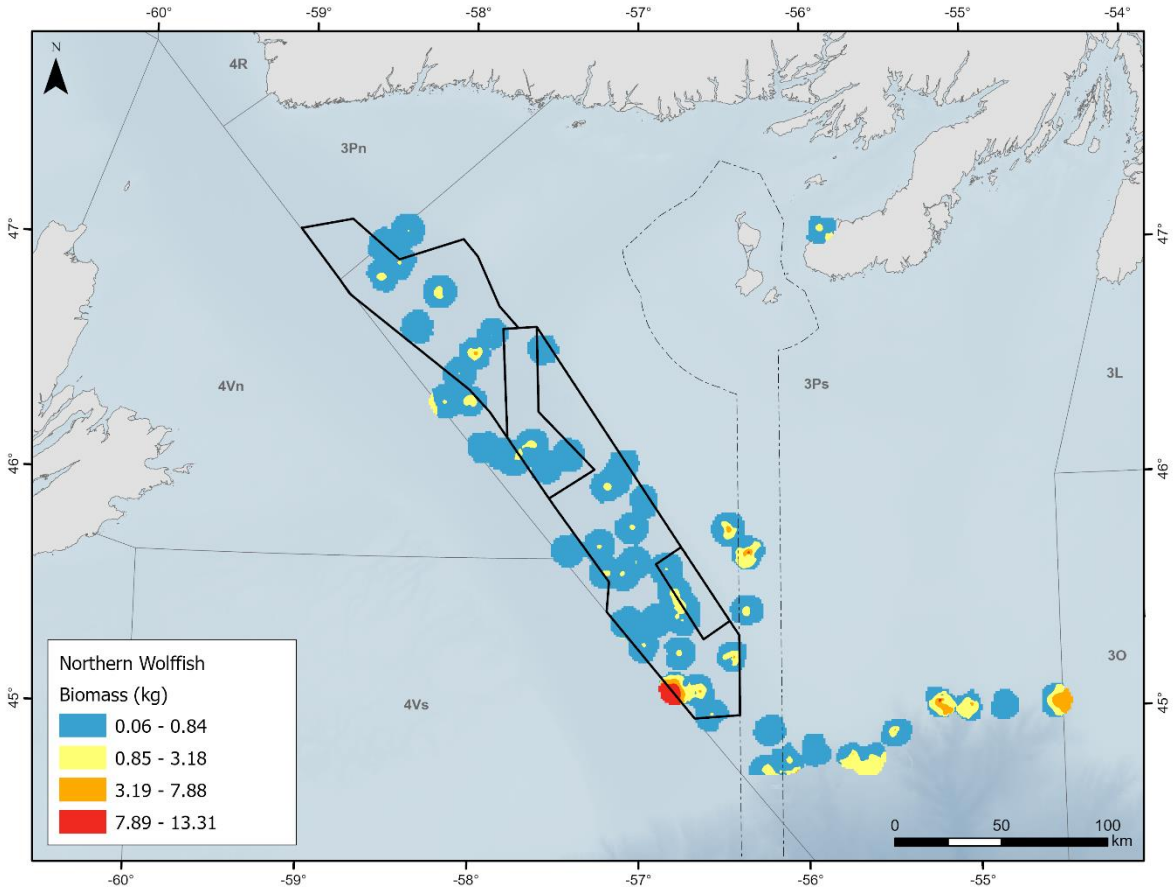

Figure 12. Inverse distance weighted (IDW) biomass of Northern Wolffish, based on DFO-NL's spring RV trawl survey in NAFO Subdivision 3Ps from 1996–2021, inclusive, using a variable search radius of 10 points to a maximum distance of 7,500 m and a power of two. The layer was classified based on natural breaks (Jenks). The Laurentian Channel MPA is shown as a solid black outline. Warmer colours (red and orange) represent higher biomass.

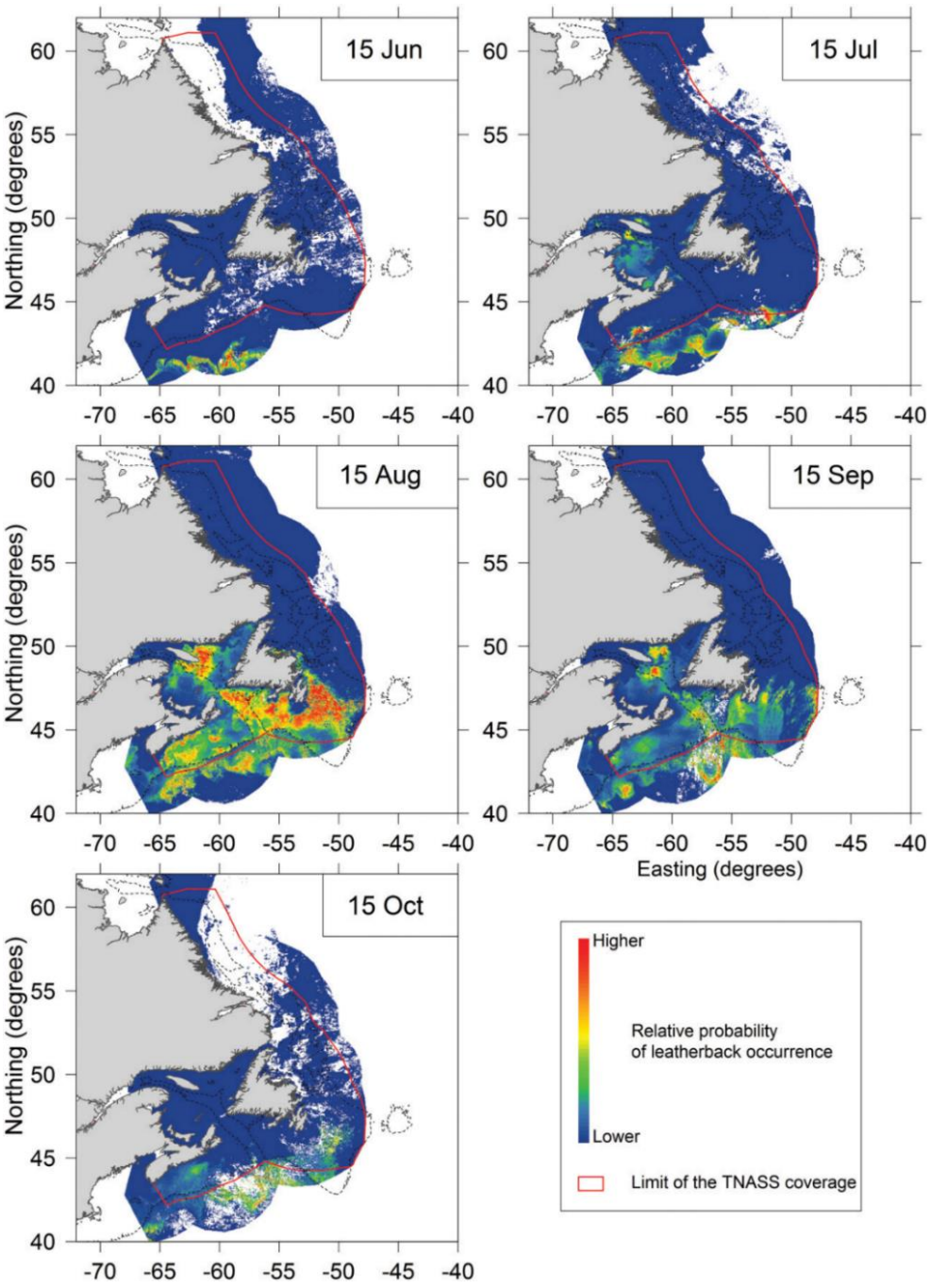

Figure 13. Relative probability of Leatherback Sea Turtle occurrence in Atlantic Canada, predicted for the period from 15 June to 15 October 2007, based on a General Algebraic Modeling System (GAMS) model linking DFO's TNASS aerial survey (Lawson and Gosselin 2009) observations to environmental variables. There were considerable seasonal changes in the relative probability of Leatherback Sea Turtle occurrence in Atlantic Canada, predicted for the period from 15 June to 15 October 2007, based on a GAMS model linking DFO's TNASS aerial survey (Lawson and Gosselin 2009) observations to environmental variables. This model included effect of 7 d lagged sea surface temperature, mean sea surface height anomalies observed during the current month, mean chlorophyll a concentration average over the last 30 d, and bottom slope. There are no predicted probabilities of Leatherback Sea Turtle occurrence from January to May and from November to December 2007 (from Mosnier et al. 2019). Warmer colours (red and orange) represent higher relative probability of occurrence

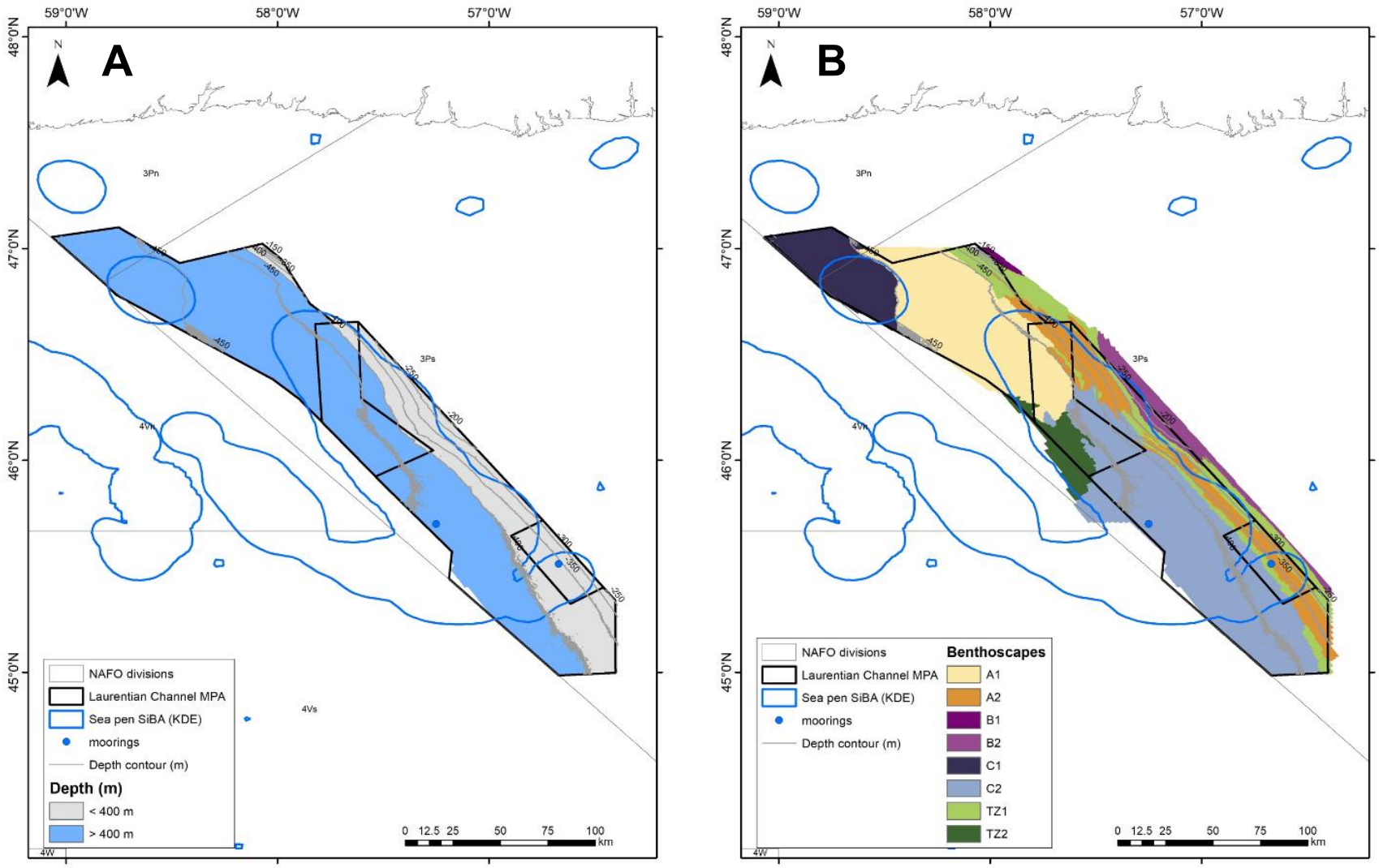

Figure 14. A) Depth distribution showing how most of the MPA is deeper than 400 m (light blue in panel A). Benthoscapes (panel B), and sea pen SiBAs (blue lines) of the Laurentian Channel MPA. Benthoscapes map layer (panel B) from Lacharité et al. (2020). Benthoscape colours are represented as follows: yellow – A1, orange – A2, dark purple – B1, light purple – B2, dark blue – C1, light blue – C2, light green – TZ1, and dark green – TZ2.

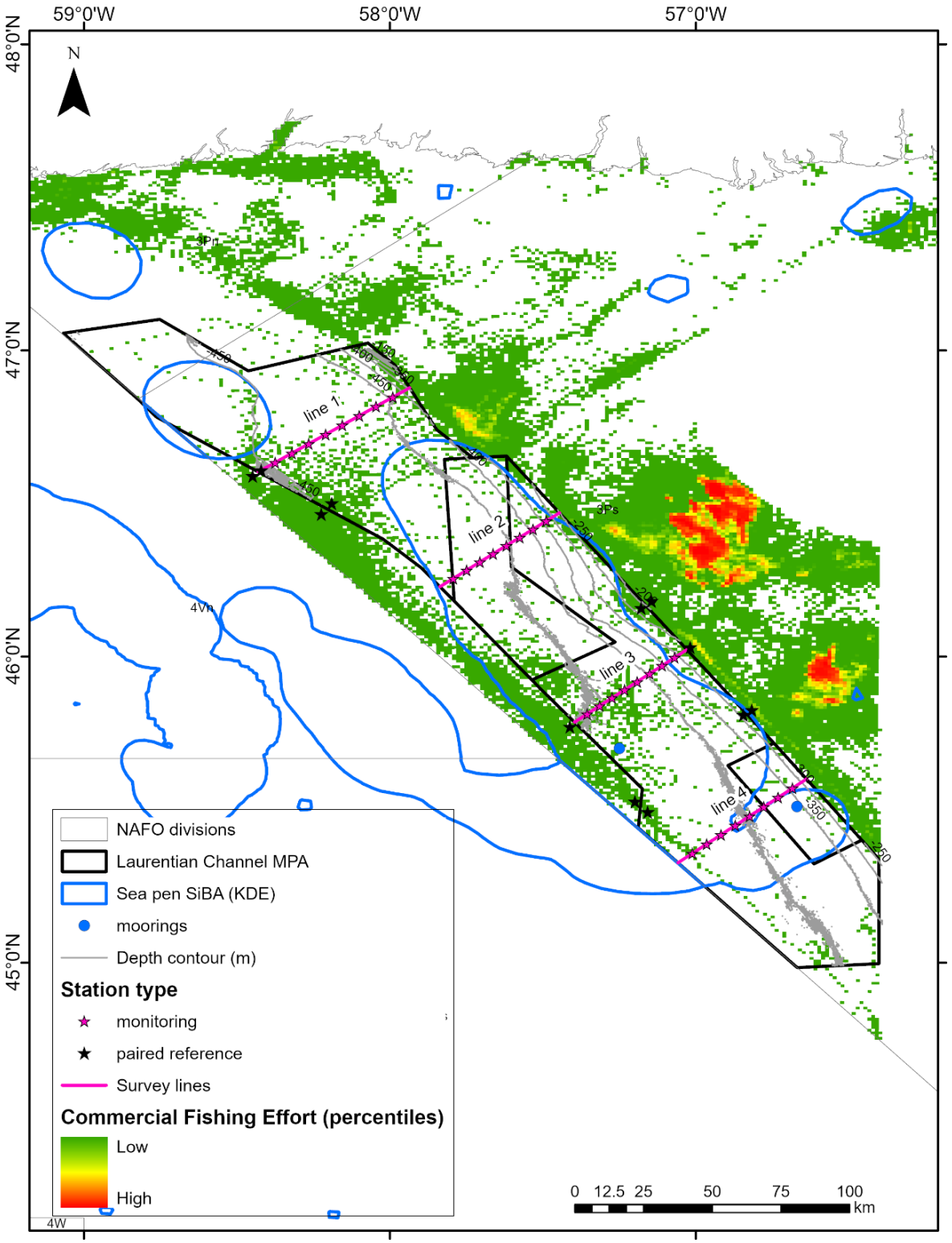

Figure 15. Commercial fishing effort (Vessel Monitoring System (VMS) percentiles) from Koen-Alonso et al. (2018) overlapped with the Laurentian Channel MPA. Areas in red represent high fishing effort and green low. Pink stars along survey lines 1–4 represent potential monitoring stations (eight per line) as part of a possible scenario, and black stars represent proposed paired reference stations where some fishing has taken place both inside and outside of the MPA.

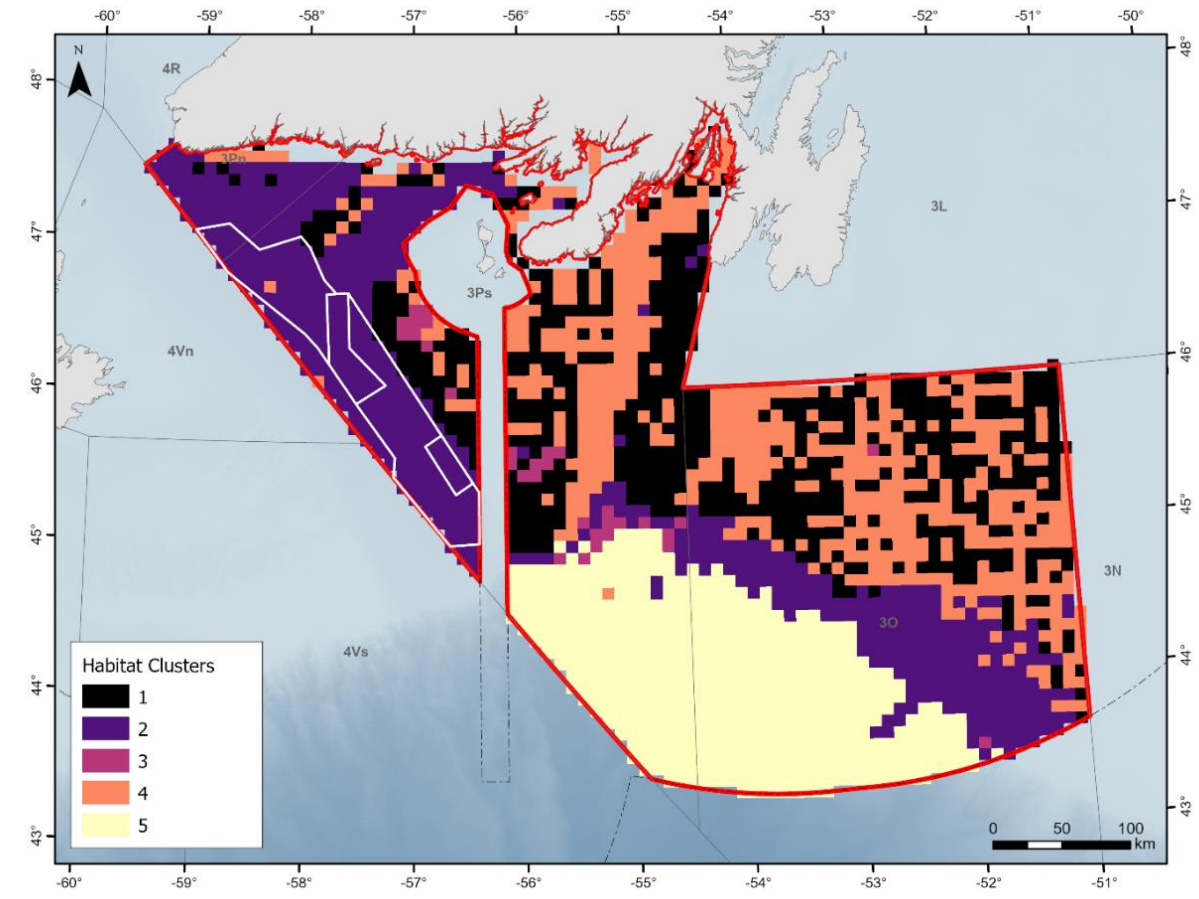

Figure 16. Map of habitat clusters from the k-means clustering analysis. The habitat mapping study area, encompassing NAFO Divisions 3OP within the Canadian Exclusive Economic Zone (EEZ) (dashed black line), is outlined in red. The Laurentian Channel MPA is shown in solid white.

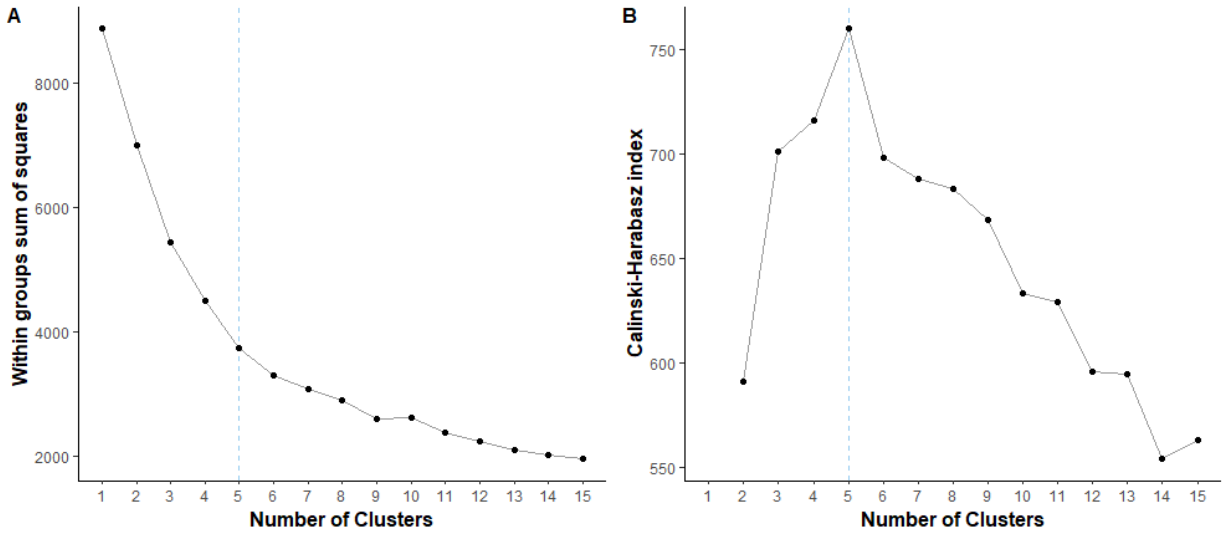

Figure 17. The within groups sum of squares (A) and the C-H index (B) used to determine the optimal number of clusters (dashed lines).

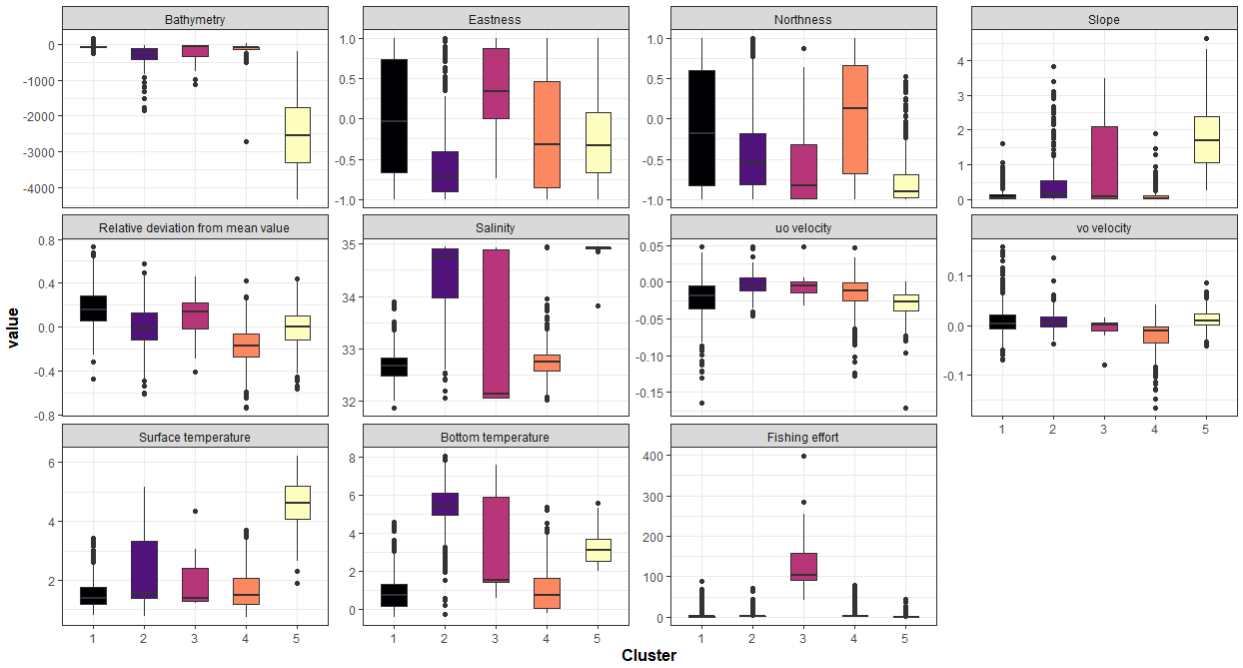

Figure 18. Boxplots showing the median and interquartile range of values for each abiotic variable across clusters.

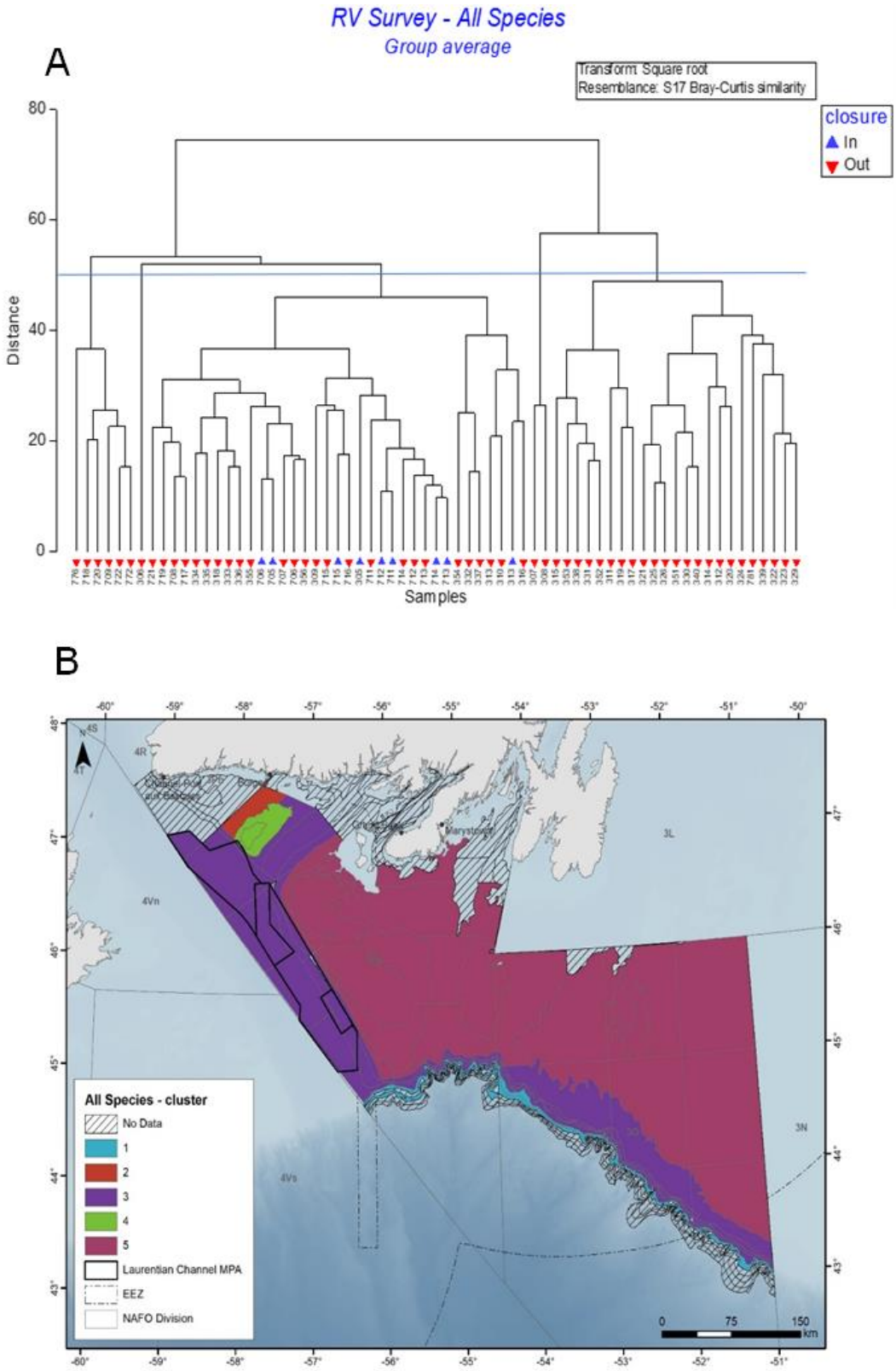

Figure 19. Strata-based community analysis for the all species group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Solid blue line in panel A indicates groupings over 50 distance.

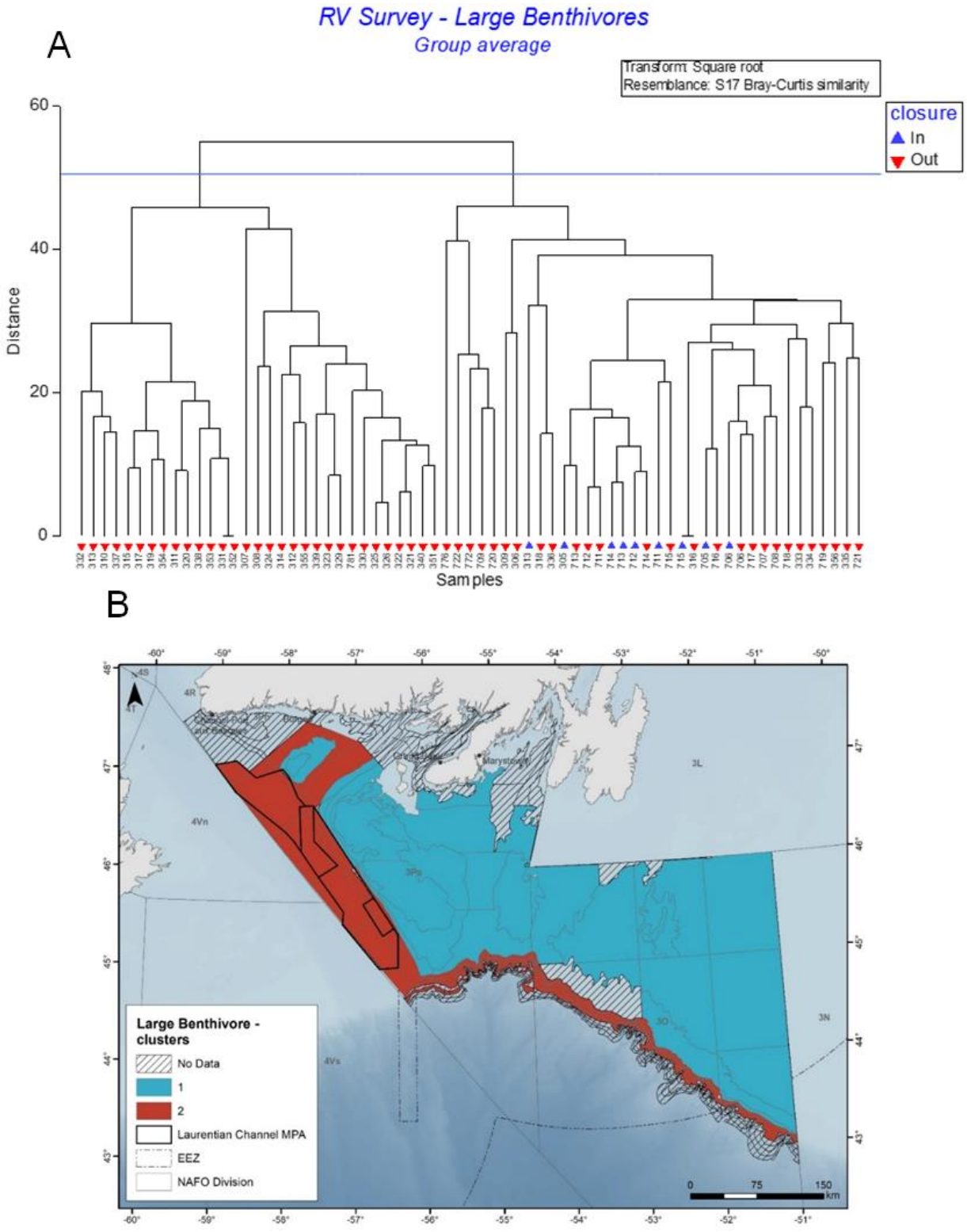

Figure 20. Strata-based community analysis for large benthivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

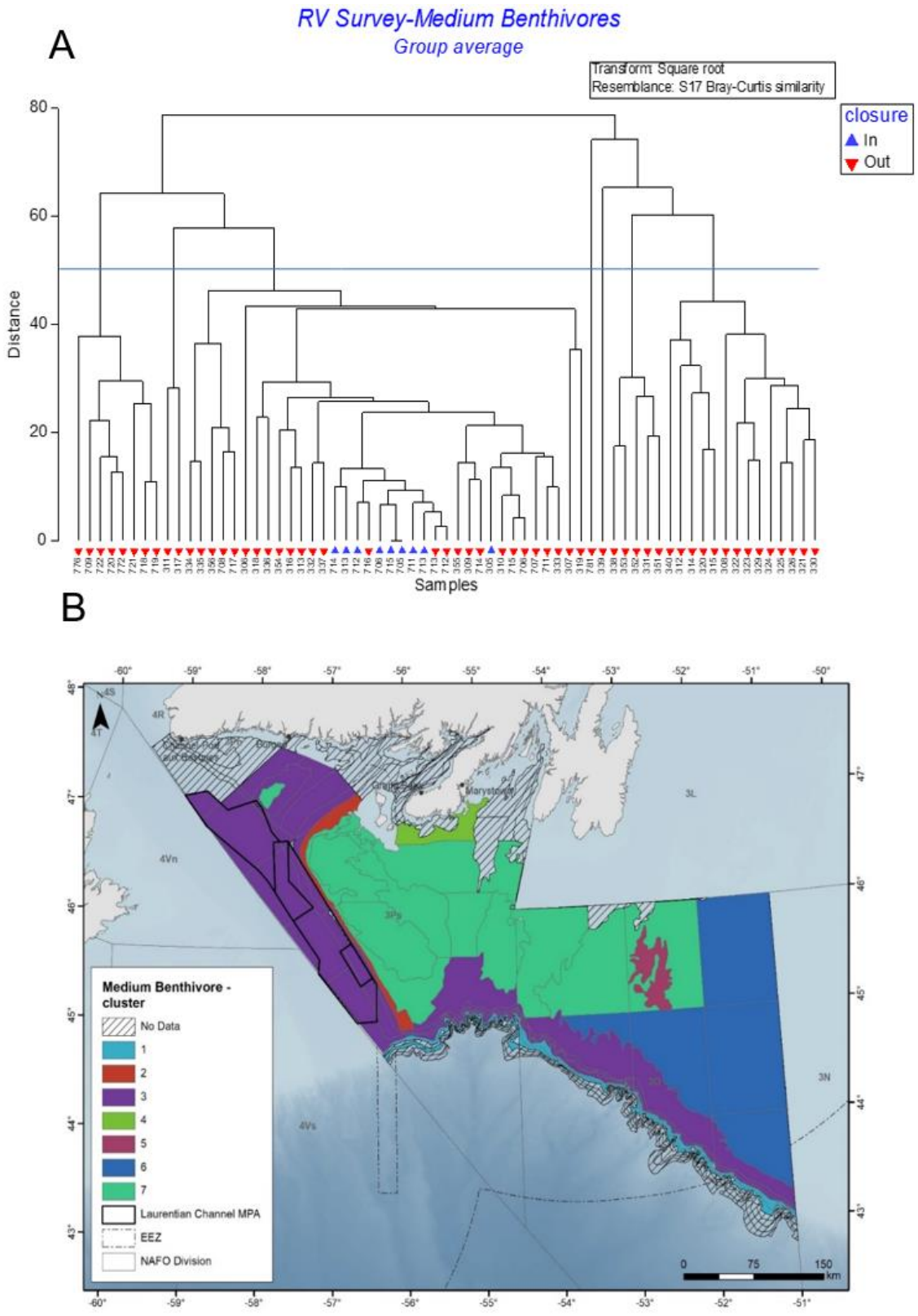

Figure 21. Strata-based community analysis for medium benthivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

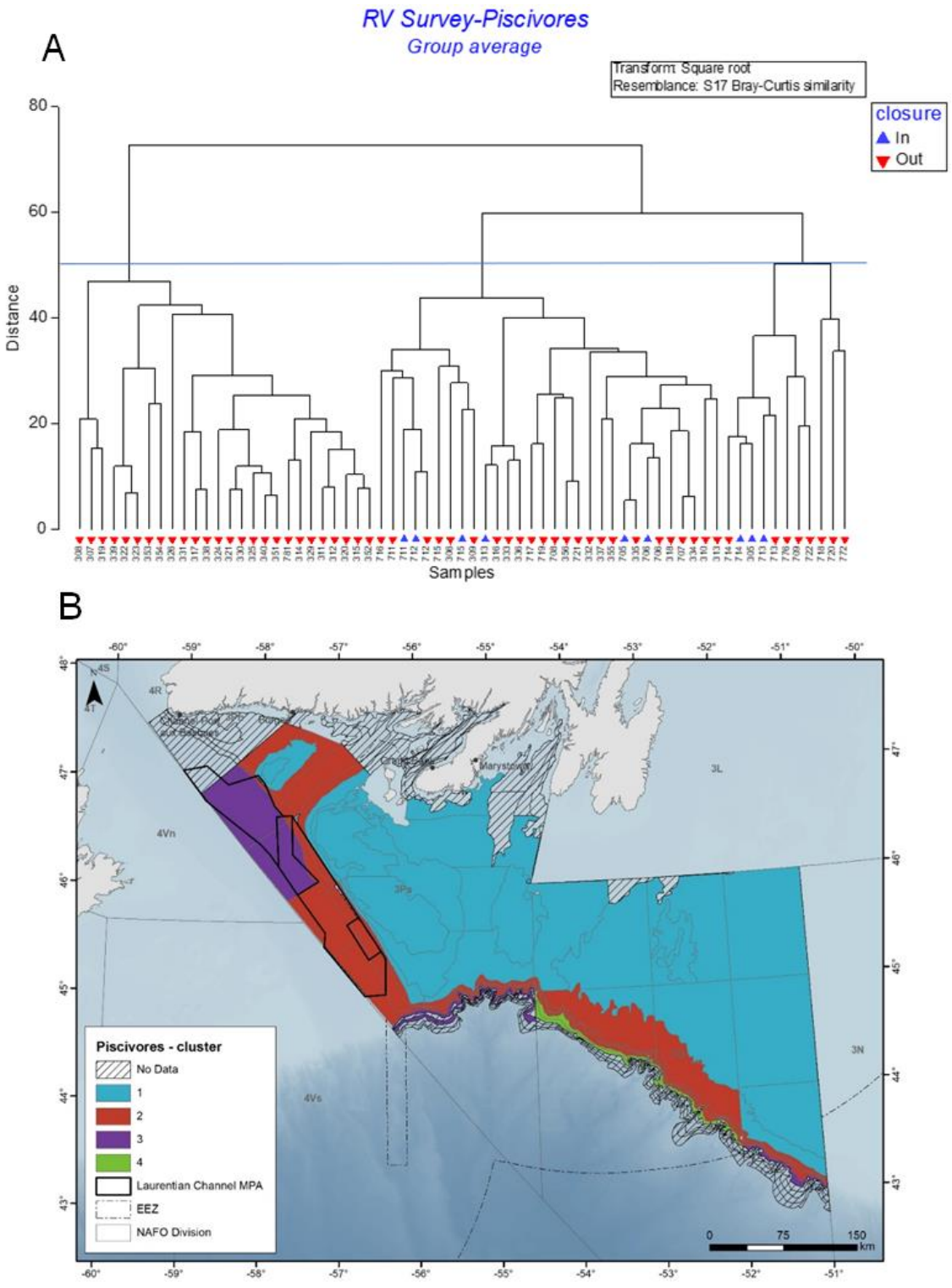

Figure 22. Strata-based community analysis for piscivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

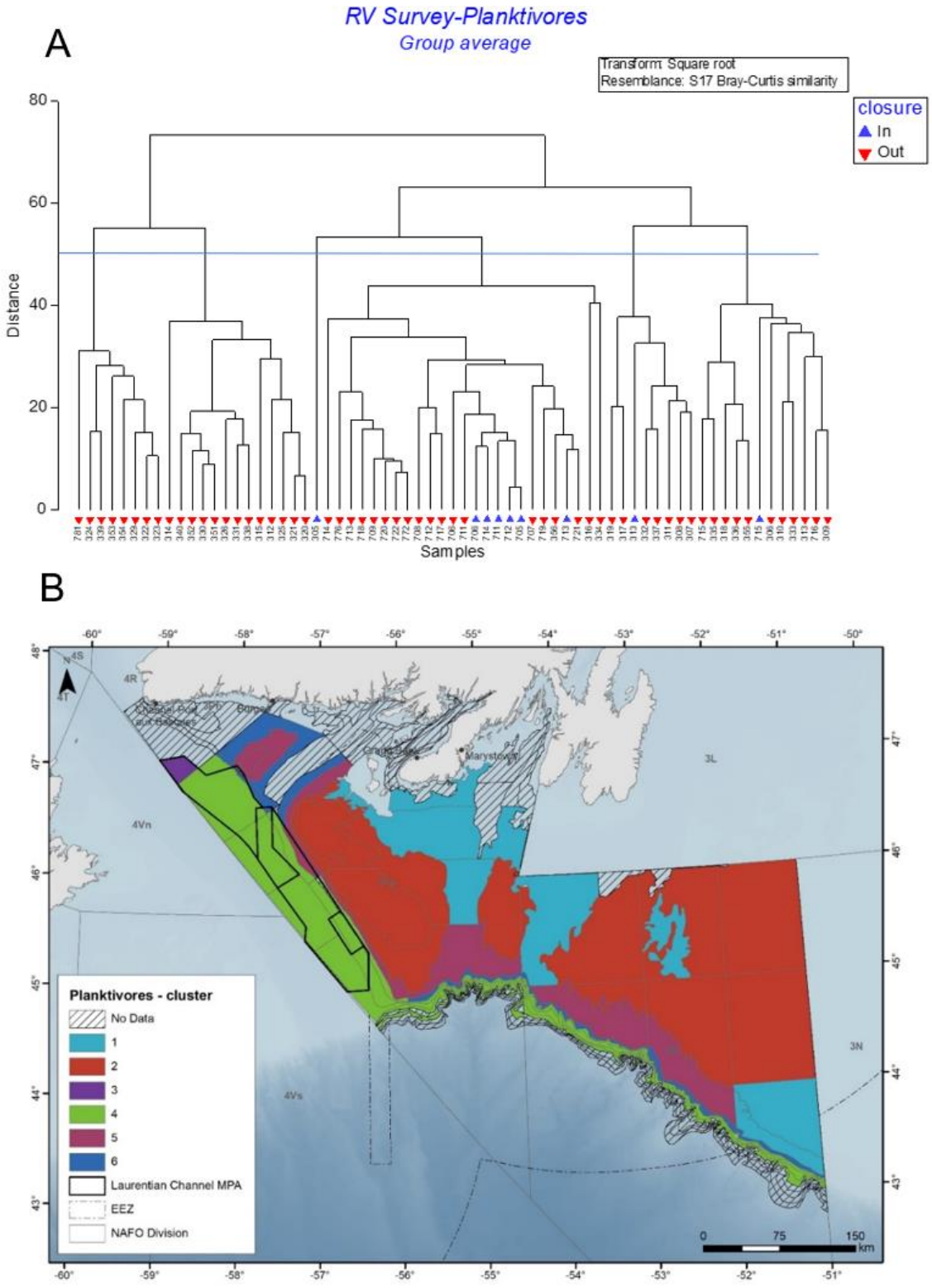

Figure 23. Strata-based community analysis for planktivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

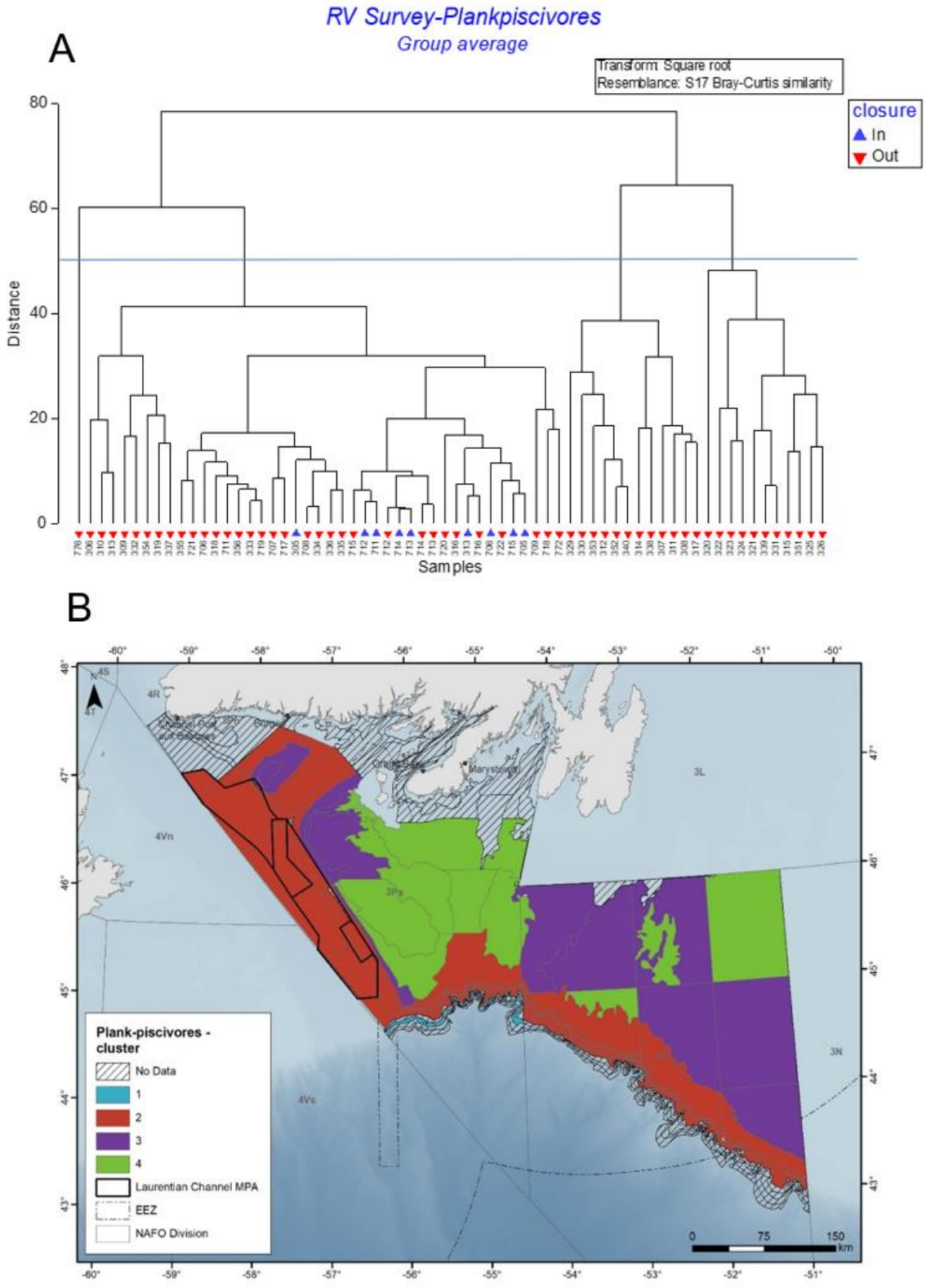

Figure 24. Strata-based community analysis for plank-piscivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

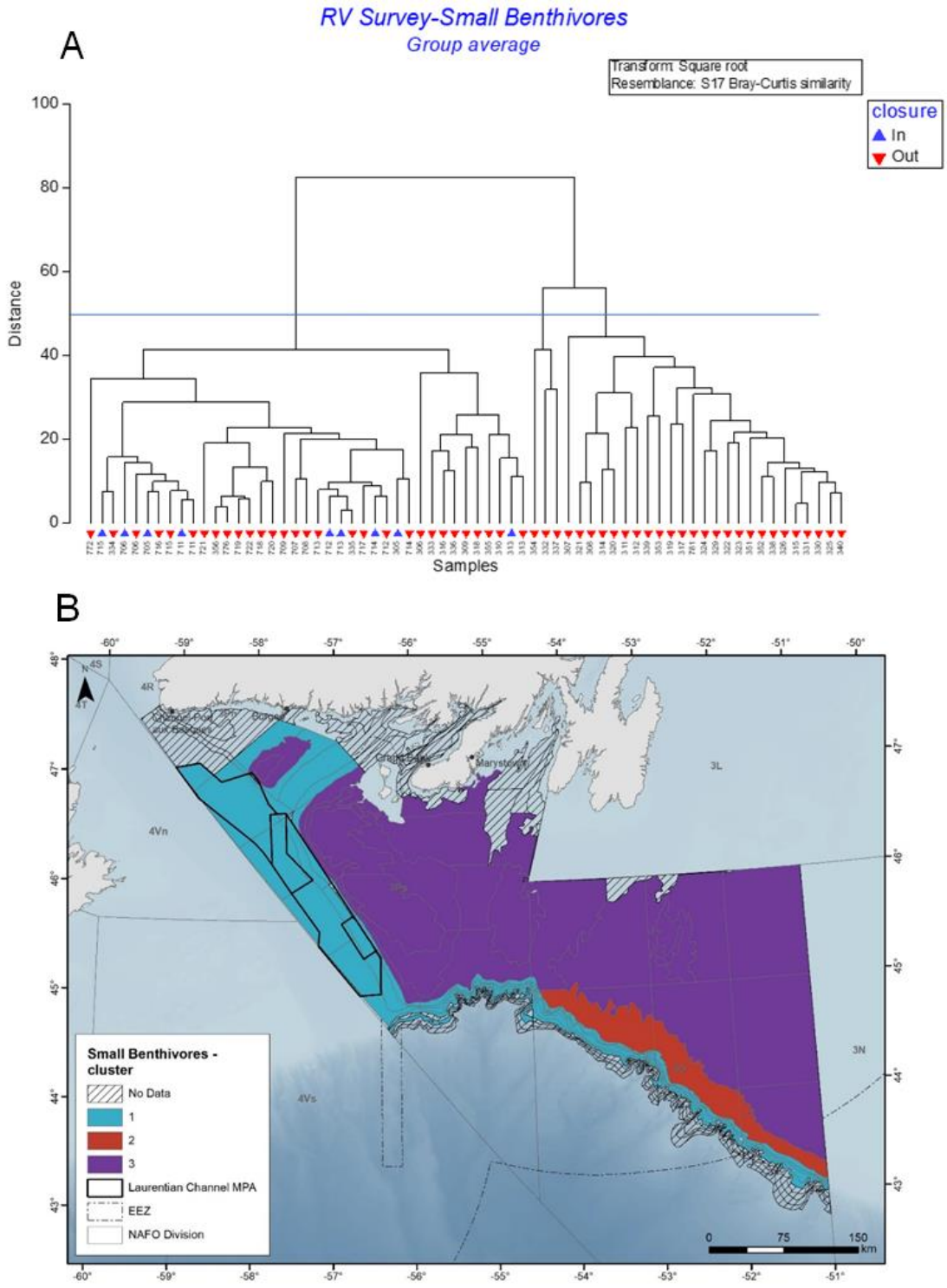

Figure 25. Strata-based community analysis for small benthivore fish functional group. A) Dissimilarity dendrogram plot and B) map of clusters with greater than 50 dissimilarity values. Blue line in panel A indicates groupings over 50 distances.

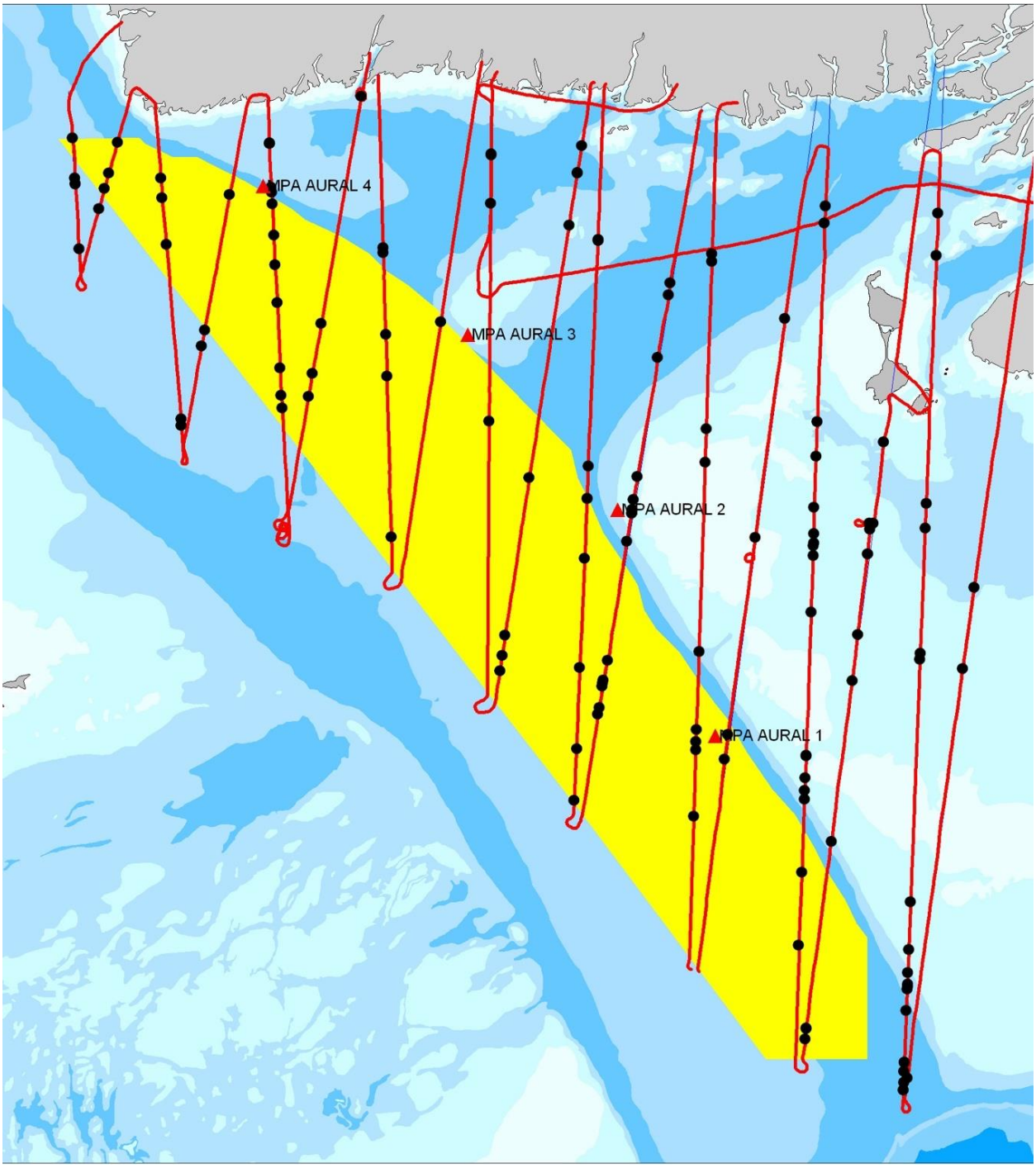

Figure 26. Aerial survey transect lines (red) flown by a DFO Science crew aboard a chartered DeHavilland Twin Otter 300 aircraft in the summer 2014. These transects crossed the Laurentian Channel MPA (yellow polygon is the Laurentian Channel AOI) at an altitude of 183 m and groundspeed of 185 km/hr. Visual sightings are indicated by black dots. Red triangles indicate positions of bottom-mounted AURAL acoustic recorders.

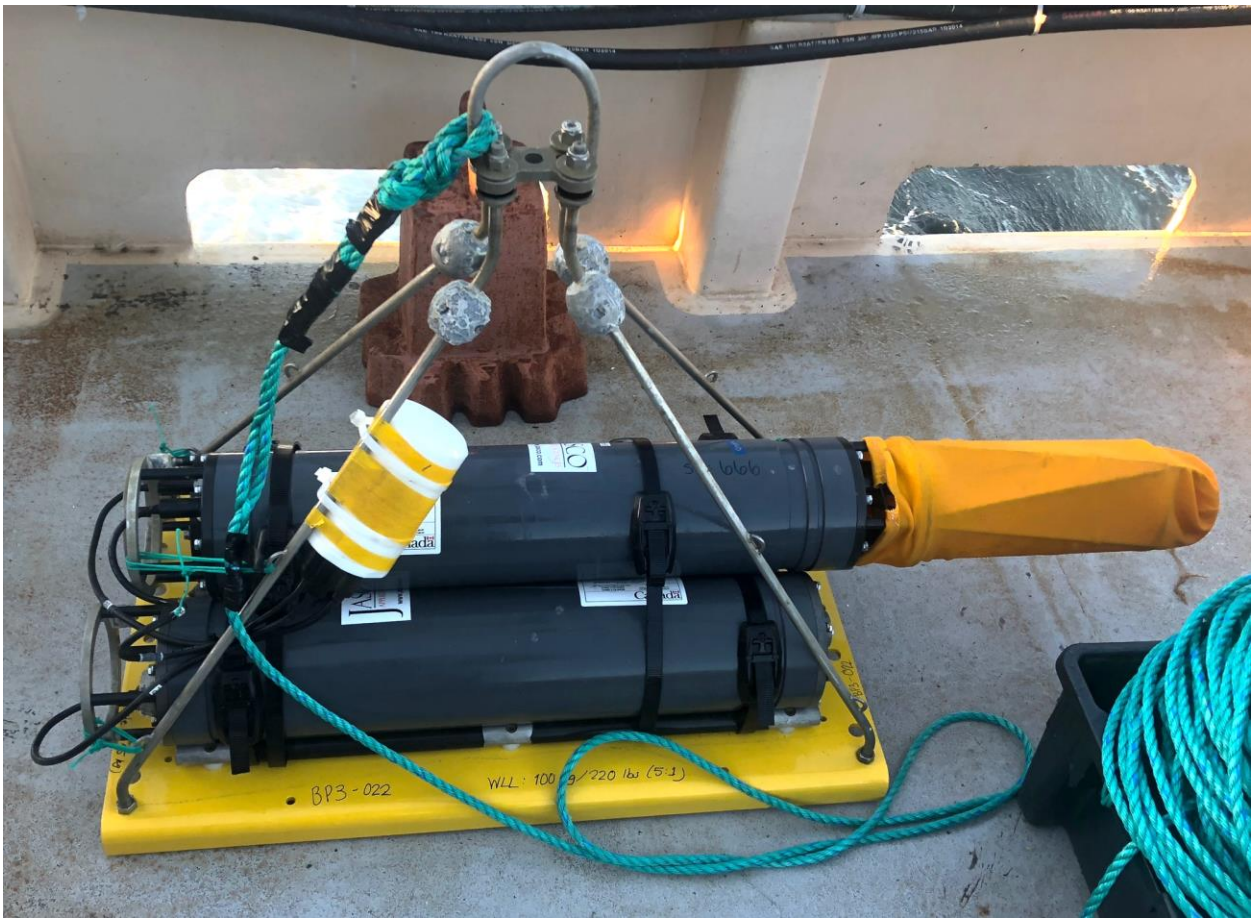

Figure 27. An AMAR autonomous acoustic recorder mooring prior to deployment to the seafloor.

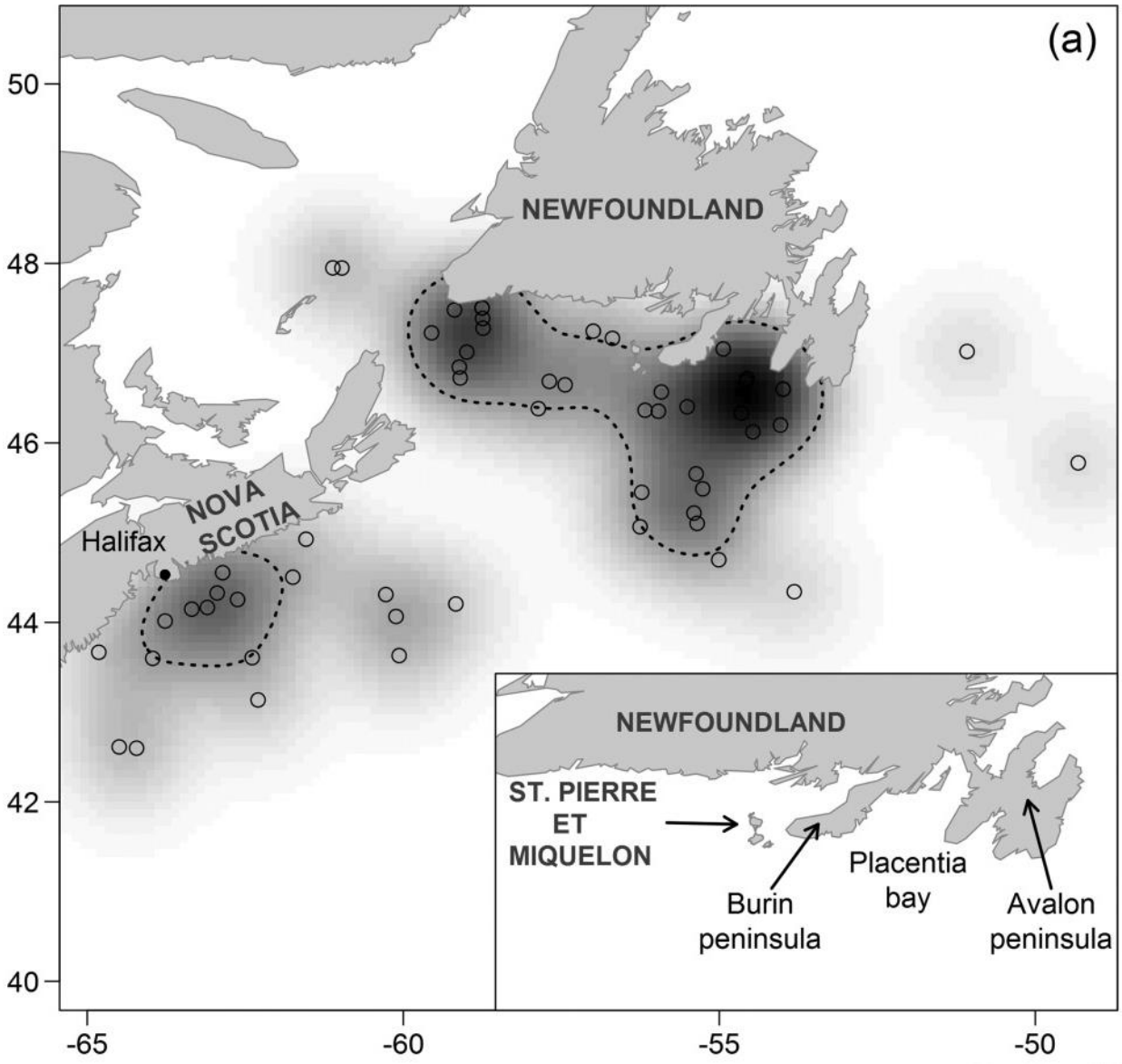

Figure 28. Kernel representation of the August density of Leatherback Sea Turtle sightings (open circles) using (a) the likelihood cross-validation method (LCV) applied to the TNASS data. The darker the shading, the greater the turtle density; the dotted curves represent the 50% kernel density contour (from Mosnier et al. 2018).

APPENDIX A

Table A1. List of species in the Small Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
ALFONSINO (NCN) CAU.LON.	*Caulolepis longidens*
ALLIGATORFISH (NS)	*Agonidae*
ALLIGATORFISH,ARCTIC	*Aspidophoroides olriki*
ALLIGATORFISH,COMMON	*Aspidophoroides monopterygius*
ALLIGATORFISH,NORTHERN	*Agonus decagonus*
ANGLEMOUTHS (NS)	*Cyclothone sp.*
ANGLEMOUTHS (NS)	*Gonostoma sp.*
ARGENTINE,LARGE EYED	*Nansenia groenlandica*
ATLANTIC GYMNAST	*Xenodermichthys (aleposomus) copei*
BATFISH,ATLANTIC	*Dibranchus atlanticus*
BIGSCALEFISHES, RIDGEHEADS	*Melamphaidae*
BLACK SWALLOWER	*Chiasmodon niger*
BLACKSMELT,GOITRE	*Bathylagus euryops*
BLACKSMELTS (NS)	*Bathylagus sp.*
BUTTERFISH (NS)	*Stromateidae*
CARDINALFISH,SHERBORN'S	*Rhectogramma sherborni*
DEEPSEA SCULPIN,PALLID	*Cottunculus thompsoni*
DEEPSEA SCULPIN,POLAR	*Cottunculus microps*
EELPOUT,SOFT	*Melanostigma atlanticum*
FANGTOOTH (Ogrefish) Ana	*Anoplogaster cornuta*
FEELERFISH,NOTCH	*Bathypterois dubius*
FOURBEARD ROCKLING	*Enchelyopus cimbrius*
FOURLINE SNAKEBLENNY	*Eumesogrammus praecisus*
GRENADIER,COMMON (MARLIN)	*Nezumia bairdi*
GRENADIER,ROUGHNOSE	*Trachyrhynchus murrayi*
GRENADIERS (NS)	*Macrouridae*
GRUBBY	*Myoxocephalus aeneus*
GUNNELS (NS)	*Pholidae*
HATCHETFISHES (NS)	*Sternoptychidae*
HOOKEAR SCULPIN (NS)	*Artediellus sp.*
LEPIDION (NCN)	*Lepidion (haloporphyrus) eques*
LIGHTFISHES (NS)	*Gonostomidae*
LOOSEJAW	*Malacosteus niger*
LUMPFISH (NS) EUM.SP.	*Eumicrotremus sp.*
MAILED SCULPINS (NS)	*Triglops sp.*
MANEFISH, ATLANTIC	*Caristius groenlandicus*
PLATYTROCTES APUS	*Platytroctes apus*
SCULPIN, ARCTIC	*Myoxocephalus scorpioides*
SCULPIN,ARCTIC STAGHORN	*Gymnocanthus tricuspis*
SCULPIN,SPATULATE	*Icelus spatula*
SCULPINS (NS)	*Cottidae*
SEA DEVIL, WARTED	*Cryptosaras couesi*
SEASNAILS (NS)	*Liparidae*
SHANNY,DAUBED	*Lumpenus maculatus*
SLIMEHEAD	*Hoplostethus sp.*
SMELTS, DEEPSEA (NS)	*Bathylagidae*
SPINYFIN	*Diretmus argenteus*
TAPIRFISH, SHORTSPINE	*Macdonaldia rostrata*
THREEBEARD ROCKLING (NS)	*Gaidropsarus sp.*
TWOHORN SCULPIN (NS)	*Icelus sp.*
WOLF EEL (NS)	*Lycenchelys sp.*

Table A2. List of species in the Medium Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
BIGEYES (NS)	*Priacanthidae*
BLENNIES (NS)	*Lumpenus sp.*
DUCKBILL EEL	*Nessorhamphus ingolfianus*
EELPOUT (NS)	*Lycodes sp.*
EELPOUT,ARCTIC	*Lycodes reticulatus*
EELPOUT,ESMARK'S	*Lycodes esmarki*
EELPOUT,VAHL'S	*Lycodes vahlii*
FISH DOCTOR (GREEN OCEAN)	*Gymnelis viridis*
FLOUNDER,WINTER	*Pseudoplueronectes americanus*
GRENADIER,LONGNOSE	*Coelorhynchus carminatus*
GRENADIER,ROUNDNOSE	*Coryphaenoides rupestris*
HAKE,BLUE	*Antimora rostrata*
HAKE,RED (SQUIRREL)	*Urophycis chuss*
HALOSAURUS (NS)	*Halosauridae*
LIPOGENYS	*Lipogenys gillii*
LONGNOSE EEL	*Synaphobranchus kaupi*
LUMPFISH,COMMON	*Cyclopterus lumpus*
MORA (NCN) HAL.AFF.	*Halargyreus affinis*
MORA (NCN) HAL.JOH.	*Halargyreus johnsonii*
MORAS	*Moridae*
SCULPIN, RIBBED (HORNED)	*Myoxocephalus sp.*
SCULPIN,FOURHORN	*Myoxocephalus quadricornis*
SCULPIN,LONGHORN	*Myoxocephalus octodecemspinosus*
SCULPIN,SHORTHORN	*Myoxocephalus scorpius*
SEA RAVEN	*Hemitripterus americanus*
SHARK,DEEPSEA CAT	*Apristurus profundorum*
SKATE,DEEPWATER (ROUND)	*Raja fyllae*
SKATE,LITTLE	*Raja erinacea*
SKATE,SOFT	*Raja mollis*
SMOOTH SKATE	*Malacoraja senta*
SNAKE BLENNY	*Lumpenus lumpretaeformis*
SNIPE EEL (NCN)	*Serrivomer brevidentatus*
SNIPE EEL,SHORTNOSE	*Serrivomer beani*
SNUBNOSE EEL	*Simenchelys parasiticus*
WHITING,BLUE	*Micromesistius poutassou*
WITCH FLOUNDER	*Glyptocephalus cynoglossus*
YELLOWTAIL FLOUNDER	*Limanda ferruginea*

Table A3. List of species in the Large Benthivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
AMERICAN PLAICE	*Hippoglossoides platessoides*
ANGLER,COMMON(MONKFISH)	*Lophius americanus*
CHIMAERA,DEEPWATER	*Hydrolagus affinis*
CHIMAERA,KNIFENOSE	*Rhinochimaera atlantica*
CHIMAERA,LONGNOSE	*Harriotta raleighana*
CHIMAERAS (NS)	*Chimaeriformes (holocephali) (order)*
CUSK	*Brosme brosme*
DEEPSEA ANGLER,BIG	*Ceratius holboelli*
GRENADIER,ROUGHHEAD	*Macrourus berglax*
HADDOCK	*Melanogrammus aeglefinus*
HAGFISH, ATLANTIC	*Myxine glutinosa*
POUT,OCEAN (COMMON)	*Macrozoarces americanus*
SEA DEVILS (NS)	*Ceratiidae*
SKATE,ABYSSAL	*Raja bathyphila*
SKATE,ARCTIC	*Raja hyperborea*
SKATE,BARNDOOR	*Raja laevis*
SKATE,JENSEN'S	*Raja jenseni*

Common Name (as displayed in NL DFO Archive)	Scientific Name
SKATE,SPINYTAIL	*Raja (bathyraja) spinicauda*
SKATE,THORNY	*Raja radiata*
SKATE,WHITE	*Raja lintea*
SKATE,WINTER (SPOTTED)	*Leucoraja ocellata*
SKATES (NS) RAJA SP.	*Raja sp.*
SMOOTHHEADS (NS)	*Alepocephalidae*
SNIPE EEL,ATLANTIC	*Nemichthys scolopaceus*
SPINY EELS (NS)	*Notacanthidae*
STURGEON,ATLANTIC	*Acipenser oxyrhynchus*
TAPIRFISH,LARGE SCALE	*Notacanthus nasus*
WOLFFISH,ATLANTIC (STRIPED)	*Anarchichas lupus*
WOLFFISH,NORTHERN (BROADHEAD)	*Anarhichas denticulatus*
WOLFFISH,SPOTTED	*Anarhichas minor*
WOLFFISHES (NS)	*Anarhichadidae*
WRYMOUTH	*Cryptacanthodes maculatus*

Table A4. List of species in the Piscivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
ANGLERS	*Lophiformes (pediculati) (order)*
BARRACUDINAS (NS)	*Paralepididae*
COD,ATLANTIC	*Gadus morhua*
COD,GREENLAND (ROCK)	*Gadus ogac*
COD,POLAR	*Arctogadus glacialis*
CODS,HAKES,ETC.	*Gadiformes (anacanthini) (order)*
DAGGERTOOTH	*Anotopterus pharao*
DOGFISH SHARKS (NS)	*Squalidae*
DOGFISH,BLACK	*Centroscyllium fabricii*
DOGFISH,SPINY	*Squalus acanthias*
DRAGONFISH,BOA	*Stomias boa ferox*
DRAGONFISHES,SCALED (NS)	*Stomiatidae*
FROSTFISH	*Benthodesmus simonyi*
GADOIDS (NS)	*Gadidae*
GREENEYE,LONGNOSE	*Parasudis truculentus*
GULPER (NCN) SAC.AMP.	*Saccopharynx ampullaceus*
HAKE (NS) MER.SP.	*Merluccius sp.*
HAKE,OFFSHORE SILVER	*Merluccius albidus*
HAKE,SILVER	*Merluccius bilinearis*
HAKE,WHITE (COMMON)	*Urophycis tenuis*
HALIBUT (ATLANTIC)	*Hippoglossus hippoglossus*
LAMPREY, SEA	*Petromyzon marinus*
LANCETFISH, SHORTNOSED	*Alepisaurus brevirostis*
LANCETFISH,LONGNOSE	*Alepisaurus ferox*
LANCETFISHES (NS)	*Alepisauridae (plagyodontidae)*
LING,BLUE	*Molva brykelange*
MAKO,SHORTFIN	*Isurus oxyrinchus*
POLLOCK	*Pollachius virens*
PORBEAGLE	*Lamna nasus*
SCABBARDFISH,BLACK	*Aphanopus carbo*
SHARK,BASKING	*Cetorhinus maximus*
SHARK,GREENLAND	*Somniosus microcephalus*
SHARK,PORTUGUESE	*Centroscymnus coelolepis*
SHARKS,MACKEREL (NS)	*Lamnidae*
TURBOT (GREENLAND HALIBUT)	*Reinhardtius hippoglossoides*
VIPERFISH	*Chauliodus sloani*

Table A5. List of species in the Plank-Piscivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
BEARDFISHES (NS)	*Polymixiidae*
COD,ARCTIC	*Boreogadus saida*
GULPER,PELICAN	*Eurypharynx pelecanoides*
HAKE,LONGFIN	*Urophycis chesteri*
REDFISH, DEEP WATER	*Sebastes mentella*
REDFISH,ACADIAN	*Sebastes fasciatus*
REDFISH,GOLDEN(MARINUS)	*Sebastes marinus*
ROCKFISHES (NS)	*Scorpaenidae*
SCOPELOSAURUS (NS)	*Scopelosauridae*
SEASNAIL (NS) CAR.SP.	*Careproctus sp.*

Table A6. List of species in the Planktivores Functional Group.

Common Name (as displayed in NL DFO Archive)	Scientific Name
ALEWIFE (GASPERAUX)	*Alosa pseudoharengus*
ARGENTINE,ATLANTIC	*Argentina silus*
ARGENTINE,STRIATED	*Argentina striata*
ARGENTINES (NS)	*Argentinidae*
BILLFISH	*Scomberesox saurus*
CAPELIN	*Mallotus villosus*
HERRING,ATLANTIC	*Clupea harengus*
HERRING,BLACK	*Bathytroctes sp.*
LANTERNFISHES (NS)	*Myctophidae*
MACKEREL,ATLANTIC	*Scomber scombrus*
MENHADEN, ATLANTIC	*Brevoortia tyrannus*
RONDELETIIDAE	*Whalefishes, redmouth*
SAND LANCE,OFFSHORE	*Ammodytes dubius*
SHAD, AMERICAN	*Alosa sapidissima*
SHANNY,RADIATED	*Ulvaria subbifurcata*
STICKLEBACK,FOURSPINE	*Apeltes quadracus*
STICKLEBACK,THREESPINE	*Gasterosteus aculateus*
STICKLEBACKS (NS)	*Gasterosteiformes (order)*