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# Biophysical and Ecological Overview of the Fundian Channel-Browns Bank Area of Interest (AOI)

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## Foreword

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

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| | |
|---|---|
| AOI | Area of Interest |
| AZMP | Atlantic Zone Monitoring Program |
| BMSY | Biomass for Maximum Sustainable Yield |
| BS | Bottom Salinity |
| BT | Bottom Temperature |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| CPR | Continuous Plankton Recorder |
| CL | Carapace length |
| DFO | (Department of) Fisheries and Oceans Canada |
| DU | Designatable Unit |
| EBSA | Ecologically and Biologically Significant Area |
| ESS | Eastern Scotian Shelf |
| ICCAT | International Commission for the Conservation of Atlantic Tuna |
| IUCN | International Union for the Conservation of Nature |
| Ka | thousand years ago |
| LFA | Lobster Fishing Area |
| LIS | Laurentide Ice Sheet |
| LJFL | Lower Jaw Fork Length |
| Ma | million years ago |
| MSC | Marine Stewardship Council |
| MSE | Management Strategy Evaluation |
| MPA | Marine Protected Area |
| MSY | Maximum Sustainable Yield |
| NAFO | Northwest Atlantic Fisheries Organization |
| NAO | North Atlantic Oscillation |
| NECCCA | Northeast Channel Coral Conservation Area |
| NEFSC | Northeast Fisheries Science Center |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |

| | |
|---|---|
| NRCan | (Department of) Natural Resources Canada |
| PCI | Phytoplankton Colour Index |
| PSAT | Pop-up Satellite Tag |
| RCP | Representative Concentration Pathway |
| RV | Research Vessel |
| SARA | Species at Risk Act |
| SFGAC | Scotia Fundy Groundfish Advisory Committee |
| SSE | Scotian Shelf Ecosystem |
| SSS | Sea Surface Salinity |
| SST | Sea Surface Temperature |
| TAC | Total Allowable Catch |
| WSS | Western Scotian Shelf |

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# ABSTRACT

The Biophysical and Ecological Overview of the Fundian Channel-Browns Bank Area of Interest (AOI) summarizes what is known about key physical and biological components of the Fundian Channel-Browns Bank ecosystem. These key attributes and description of their ecosystem function can be used to inform the development of Conservation Objectives and management measures, should the study area be established as a Marine Protected Area under Canada's *Oceans Act*. The Fundian Channel-Browns Bank is an offshore AOI that includes representative portions of the continental slope, Browns Bank, Georges Basin, the Fundian Channel, and Northeast Channel. Diverse assemblages of fishes and invertebrates are associated with the correspondingly diverse topographic features and unique oceanographic processes of the area. Significant concentrations of corals and sponges have been identified within the Northeastern Channel Coral Conservation Area and southern Browns Bank that are encompassed by the proposed boundaries. High productivity within the AOI is linked to the unique oceanographic features including upwelling and circulation gyres, as well as dynamic features of the warm Gulf Stream. The AOI encompasses an area of highly suitable habitat for juvenile Atlantic Halibut, as well as several depleted species and species at risk including Atlantic Cod (Endangered – COSEWIC), Atlantic Wolffish (Special Concern – SARA), Cusk (Endangered – COSEWIC), Spiny Dogfish (Special Concern – COSEWIC), Smooth Skate (Special Concern – COSEWIC), Thorny Skate (Special Concern – COSEWIC), and White Hake (Threatened – COSEWIC). The area also encompasses foraging habitats for cetaceans, sea turtles and large pelagic fishes such as Bluefin Tuna and Swordfish. The Fundian Channel-Browns Bank area is also noted as important foraging ground for most functional guilds of marine birds, including several species listed by SARA and the IUCN.

# INTRODUCTION

## CONTEXT

The Government of Canada has agreed to a suite of international biodiversity conservation goals and targets (the Convention on Biological Diversity 2011–2020 Strategic Plan for Biodiversity's Aichi Targets) and adopted complementary domestic 2020 Biodiversity Goals and Targets for Canada. Both international and domestic targets (Aichi Target 11 and Canada's Target 1) call for the conservation of 10% of coastal and marine areas by 2020. Further, to highlight these targets as a priority, the Government of Canada identified an interim target of 5% protection that was achieved in the fall of 2017.

The designation of new Marine Protected Areas (MPAs) in Canadian waters has been identified as one part of the national strategy to meet the Conservation Targets. Under the *Oceans Act*, the Department of Fisheries and Oceans Canada (DFO) is authorized to protect selected coastal and ocean areas through the establishment of MPAs. The Fundian Channel-Browns Bank was announced as an AOI on March 22, 2018. It was identified, in part, through an MPA network design analysis for the Scotian Shelf Bioregion that considered available ecological and economic information. Discussions with other government agencies, First Nations and Indigenous groups, and key stakeholders also informed the selection of this AOI.

Within the context of the emerging MPA network, the Fundian Channel-Browns Bank AOI encompasses many of the conservation priorities that have been identified for the Scotian Shelf Bioregion (DFO 2018c). Some of the most notable ecological features identified during the site selection process include significant concentrations of gorgonian corals (e.g., Bubblegum Coral (*Paragorgia arborea*)); significant concentrations of sponges; areas of high diversity and productivity for fish and invertebrate species, including larvae; important foraging habitat for various seabird species; and distinctive oceanographic processes, such as upwelling that creates unique ecological conditions. This area may include a migratory corridor between the Gulf of Maine and Bay of Fundy. This area has been noted to include habitat for a variety of species of concern including Atlantic Cod (*Gadus morhua,* hereinafter Cod; Endangered – Committee on the Status of Endangered Wildlife in Canada (COSEWIC), Atlantic Wolffish (*Anarhichas lupus*; Special Concern – Species at Risk Act (SARA), Cusk (*Brosme brosme*; Endangered – COSEWIC), Spiny Dogfish (*Squalus acanthias,* Special Concern – COSEWIC), Smooth Skate (*Malacoraja senta*; Special Concern – COSEWIC), Thorny Skate (*Amblyraja radiata*; Special Concern – COSEWIC), and White Hake (*Urophycis tenuis*; Threatened – COSEWIC). Another defining characteristic of the AOI is the broad-range of habitats it encompasses, including bank, basin, channel, shelf edge, and slope habitats.

The identification of an AOI is a first step in the assessment process that aids in decisions toward formal MPA designation. Once an AOI is identified, more detailed information on the key biophysical and ecological attributes of the area is required, especially as it pertains to potential conservation priorities and their linkages to the surrounding ecosystem. A review of available scientific knowledge will provide details on conservation priorities and highlight additional important ecological features of the area. The biophysical and ecological overview will also assist in formulating and/or refining conservation objectives, delineating the proposed MPA boundary (and zones if required), and completing an ecological risk analysis to inform the development of the regulatory approach for the MPA. The information contained within will also inform subsequent advice on monitoring protocols and strategies, identification of information gaps requiring further research, and the development of a management plan for the area.

Areas adjacent to the AOI may need to be considered in this exercise to capture the necessary breadth and scope of the various components of the ecosystem. The Fundian Channel-Browns Bank AOI includes two geographically separate components centered on Georges Basin to the west and the Fundian Channel[1] and part of southern Browns Bank to the east. The study area for this overview will span the southwestern Scotian Shelf with specific focus on the Northeast Channel, Browns Bank, Georges Bank and Georges Basin.

The Ecosystems Management Sector of DFO has requested DFO Science provide advice and supporting document(s) through this Canadian Science Advisory Secretariat Regional Peer Review to inform the establishment of the Fundian Channel-Browns Bank AOI as an MPA. The Ecosystems Management Sector will be conducting consultations concerning the MPA establishment process in 2018 onwards.

## PHYSICAL SETTING

The Fundian Channel-Browns Bank is an offshore AOI of approximately 7,200 km$^2$ composed of two geographically separate components (Figure 1). The western component of the AOI is centered on Georges Basin and the larger eastern component includes portions of Browns Bank, Fundian Channel, the Scotian Shelf, and the continental slope (Table 1). The western-most boundary of the AOI lies along the international boundary between Canada and the United States transecting Georges Basin. Several existing fisheries closures – the Northeast Channel Coral Conservation Area (NECCCA); nearly 50% of Lobster Fishing Area (LFA) 40, which is currently closed to lobster fishing; and portions of the Browns Bank groundfish spawning seasonal closure (1970–current) – overlap with the AOI (Figure 2). A juvenile Redfish closure known as the “bowtie” extends northeastwards out from a small overlap with the Browns Bank portion of the AOI.

The Fundian and Northeast channels are two separate components of the same large channel. The Northeast Channel begins at the continental slope and bounds Georges Bank to the east and Browns Bank to the south, physically separating the two banks. The Fundian Channel, north of Georges Bank, is approximately 45 km wide and is bounded to the north by Browns Bank on the Scotian Shelf before narrowing southeastward into the Northeast Channel, which is approximately 28 km wide. This channel represents the main hydrodynamic connection between the Gulf of Maine and the Continental Shelf (Todd et al. 1999). Both the Fundian Channel and Georges Basin bound Georges Bank to the north.

The bathymetry of the AOI varies from approximately 50 m on Browns Bank to 370 m depth in Georges Basin, with depths up to 2,200 m extending from the eastern section of the AOI to the continental slope (Figure 3). Much of the AOI is contained within the Fundian Channel, which has depths ranging from approximately 200 m to 400 m (Figure 3). The seaward sill of the channel raises to approximately 230 m, and the channel mouth is incised by submarine canyons

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[1] The Fundian Channel includes the Northeast Channel, which denotes the portion of channel proximate to the continental slope that separates Browns and Georges banks. In this document, Fundian Channel is generally used, except when other studies cited here specifically note the Northeast Channel.

leading to the deepest portions of the AOI on the continental slope. The channel mouth area, leading to the rapid depth gradient associated with the slope, is associated with distinct oceanographic processes and is often referred to as “Hell Hole”. This wide range in depths within the AOI contributes to its overall habitat complexity, and creates distinct invertebrate and fish communities that prefer different depths and associated substrates.

## GEOSCIENCE SUMMARY OF THE SOUTHERN SCOTIAN SHELF

The seabed geology within the boundaries of the AOI is typical of much of the Scotian Shelf. Thin deposits of glacially-derived muds, sands, and gravels overlie an eroded and truncated sedimentary bedrock surface. Muddy sediments have been deposited and preserved at the seabed in the deeper portions of the channels and on the continental slope. Sand and gravel deposits on the shallow, flat bank tops in the AOI are frequently disturbed and redistributed by both tidal currents and storm waves. The Northeast Channel is similar to other shelf-crossing troughs that have been eroded by past glacial ice streams; the channel hosts a thick sequence of sediment overlying bedrock including glacial till, postglacial sands and muds, and a surface veneer of reworked sand or mud in deeper water. The Northeast Channel is more energetic compared to other shelf-crossing troughs. Strong currents have produced migrating sand waves in parts of the channel. In places, glacial deposits are exposed at the seabed in morainal ridges that protrude tens of meters above the surrounding seafloor. Boulders, cobbles, and pebbles create an irregular surface on these moraines.

Variation in seabed geology and sediment type is often associated with patterns in benthic biodiversity and biotic assemblage. Seafloor communities will vary significantly between the higher-energy, frequently mobilized sandy bank tops and on the flanks of Northeast Channel, compared to deep water areas where sediments are deposited and infrequently, or never, disturbed. Continental slope edge canyons provide a variety of habitats across the shelf edge, floor and canyon walls. Morainal ridges, due to their coarse sediment and irregular relief, provide a complex seabed habitat for benthic species.

The seabed within the Fundian Channel–Northeast Channel AOI has not been fully investigated. Significant portions of the AOI have not been mapped with multibeam sonar, and the deep water portions of the AOI are poorly surveyed for both bathymetry and geology (Figure 4). More detailed efforts would be required to map all unique and/or sensitive seabed habitats within the AOI, with particular focus to those areas lacking coverage within the AOI, including southern Browns Bank, Georges Basin and the deep water areas (> 500 m) of the Scotian Shelf Slope.

A list of relevant published resources on the geology of the southern Scotian Shelf provided by Natural Resources Canada.

### Geomorphology

The southern Scotian Shelf/Gulf of Maine region encompasses, from north to south, German Bank, Browns Bank, Fundian and Northeast Channels and northeastern Georges Bank (Figure 1). The geomorphology of the region is the result of sediment deposition during the Mesozoic (65–251 million years ago [Ma]) and Cenozoic (0–65 Ma) eras, erosion during the Tertiary Period (1.8–65 Ma), and glacial erosion and deposition during the Pleistocene Epoch (11.4 thousand years ago [ka]–1.8 Ma).

Georges Bank flanks the seaward side of the Gulf of Maine and rises more than 100 m above the Gulf of Maine sea floor. Most of the Canadian portion of Georges Bank has water depths between 60 and 90 m, but also depths as shallow as 42 m. The bank surface gradually deepens seaward. The 200 m isobath along southeastern margin of Georges Bank approximates the continental shelf break. Seaward, water depths increase down the continental slope. The seaward margin of the bank is incised by a number of submarine canyons; in the Canadian sector the largest of these are Corsair and Georges canyons.

## Bedrock

Browns Bank and Georges Bank are underlain by Tertiary and Late Cretaceous sedimentary rocks; their upper surface is marked by a pronounced erosional unconformity. Northeast Channel is underlain by Jurassic and Early Cretaceous sedimentary rocks with an Early Tertiary cover, also partly eroded and uniformly blanketed by Late Tertiary fluvial and early glacial sediments. A thin (0–200 m) Quaternary sediment cover is mainly comprised of till deposits. The present topography strongly reflects the underlying bedrock surface, largely carved by later glacial processes.

## Glacial history

During the last glacial maximum (c. 24–20 ka), the southeast margin of the Laurentide Ice Sheet (LIS) occupied the study area and extended to the shelf break. Geophysical surveys revealed sets of small ridges interpreted to be recessional moraines indicative of retreat of the LIS. Subsequently, multibeam sonar seafloor mapping of local-scale glacial landforms on the inner Scotian Shelf revealed details and patterns enabling recognition of the advance and retreat dynamics of the ice sheet.

## Surficial sediments

The surficial sediment in the region is dominated by glacial deposits transported by the LIS during the late Pleistocene from the Bay of Fundy and continental areas to the north. Marine processes subsequently reworked and redistributed the glacial sediments during rising sea levels in the Holocene epoch (present to 11.4 ka), sorting the sediments into sand and gravel on banks and mud in basins (Figure 5). The present distribution and character of sediments enables the reconstruction of the glacial and post-glacial history of the area. Interpreted seismic reflection profile across Fundian Channel and Northeast Channel (Figure 6) shows eroded bedrock in infilled with several glacial till layers. Not visible at this vertical scale is an overlying thin sand layer reflecting modification by currents (Figure 7). Iceberg scours and pits are prominent sea floor features in the channels (Figure 7). Although most are relict (i.e., no longer being formed) features from seaward-moving modest sized icebergs generated by the retreating LIS, some wide, deep, and long furrows at the mouth of Northeast Channel are evidence of the flux of large icebergs south from the Labrador Sea.

Glacial and sea level processes governed the main distributional surficial sediment patterns; the deposits are essentially relict and stable. However, the shallowest areas of Georges Bank and Browns Bank, tidal currents and storm-generated currents periodically remobilize surficial sediments (Figure 8). The sand is redistributed, primarily in small and large sand waves (dunes), but also as thin, mobile sand sheets. On the flanks of Northeast Channel in deep water (> 200 m), tidal currents mobilize surficial sediment.

Over time, some sand is transported off the banks and into the channels. Sand is also transported southeast down the continental slope off the Georges Bank shelf break.

### Unique aspects of the region

Glacially-carved shelf-crossing troughs are common geomorphic elements along the glaciated east coast of Canada and the northeast United States, thus the Fundian and Northeast Channels are not singularly unique. Most of these shelf-crossing channels are filled with till with preserved relict iceberg scours, patches of sand (sometimes mobile), and mud-filled basins.

The persistent and evolving influence of strong currents on the surficial sediments of the Northeastern Channel is regionally unique. Large bedform fields on the inner reaches of Northeast Channel appear relict. In contrast, bedform fields on the flanks of Northeast Channel appear active, with bedform migration occurring in complex patterns in response to currents.

### Gaps in geoscience knowledge

Less than half of the AOI has been surveyed with multibeam sonar. Given that detailed bathymetric information underpins geological evaluation, completing the sonar surveys is a priority for continued geological assessment.

Geoscience knowledge of the continental slope (in water depths greater than approximately 200 m) is lacking. The glacial history remains unresolved, the canyon-forming (and maintenance) processes are unknown, and thus the related geohazard analysis cannot be undertaken. This knowledge gap is particularly acute on the slope off Northeast Channel.

## PHYSICAL OCEANOGRAPHY

### Ocean Circulation

The circulation on the Scotian Shelf is characterized by a general northeast-southwest flow, where waters adjacent the Atlantic Canadian shelf represent a confluence zone between the warm northeast flowing Gulf Stream and the cold southwest flowing Labrador Current (Figure 9) (Loder et al. 1998). Water flows between the Scotian Shelf and Gulf of Maine are dynamically-constrained, turning clockwise following the local bathymetry south of Cape Sable and on the northeastern side of Northeast Channel. Flow within the Gulf of Maine is generally cyclonic (Bisagni and Smith 1998) driven by buoyancy associated with coastal currents from inflowing Scotian Shelf water, local river runoff, and cyclonic gyres over Georges and Jordan basins resulting from deep inflows of slope water. Large amounts of freshwater within the Gulf can sometimes result in anticyclonic flow over Jordan Basin. In Georges Basin, the flows are mostly southward. Currents west of the Northeast Channel generally flow eastward before joining the southward flowing shelf edge current.

Empirical data collected near the northeastern limit of the Northeast Channel (42$^{o}$ 17’ N, 65$^{o}$ 58’ W) from 1976 to 1978 show that the deep flows in the Channel occur at three time scales: 1) tidal frequencies; 2) low-frequency flows at 4–10–day range; and 3) mean flows with periods of three months or longer (Ramp et al. 1985). The dominant tidal constituent is the principal lunar semidiurnal (M2) tide. The low frequency flows have strong seasonality and they are associated with a large-scale setup or setdown of the Gulf of Maine by wind stress. Outflow from the Northeast Channel is generally restricted to the southwestern slope, whereas inflows to the Channel do not have mean spatial association and is comprised of both Warm Slope water and colder Labrador slope water (Ramp et al. 1985). These outflow-inflow patterns are also reflected to some extent at the surface. Gulf Stream features (meanders and warm-core rings) likely do not play a significant role in driving the currents through Northeast Channel (Ramp et al. 1985).

Both Georges Bank and Browns Bank have significant mean flows that result from tidal rectification (Greenberg 1983) and baroclinic jets associated with tidal mixing fronts (Loder and Wright 1985). These circulation features contribute to the strong inflow on the northeastern side of the Northeast Channel and the outflow on the southwest side (Smith et al. 2001), as branches of a clockwise gyres around Browns Bank (contributes to inflow) and a clockwise gyre around Georges banks (contributes to outflow; Figure 9). Crossover of Scotian Shelf water from Browns and Georges Bank was reported in Smith et al. (2003). Shore et al. (2000) discovered a direct near-surface pathway from outer Browns Bank to outer Georges Bank, with a downstream continuation along the shelf edge with noted seasonal variability. A permanent clockwise gyre on Browns Bank has current strengths reported at up to 20 cm/s (Kostylev et al. 2001). Current speed and tidal flushing are one determinant of species distributions and abundances in the AOI, with filter-feeders being found in areas of faster currents (Kostylev et al. 2001, Lacharité and Metaxas 2018). Surface currents play an important role regulating the dispersal, survival, and connectivity of pelagic larval organisms. Spawning activity of meroplanktonic species is often associated with persistent circulation features that facilitate retention and provide optimal survival conditions. Within the AOI, spawning aggregations of Haddock (*Melanogrammus aeglefinus*) have been documented in association with the persistent gyre.

Temperature across the bioregion decreases with latitude and correspondingly the AOI is generally warmer than waters of a similar depth in the Bay of Fundy and Eastern Scotian Shelf (ESS) (Figure 10). Particularly in the winter months (January–March), bottom temperatures in the AOI are among the warmest in the region with average temperatures over the past decade (2008–17) reaching 6.53 ± 1.23°C and 4.74 ± 1.89°C for the rest of the region. Within the AOI bottom temperatures are generally warmer (7.38 ± 0.73°C) on the Shelf (Browns Bank, Northeast Channel, and Georges Basin) than the slope (200–1500m; 3.85 ± 0.06°C) and deeper waters (< 1500m; 4.59 ± 0.66°C). Surface temperatures exhibit a more uniform north-south temperature gradient across the bioregion and are more seasonally variable than at the bottom (Table 2; Figure 10, Figure 11). Averaged over the last decade (2008–17), seasonal sea surface temperatures recorded in the AOI were warmer ( 1.37 ± 0.35°C) than those on the Scotian Shelf.

Surface temperature in the region is generally more temporally variable than at depth, demonstrating a close correlation with the position of the warm Gulf Stream. For example, Gawarkiewicz et al. (2012) reported that an abnormal warm event on the Southern New England Shelf in late 2011 was due to a large meander of the Gulf Stream that transported warm water into this region. Similarly, Brickman et al. (2018) report that the anomalous warm events in 2012, 2014, and 2015 observed in the subsurface waters in the Scotian Shelf region likely originated from the interaction between the Gulf Stream and the Labrador Current at the tail of the Grand Banks (south of Newfoundland), based on simulations from a high-resolution circulation model adapted for the Northwest Atlantic (Wang et al. 2016). The frequency of warm water intrusions from the Gulf Stream onto the Scotian Shelf, and through the AOI appears to be increasing. In 2018, a 6°C anomaly of sea surface temperature linked to the position of the

Gulf Steam was reported by the Atlantic Zone Monitoring Program (AZMP) in surface waters near the Northeastern Channel (D. Hebert, DFO, pers. comm.).

Temperatures reported here are based on the Bedford Institute of Oceanography North Atlantic model (Wang et al. 2018). The BNAM is an ocean model based on NEMO 2.3 (Nucleus for European Modelling of the Ocean), which includes an ocean component OPA (Océan Parallélisé; Madec 2008) and the Louvain-la-Neuve Sea Ice Model (Fichefet and Maqueda 1997). The modelled domain of BNAM includes the North Atlantic Ocean (7 – 75°N and 100°W – 25°E) with a nominal resolution of 1/12°. The model has a maximum of 50 levels in the vertical, with level thickness increasing from 1 m at the surface to 200 m at a depth of 1250 m and reaching the maximum value of 460 m at the bottom of the deep basins. The maximum depth represented in the model is 5730 m. Further details about this model can be found Wang et al. (2018). Surface forcing data used for the 2008–2017 period are from the National Centers for Environmental Prediction.

## Climate Projections

The impacts of ephemeral warming events linked to Gulf Stream intrusions (sensu Brickman et al. 2018, Gawarkiewicz et al. 2012) and overall warming associated with climate change (i.e., Brickman et al. 2016) remain unresolved, but could have a strong impact on species distribution (e.g., Pinsky et al. 2013, Stanley et al. 2018, Zisserson and Cook 2017) and, in particular, survival of sensitive life history stages of several vertebrate and invertebrate species. For example, sustained warming in the Gulf of Maine and short-term incursions of warm slope water onto the Scotian Shelf have been linked to decreased survival and local population declines of juvenile Cod (Pershing et al. 2015) and Snow Crab (*Chionoecetes opilio*) (Zisserson and Cook 2017), respectively. Continued warming of the bioregion is expected and has been simulated using a regional ocean model (Wang et al. 2018). Warming may be particularly pronounced in the waters surrounding the AOI. Indeed, across the simulated model domain (31–74°N), projected anomalies for surface and bottom temperatures were the highest in the Gulf of Maine and Western Scotian Shelf (WSS) (1.1°C and 1.6°C, for surface and bottom temperature, respectively) (Brickman et al. 2016; Figure 12, Figure 13). Projected surface and bottom temperature anomalies for the year 2075 in the AOI are warmer by 0.26°C, on average, than those projected for the Scotian Shelf Bioregion (see seasonal averages in Table 3). Projected anomalies within the AOI were higher for waters on the Shelf (Northeastern Channel, Browns Bank, and Georges Basin) than for those areas on the shelf slope and deeper (4.92 ± 0.89°C and 3.11 ± 2.04°C, mean ± SD, respectively). The impact of these warming temperatures is unknown at this time, but will likely result in changes in species assemblage with introductions of new species from the south and movement of existing species to the north.

## A Bio-production Pump at Work – Nonlinear Internal Waves

### Physics of Internal Waves

Internal waves are a ubiquitous feature of the world's ocean. Nonlinear internal waves are known to be one of the key processes to bring nutrients and pelagic dispersing organisms to the stratified coastal ecosystems (Woodson et al. 2012). Like surface waves, internal solitary waves can travel long distances in the ocean. For example, in the South China Sea internal solitary waves propagate from Luzon Strait and travel 1000 km to Hainan island (Jackson and Apel 2004). In the Gulf of Maine, internal solitary waves travel approximately 200 km from Georges Bank to coastal waters (Scotti and Pineda 2004). When linear internal waves generated in the middle of the ocean propagate to the shelf, they become nonlinear and have the capacity to transfer water volume as they propagate. Nonlinear internal waves can also be generated in coastal areas when tidal currents flow over steep bottom topography, such as Georges Bank and Browns Bank. Propagation of nonlinear internal waves across the continental shelf eventually diminishes and leads to significant turbulence, mixing and the release the offshore water they carries.

The near-resonance semi-diurnal tide of the Gulf of Maine and Bay of Fundy basin system amplifies the semidiurnal tidal amplitude in the Bay of Fundy and the currents across Georges Bank (Garrett 1972), which together with steep topographic features, make Georges Bank and Browns Bank hotspots for internal wave generation (Chen et al. 2011). Internal waves generated in these areas propagate to the Scotian Shelf and through the Gulf of Maine. Figure 14 shows an example of a series of internal waves propagating from Georges Bank to the shelf of Gulf of Maine observed by synthetic aperture radar (refer to Jackson (2004) for observation details). In this example, most of these internal waves are generated around Georges Bank. The magnitude of these nonlinear internal waves around Georges Bank can be as large as 80 m (in situ measurement by RV Albatross AL9801 cruise; Sibunka 1993).

### Ecosystem Impact of Internal Waves

Internal waves bring significant modulations to the regional ocean physical environment, enhancing water mass exchange and mixing. These modulations can result in important and measurable ecosystem responses. For example, primary productivity of surface waters are often limited by a lack of nutrient supply after the spring bloom, particularly in well stratified systems where benthic-pelagic nutrient transport is limited. Internal waves can reduce this limitation, bringing nutrient rich benthic waters to the euphotic layer and thus increasing productivity locally, while at the same time moving phytoplankton rich chlorophyll maximum layers deeper. Because of these characteristics, internal waves are considered important mechanisms for benthic pelagic food coupling in marine systems (Kaartvedt et al. 2012) and specifically in the AOI. In an early experiment in the Gulf of Maine at the Ammen Rock Pinnacle, it was found that internal waves delivered phytoplankton to deep habitats by displacing the subsurface chlorophyll maximum layer by approximately 20 m depth in as few as 15 minutes (Witman et al. 1993). In this way, vertical coupling associated with internal waves is significant for modulating benthic food webs (e.g., by enhancing the secondary productivity suspension-feeding benthic organisms) for communities associated with complex topographic features where internal waves are generated.

At regional scale, larval transport, abundance and connectivity are most often associated with mesoscale ocean dynamical features (Phelan et al. 2018), such as internal waves. Exchange of deep offshore waters in addition to enhanced turbulence and mixing, are important features of internal waves in the coastal zone. Internal waves have been shown to influence a variety of important biophysical near-shore processes, including exposure to extreme weather events, climate variability, nutrient and food supply, larval connectivity, predator-prey dynamics, and broadcast spawning and fertilization (Woodson 2018).

The exchange of offshore waters to the nearshore ecosystems is an important contribution of internal waves that, in particular, provides a key mechanism of nutrient subsidy in nearshore systems. Water transport associated with internal waves has also been linked to larval dispersal, facilitating connectivity and recruitment to adult habitats (Woodson et al. 2012). Shanks (1983) and Kingsford and Choat (1986) suggested that internal waves could be an essential process for transporting crab, barnacle, and fish larvae shoreward. Nonlinear internal waves can also enhance local turbulence and mixing, which may re-suspend particulate matter and enhance broadcast spawning efficiency. Nonlinear internal waves and bores often have trailing turbulent wakes with turbulence levels 10–100 times higher than ambient levels that can persist for several hours after internal-wave passage (Alford 2003). This elevated turbulence could also enhance fertilization rates for both sessile and mobile broadcast spawners during spawning aggregations by as much as ten-fold (Crimaldi and Browning 2004). There is also evidence that spawning sites of large fishes can be linked to internal-wave activity and it is likely that spawning of groundfish on southern Browns Bank, within and surrounding the AOI, is influenced by the local oceanography, including the heightened presence of internal waves and a persistent gyre.

Internal waves may also modulate predator-prey dynamics through a variety of mechanisms including increased encounter rates (e.g., larval fish and predators - Greer et al. 2014, whales and plankton - Pineda et al. 2015) and the disruption of suitable foraging conditions resulting from sediment resuspension. Correspondingly, the behaviour of predators to these mechanisms has been documented. For example, the frequency of vertical movement by fish has been shown to increase in the presence of a passing internal wave (Kaartvedt et al. 2012), and thus likely increases the frequency of contact between predators and prey. Co-occurrence of whale sightings and internal waves (Pineda et al. 2015) has similarly been attributed with internal waves changing the landscape of predator prey interactions.

### Internal Waves in Fundian Channel-Browns Bank

Physically, at a regional scale, the Fundian Channel and Browns Bank belong to the Georges Bank Coastal System, which is part of a coastal current system flowing from the Labrador Sea to the Mid-Atlantic Bight (Chapman and Beardsley 1989). In contrast to Georges Bank, where the water is generally well mixed due to strong year-long turbulent tidal forcing, the AOI is stratified during summer with mixing generally only occurring when stratification breaks down during the winter, especially in the shallow area associated with Browns Bank.

With stratification, internal waves are generated when strong barotropic tidal currents flow over steep topography. The stronger the tidal currents, the bigger the internal waves will be. For the tidal dynamics, the Gulf of Maine region is characterized by large semidiurnal M2 (12.42H) tidal currents, with the world's highest tidal range of (> 8 m) occurring in the upper reaches of the Bay of Fundy (Garrett 1972). In addition to the shallow Bay of Fundy and adjoining shoal area south of Cape Sable, Nova Scotia, semidiurnal currents are strong over the two shallow submarine banks – Georges and Browns banks – that separate the deeper inner Gulf of Maine from the North Atlantic (Bigelow 1927).

Regionally, M2 tidal energy is the strongest through the boundaries of the AOI (Figure 15). Using a Finite Volume Community Ocean Model (FVCOM) Chen et al. (2011) estimated internal tidal energy fluxes and found the most energetic areas of Gulf of Maine were the northeastern flank of Georges Bank and the Northeast Channel. When propagating to the shelf slope, internal tides associated with these energetic areas evolve into high frequency internal waves when stronger nonlinearity develops, which explains the frequency of internal waves in the Fundian Channel-Browns Bank area (Figure 16).

The steep bottom topography and strong barotropic semidiurnal tidal current in the Northeast Channel causes internal waves to be generated throughout the year. The direction of these internal waves is regulated by local currents, and can propagate inshore to the Gulf of Maine, offshore to the mid-Atlantic, or northeastward along the Scotian Shelf.

Figure 16 shows the internal wave patterns in the vicinity of the Fundian Channel-Browns Bank, where multiple packages of internal waves originate from the Northeast Channel before propagating in different directions. Notably, waves can be seen propagating towards Georges Basin and to the Scotian Shelf.

### Impact of Internal Waves on Local Ecosystems in the Gulf of Maine

As discussed previously, internal waves exert significant modulation to the local ocean dynamics, resulting in important impact to the local ecosystem.

Internal waves are a key component of the Gulf of Maine ecosystem. Brickman and Loder (1993) document that the internal wave packets likely provide a significant supply of inorganic nutrients to primary production in frontal zones, acting as a nutrient pump, mixing water and associated nutrients across the water column. The breaking internal disturbance associated with internal waves could service the nitrate demand in the frontal zone on Georges Bank, in the order of 0.36 μmol $m^{-2}s^{-1}$ (Horne et al. 1989). The thermocline and phytoplankton-rich chlorophyll maximum layers have been shown to be vertically displaced by internal waves. Amplitudes of these displacements have been recorded as high as 27 m over a rocky pinnacle in the central Gulf of Maine (Witman et al. 1993). Such predictable downwelling events were linked to rapid, 2- to 3-fold increases in chlorophyll *a* concentrations in water near the water-sediment interface (at up to 29 m depth). Water transport associated with internal waves also been linked to rapid temperature fluctuations, on the order of 1.5–8.5ºC in 2–15 min. Every spike in bottom temperature was mirrored by a rapid increase in chlorophyll a concentration, on the order of 0.5–5 μg/L, often matching the period of temperature fluctuations exactly (Witman et al. 1993). It was estimated that the surface chlorophyll maximum and thermocline are pushed down to the bottom by passing internal waves 8–20 times daily during an six month (May–October) period of thermal stratification in the outer Gulf of Maine.

## CHEMICAL OCEANOGRAPHY

## Nutrients

Dissolved inorganic nutrients, including nitrate, silicate, and phosphate, strongly co-vary in space and time. The overall nutrient budget for the Gulf of Maine is strongly controlled by nutrient-rich offshore, deep water input through the Northeast Channel, with up to 44% of new nitrates entering the Gulf through this deep channel (Thomas et al. 2003, Townsend et al. 1987). Since the 1970s, the deeper waters in the interior Gulf of Maine have become both fresher and cooler, with lower nitrate levels but higher silicate concentrations, with both nutrients now occurring in roughly equal proportions (Townsend et al. 2010).

Nitrate, silicate, and phosphates tend to increase in concentration from fall into winter in the Gulf of Maine, and remain at low levels in spring and summer (Petrie and Yeats 2000). Winter nitrate levels are higher on the Scotian Shelf than in the Gulf of Maine. The Gulf of St. Lawrence is the primary source of nitrates on the Scotian Shelf, while offshore inputs into the Gulf of Maine from the Northeast Channel is the primary advective source of nitrate (Petrie and Yeats 2000). Nitrates are also introduced into the Gulf of Maine via the inner shelf off southwest Nova Scotia. Vertical diffusion of these nutrients is nearly as strong as the advective flux of nutrients from the

Northeast Channel, suggesting that this vertical diffusion plays a strong role in determining primary production in the Gulf of Maine (Petrie and Yeats 2000).

On the Browns Bank Line, AZMP analyses show generally positive anomalies for nitrates at 0–50 and > 50 m depths between 2008 and 2015. Silicates are more variable but anomalies are generally negative between 2008 and 2015 at 0–50 and > 50 m depths, while phosphates show negative anomalies at 0–50 m depth since 2011, and at > 50 m since 2013 (Johnson et al. 2017).

## Oxygen

Marine species in general have a broad tolerance range for dissolved oxygen (DO) levels, corresponding to the requirements of their respective life histories. DO levels in the Gulf of Maine correspond with changes in temperature and salinity over time, showing a strong, negative correlation with these variables. In the Scotian Shelf and Gulf of Maine, DO was also found to be highly correlated with nitrate levels (Petrie and Yeats 2000). DO anomalies were high in the 1960s as increased Labrador slope water entered the region, but decreased in the following years as Warm Slope water entered the Gulf of Maine and Scotian Shelf. In 1998, a greater influx of Labrador slope water raised DO levels to those comparable to the 1960s (Petrie and Yeats 2000).

Dissolved oxygen concentrations are measured by CTD sensors as part of the AZMP cruises and Maritime Region Summer Ecosystem Survey. The lowest oxygen saturation levels are observed in deep basins, where nutrients and temperatures are highest. In 2015, bottom oxygen saturation levels were mainly observed in and around the deep basins of the central Scotian Shelf (LaHave and Emerald basins), while saturation levels were highest in the Bay of Fundy and over the banks on the Scotian Shelf (see Figure 14 in Johnson et al. 2017). Similarly, in the summers and winters of 2016 and 2017, an interpolation model of dissolved oxygen measured from CTDs shows lower oxygen levels in the deep portions of the Gulf of Maine, deep basins on the Scotian Shelf (such as Georges Basin), and along the continental slope, corresponding to generally warmer areas (Figure 17). As such, dissolved oxygen is generally lower within the AOI relative to the shallower parts of the Scotian Shelf and the Bay of Fundy.

## pH

Three mineral forms of calcium carbonate exist in the marine realm, including aragonite, calcite, and magnesium-calcite, with aragonite being the most soluble. The aragonite saturate state is used to evaluate the corrosiveness of sea water on calcifying animals, though all forms of calcium carbonate shells and skeletons are susceptible to ocean acidification. The reaction between water and carbon dioxide ($CO_2$) to create carbonic acid is ubiquitous through the world's oceans, and correspondingly increased levels of atmospheric $CO_2$ have led to increased acidity of the global ocean, known as ocean acidification (Zeebe 2012). The pH of the marine environment has direct impacts on marine ecosystems because of its critical role regulating physiological reactions. When $CO_2$ dissolves in the surface ocean, it also decreases the availability of carbonate ions, which are used by some species (such as shellfish, pteropods, and corals) as a basis for a skeleton of calcium carbonate. Decreased availability of carbonate ions increases the energy required for shell formulation and thus leads to stress in shell forming organisms (Waldbusser et al. 2015).

The Gulf of Maine and Scotian Shelf waters have a reduced capacity to buffer against pH changes because of relatively high freshwater input from the Gulf of St. Lawrence and Labrador Current (Gledhill et al. 2015). Generally, minimum monthly calcium carbonate saturation in the Gulf of Maine and Fundian Channel are lower than waters to the south because of the colder temperatures and lower salinity, which reduce calcium carbonate saturation (Gledhill et al. 2015). During the winter months, in particular, the cold Scotian Shelf waters have among the lowest carbonate saturation states for Nova Scotia and New England. After the spring phytoplankton bloom, net uptake of $CO_2$ and increasing water temperature increases calcium carbonate saturation state into the summer. In the fall and winter, surface waters of the Gulf of Maine mix with subsurface corrosive waters that result in periodic surface calcium carbonate under-saturation (Gledhill et al. 2015). Gledhill et al. (2015) provide a review of the biological responses observed for different life stages of commercially important marine species in the New England – Nova Scotia region. Overall, the effects of short-term versus long-term acidification events on marine plants, invertebrates, and fishes will require additional study in the Gulf of Maine and Scotian Shelf regions.

## Contaminants

Contaminants in the Gulf of Maine and southern Scotian Shelf include sewage point sources, agricultural runoff, trace metals including mercury, petroleum residues, PCBs, and pesticides (Chase et al. 2001). Heavy metals are introduced into the marine environment by natural processes and human activities, including river runoff, precipitation, hydrothermal vents, mining, and industrial uses of heavy metals (Breeze and Horsman 2005). Heavy metals may then be deposited into marine sediments or transported offshore. Metals such as cadmium, copper, and chromium are introduced into the marine system from coastal inputs and oceanic cycling. Cadmium concentrations decrease as salinity increases, but increase with phosphate concentrations, while copper concentrations are also higher in low salinity areas (Breeze and Horsman 2005). No temporal trends in surface concentrations of cadmium or copper have been detected on the Scotian Shelf (Breeze and Horsman 2005). Heavy metals in sediments tend to increase in concentration with decreasing sediment grain size, and can be estimated from this relationship. Higher concentrations are thus assumed to be in areas along the continental slope and in basins, such as Georges Basin, where clay and silt accumulate. Chromium, copper, zinc, and lead concentrations in sediments within the AOI are at background concentrations, but the analyses by Breeze and Horsman (2005) did not include Georges Basin, where sediment grain sizes are small.

Mercury enters the environment from natural and anthropogenic sources (e.g., mining, coal-fired power plant emissions). In aquatic ecosystems, mercury occurs as methylmercury in sediments and the water column. In the Gulf of Maine region, total mercury inputs are primarily from oceanographic circulation, atmospheric deposition, wastewater or industrial sources, and rivers (Sunderland et al. 2012). Potentially > 5000 kg of mercury enter the Gulf of Maine each year through natural circulation from the Scotian Shelf and through the Northeast Channel (Sunderland et al. 2012). Methylmercury also occurs in coastal sediments, which provide a source of mercury in offshore pelagic food webs and mercury levels in fish in the New England region are among the highest in the United States (Chen et al. 2009). Methylmercury can bioaccumulate in shellfish, forage fish, larger predators, and eventually can be consumed by humans. In the Bay of Fundy region south of the AOI, the concentrations of mercury ranged from 2.8 ng $g^{-1}$ of wet weight tissue in phytoplankton to 590 ng $g^{-1}$ in Harbour Seals and 606 ng $g^{-1}$ in Double-crested Cormorants (*Phalacrocorax auritus*) (Sunderland et al. 2012).

# BIOLOGICAL OCEANOGRAPHY

## RESEARCH SURVEYS ON THE WESTERN SCOTIAN SHELF AND GULF OF MAINE

Numerous surveys for oceanography, larval fish, groundfish, and invertebrates have been conducted in the Western Scotian Shelf and Gulf of Maine area since the 1970s. These include several long-term and ongoing annual surveys such as the summer and winter ecosystem surveys, and surveys which existed for shorter time-scales such as surveys for larval fish in the 1970s and a fall ecosystem survey from 1978–1984. Here we describe several long-term surveys which were used as data sources for the analyses conducted in this document.

### Maritime Region Summer Ecosystem Survey

The DFO Maritime Region Summer Ecosystem Survey of the Scotian Shelf and Bay of Fundy (4VWX5Yb), also known as the research vessel (RV) or trawl surveys, have been conducted annually since 1970 using a standardized sampling protocol. Standardized sampling protocols have been in place since the beginning of the survey with a gear change in 1982 associated with the implementation of a new survey vessel. Currently the RV survey uses a Western II-A Otter Trawl net with a target wingspread of 12.5m and tow distance of 1.75 nautical miles (3.24 km) and total tow time between 20 and 30 minutes. There is overlap of the AOI with portions of RV survey strata 477, 478, 480:483, and deeper strata 498,5Z9, 501:505 and 560 (Figure 18, Figure 19). Only the southwestern portion of the AOI is not encompassed by survey strata (Figure 18). Since 1970 there have been 360 sets within the AOI boundaries averaging 7.5 ± 2.7 (mean ± standard deviation) sets per year (Figure 20) with a depth range of 70 to 360 m (median 115 m). There is currently no multispecies trawl sets for the southern portion of the channel and the deepest areas of the AOI on the Scotian Shelf slope (Figure 19). In total approximately 0.2 % of the AOI, or 14.5 $km^2$, have been sampled as part of multispecies trawl surveys since 1970. These samples are primarily located on Browns Bank (< 200 m–250 trawl sets and 10.1 $km^2$), with the remaining area distributed approximately evenly among the Georges Basin subcomponent (51 samples and 2.03 $km^2$) and the Northeast Channel (59 sets and 2.4 $km^2$). A Winter Ecosystem Survey also occurs annually, but data from this survey was not analyzed as it primarily focuses on Georges Bank.

### Industry-DFO Longline Halibut Survey

The Industry-DFO Longline Halibut Survey is a fixed and random station survey that began in 1998 to develop an index of abundance for exploitable Atlantic Halibut on the Scotian Shelf and Grand Banks (Cox et al. 2018). This survey collects information on Atlantic Halibut, bycatch, oceanographic conditions, and trophic relationships. Since its inception the survey has used a standardized sampling protocol whereby each set deploys 1000 circle hooks from vessels less than 65 feet long and is conducted each year from mid-May to mid-July. Sampling design has alternated between stratified random (1998, 2017-current) and fixed station (1999–2016) surveys (Cox et al. 2018).

The purpose of this survey is to provide information on a broader size range of Atlantic Halibut than is typically caught by the RV Survey. It also provides information on the distribution, sizes, and abundances of species that are not well surveyed by trawl gear, such as Cusk (*Brosme*

*brosme*) (Harris et al. 2018). The distribution of concurrent fixed and random survey locations within the vicinity of the AOI are shown in Figure 21.

### Individual Transferable Quota Fixed Station Mobile Gear Survey

The Individual Transferable Quota (ITQ) survey was a joint industry – DFO survey conducted in NAFO Division 4X to obtain information on the distribution of Atlantic Cod, Haddock, and Winter Flounder. The survey began in 1995 and covers an area of 4X further inshore (i.e., inshore of 90 m depth) than the summer RV Survey due to its 'rock hopper' design (O'Boyle et al. 1995). The ITQ Survey conducts tows standardized to one nautical mile at fixed stations, varying in duration. Four otter trawlers using a balloon trawl with a 19 mm cod-end liner fish a particular geographic zone within the total survey area.

The ITQ Survey consistently captured American Lobster (*Homarus americanus,* hereinafter Lobster), particularly in LFA 34, but also from LFAs 35–38, and 40–41. Since 1996, this survey began recording the number of Lobster caught, and, beginning in 2005, recorded more detailed information (size, sex) on each Lobster. The ITQ Survey captures the most Lobsters relative to the summer RV Survey and Scallop Survey (Pezzack et al. 2015a, Pezzack et al. 2015b). For this reason, in 2013 the ITQ survey evolved into the Inshore Lobster Trawl Survey and is currently led by the Lobster science team at DFO.

### DFO Offshore Scallop Science Survey

The DFO Offshore Scallop Science Survey is the primary source of information for Sea Scallop stock assessment in the DFO Maritimes Region. The Offshore Scallop Survey has occurred on Browns Bank North annually from 1991–2018, and on Browns Bank South 18 times between 1985 and 2018; both surveys use a stratified random sampling design. The surveys provide abundance data at a high spatial resolution and can provide information on the Scallop distribution in the region. Atlantic Zone Monitoring Program

The Atlantic Zone Monitoring Program collects and analyzes biological, chemical, and physical oceanographic data in the Gulf, Quebec, Maritimes, and Newfoundland and Labrador regions. The program began in 1998 (Therriault et al. 1998) with the aim of increasing DFO's capacity to understand, describe, and forecast the state of the marine ecosystem including quantifying seasonal, inter-annual, and decadal scale trends. The program involves four core components for data collection: 1) bi-weekly or monthly high-frequency station occupations (Halifax-2, and Prince-5 in the Maritimes); 2) "core" seasonal cross-shelf sections, including Cabot Strait, Louisbourg, Halifax, and Browns Bank lines, and other non-core ancillary sections such as the Northeast Channel Line; 3) seasonal ecosystem survey samples at random stratified station locations (e.g., CTD casts at summer RV Survey stations); and 4) remote sensing data to characterize surface conditions. Data from each year or season are generally reported as anomalies relative to long-term averages that occasionally reveal environmental trends (e.g., ocean warming or cooling), CTD casts and water samples provide information on the vertical structure of numerous parameters that include but are not limited to temperature, salinity, chlorophyll, nutrients, and dissolved oxygen; and vertical plankton tows (202 µm mesh) collect zooplankton at each station.

Additionally, a Continuous Plankton Recorder (CPR) (McQuatters-Gollop et al. 2015, Richardson et al. 2006) collects plankton on cruises in the Western and Eastern Scotian Shelf, and the Newfoundland Shelf (Head and Pepin 2009), including in the vicinity of the AOI (Figure 22). The CPR is towed at a depth of 7 m, and a 270 µm mesh filters phyto- and zooplankton from the water with the positions along the mesh corresponding to different sampling stations (Richardson et al. 2006). The CPR samples are analyzed for relative abundances of phytoplankton (through colour analysis and relative numerical abundance) and zooplankton for different seasons, years, or decades. Stations relevant to monitoring the oceanography in the vicinity of the AOI include the Browns Bank Line (Figure 23,Figure 24), the Northeast Channel Line with portions of each section in the Fundian Channel, and the Portsmouth Line (Figure 25, Figure 26, Figure 27), which includes stations in Georges Basin and the Fundian Channel.

### Surveys Conducted by the United States

Surveys are conducted in the spring (March-May) and fall (September-November) by the Northeast Fisheries Science Centre (NEFSC), a research institute of the National Oceanic and Atmospheric Administration (NOAA). These surveys were initiated in the late 1960s, and both use the same depth stratified random sampling design. The surveys are designed to collect data on abundance, distribution, feeding ecology, size and age composition of economically and ecologically important stocks, as well as oceanographic and plankton data to monitor the health of the region. Their study area extends from the Scotian Shelf to Cape Hatteras, and includes the Gulf of Maine and Georges Bank. The strata are further subdivided into sampling units to achieve a more even sampling distribution across this area. Prior to 2009, otter trawls were dragged for 30 minutes at 3.5 knots, for a swept distance of 1.75 nm. From 2009 to present, a bottom trawl is used which is towed at a speed of 3.0 knots for 20 minutes, yielding a swept distance of 1 nm (Cook et al. 2017, NOAA 2017).

## PLANKTON

### Phytoplankton and Other Microbes

Phytoplankton show high temporal and spatial variability in shelf waters. Phytoplankton are the base of the marine food web and are typically quantified using remote sensing of chlorophyll *a*. The distribution and seasonal abundances of phytoplankton in the Gulf of Maine is determined by bathymetry, seasonal advection, tidal mixing, and stratification of the water column (Thomas et al. 2003). Phytoplankton consist of both eukaryotes and prokaryotes, of which the dominant prokaryote in the Gulf of Maine is the cyanobacteria *Synechococcus* (Li et al. 2011). Between 1,000 and 10,000 taxa of eukaryotic phytoplankton have been recorded in the Gulf of Maine, comprising a mix of temperate and boreal species (Li et al. 2011). The phytoplankton community in the Gulf of Maine and Scotian Shelf is primarily composed of diatoms and dinoflagellates which bloom in the spring followed by a smaller bloom in the fall (Johnson et al. 2017). The magnitude of these blooms depends on nutrient supply. By the summer, much of the spring bloom ends after grazing by zooplankton, or sinking as the phytoplankton aggregate, become heavier, and sink. The short spring blooms that occur from late March to early April control the carbonate system of the Gulf of Maine (Gledhill et al. 2015). The Gulf of Maine in general is a biogeographic transition zone for phytoplankton, being the northern limit for warm-water species and the southern limit for cold-water species (Li et al. 2011).

Analyses from the CPR (Richardson et al. 2006) show peaks in phytoplankton colour index (PCI; a relative measure of phytoplankton abundance) and diatom abundance in March to April on the Western and Eastern Scotian Shelf, and low values in the summer (SAHFOS 2018). In fall and winter, PCI is low, but diatom abundance increases in the fall and remains high in winter (Johnson et al. 2017). Dinoflagellate abundance shows no clear seasonal pattern on the

Western or Eastern Scotian Shelf. Relative abundances are highly variable across seasons and across years though, as of 2014, the PCI anomalies were similar to the 1992–2010 average for both the Western and Eastern Scotian Shelf (Johnson et al. 2017). Data from the CPR in the vicinity of the AOI (see Figure 22 for sample locations) shows a generally higher PCI outside the AOI relative to inside (Figure 28), though the mean number of diatoms and dinoflagellates shows no clear patterns within and outside the AOI (Figure 29, Figure 30).

The continental slope and mouth of the Northeast Channel tend to have high levels of chlorophyll-a and primary productivity overall. Oceanographic features, including upwelling and internal waves, concentrate nutrients along slope waters. Seasonal phytoplankton blooms attract zooplankton and other predators, which in turn attracts even larger predators including large pelagic fishes and cetaceans. The unique food webs in areas of high chlorophyll concentrations (i.e., the Scotian Shelf slope) have previously been shown to be excellent predictors of cetacean distributions, including Blue Whales (Gomez et al. 2017).

## Zooplankton

Zooplankton are a critical component of the marine ecosystem, feeding on phytoplankton and bacteria, and providing food for fish, birds, baleen whales, and sea turtles. This group encompasses a wide variety of organisms including ciliates, copepods, pelagic molluscs, meroplanktonic larvae, krill, arrow worms, amphipods, mysids, salps, and scyphozoans (Kennedy et al. 2011). Generally, zooplankton biomass peaks after the spring phytoplankton bloom. The zooplankton community expected within the AOI would correspond to that observed within Gulf of Maine. Copepods are the dominant zooplankton within and adjacent to the AOI boundaries including Browns Bank, the Fundian Channel, and Georges Bank. *Calanus finmarchicus, Pseudocalanus* spp., *Paracalanus parvus, Centropages typicus, C. hamatus,* and *Oithona similis* are the six dominant species that make up 80% of the mesozooplankton biomass on Georges Bank (Davis 1987, Kennedy et al. 2011). Other species that are relatively common in the Gulf of Maine and are likely in the AOI include *Metridia lucens, Microcalanus pusillus, Acartia* spp., *Eurytemora* spp., *Tortanus discaudatus,* and the cladocerans *Evadne nordmanni* and *Podon* spp. (Johnson et al. 2011).

Johnson et al. (2011) conducted a comprehensive census of zooplankton and pelagic nekton in the Gulf of Maine, and from the Atlantic Zone Monitoring Program (AZMP), identifying 533 metazoan species, including 247 fish species, 237 crustaceans, and 49 species of other phyla such as ctenophores and chaetognaths. Their study noted that copepod diversity shows clear patterns of seasonal and interdecadal variability in diversity with peaks occurring annually in the summer months and a marked period of high copepod diversity in the 1990s. Copepod diversity on the Scotian Shelf appeared to be highest at the shelf break, where warm water offshore species mix with cold water shelf species (Johnson et al. 2011). In recent years, the biomass of zooplankton and the abundance of *Calanus finmarchicus* on the Scotian shelf, and specifically on the AZMP Browns Bank line, have been declining (negative long-term anomalies) since the early 2000s corresponding to similar declines in large phytoplankton over the same period (Johnson et al. 2017). *Pseudocalanus moultoni* and *P. newmani* are abundant copepods over Georges Bank from the winter into the summer, during which time they are likely reproducing (Bucklin et al. 2001). *P. moultoni* peaks over Georges Basin in April but shifts to Georges Bank by May, while *P. newmani* tends to be more abundant south and east of Georges Bank, suggesting this species may be transported into the region from populations on the Scotian Shelf and Browns Bank (Bucklin et al. 2001). McLaren et al. (1989) showed that *P. newmani* is common over Browns Bank in winter, but more common offshore, while *P. moultoni* also occurs on Browns Bank, but is less common than *P. newmani*.

Krill are large zooplankton and an important prey species for fishes, birds and cetaceans, representing a link between smaller zooplankton and phytoplankton and these predators. Eight species of krill (euphausiids) have been reported from the Gulf of Maine, including six species from the interior Gulf (*Thysanopoda acutifrons, Thysanoessa* spp., *Meganyctiphanes norvegica*), and two species from the slope (*Nematoscelis megalops* and *Euphausia krohni*) (Bigelow 1926, Johnson et al. 2011, Lowe et al. 2018). *M. norvegica,* in particular, forms large surface swarms that provide prey for whales and Atlantic Herring, making up approximately 30% of the diet of herring (Nicol 1984, Stevick et al. 2008). Abundances of krill were lower than normal on the WSS in 2014, while hyperiid amphipod abundances were higher than normal in 2014 (Johnson et al. 2017). Studies have demonstrated that inter-annual patterns in euphausiid abundance in the Gulf of Maine region are positively correlated with intrusions of warmer and more saline water (Lowe et al. 2018). In general, krill are more abundant over deeper water, and are less abundant over the shallow shelf. This is because krill undergo vertical migrations, and deeper waters provide refuge from predation (Lowe et al. 2018). Krill, especially *Thysanoessa* spp. and *Meganyctiphanes norvegica*, are key prey species for Blue Whales (*Balaenoptera musculus*) and observed and predicted distributions of such krill aggregations were used to predict important foraging/feeding and socializing areas for Blue Whales in Atlantic Canada, including the continental shelf edge of Nova Scotia (Lesage et al. 2018).

Recent trends in zooplankton richness and abundance have been observed under warming ocean temperatures in the Gulf of Maine and on the Scotian Shelf. An overall shift in the zooplankton community in recent years (reported in 2016) has been characterized by lower abundance of large copepods, especially *Calanus finmarchicus*, and a higher abundance of small, warm water copepods (both subtropical and offshore species) and non-copepods, including larvae of benthic macroinvertebrates (DFO 2017g). Negative anomalies of both *Calanus finmarchicus* and *Pseudocalanus* spp. occurred across the Scotian Shelf and Browns Bank, though positive anomalies for *Pseudocalanus* occurred in the Gulf of St. Lawrence and Newfoundland region (DFO 2017g). Positive anomalies of warm and deep water copepod species are likely the result of warming temperatures in the Maritimes Region over the past decade and changes in onshelf transport, transporting these species into the Gulf of Maine and Scotian Shelf and allowing them to thrive. Data from the Continuous Plankton Recorder in the vicinity of the AOI (Figure 22) shows a general decline in small copepods both within and outside of the AOI since the early 1990s (Figure 31). The mean abundance of large copepods demonstrates a similar trend, with the exception of a notable peak in 2008 (Figure 32).

## BENTHIC HABITATS AND COMMUNITIES

### Classification of Benthic Habitats and Communities of the Scotian Shelf

The AOI is part of the Maritime Scotian Shelf Bioregion, which bounded by the Laurentian Channel to the Fundian/Northeast Channel and Georges Bank. The Bioregion includes coastal waters and extends to the continental shelf and abyssal plains. The Scotian Shelf is generally characterized by shallow, offshore banks, with deep basins and channels between them (DFO 2016a). At a finer scale, the AOI is a component of the Gulf of Maine and Baccaro and LaHave banks biophysical classification based on shared physiographic and oceanographic characteristics (DFO 2016a). The AOI overlaps a variety of geomorphic units including shelf channel, shelf basin, shelf bank, shelf flat, and continental slope (DFO 2016a). These classifications are based on geomorphological characteristics (e.g., shape and topography) that are assumed to have distinctive biological assemblages. These biophysical and geomorphic units provide an important large-scale (100–1000s km$^2$) classification for marine spatial planning, ensuring representativity and equitable distribution of marine conservation efforts (DFO 2016a).

Seabed classification by World Wildlife Fund (WWF Canada 2009) divides the AOI into four main areas: Outer Gulf of Maine; Scotian Slope West – Fan; Outer Scotian Shelf – Saddle; and Outer Scotian Shelf – Bank (Table 4). Within the Outer Gulf of Maine area, the AOI is further divided into channel and basin subareas. The Scotian Slope West Saddle is characterized by depths < 200 m and a sandy substrate with gravel. The Outer Scotian Shelf Banks are primarily covered in sand and gravel, with some mud or boulder patches. Phytoplankton are abundant over these banks, providing food for filter-feeders and grazers, including scallop, clams, and sand dollars. Horse Mussels, brittle stars, crabs and Lobster are also common on shelf banks. Fish that are commonly found in the Bank habitat are Atlantic Cod, Haddock, Pollock, and Silver Hake. The Scotian Slope West Fan begins at the mouth of the Northeast Channel and extends into deeper water. Animals in this area include soft corals and sponges, and redfish living amongst them. The pelagic zone of this area is highly productive and provides food for whales. The Outer Gulf of Maine Basin component is a deep depression with a smooth seabed and glacial till, which provide substrates for corals, sponges, and anemones. The Channel component of the Outer Gulf of Maine lies between Georges and Browns banks, with depths of 200–300 m (Figure 2). The channel is characterized by strong tidal currents and the presence of large gorgonian corals. These conditions provide important biogenic habitat for juvenile Redfish. At the surface of the channel, aggregations of whales, swordfish, and other pelagic fish are attracted to an abundance of prey driven by high primary productivity, especially in the waters above submarine canyons (i.e., the Hell Hole) that incise the continental shelf slope (WWF Canada 2009).

## Scope for Growth

The AOI is considered an area of relatively high scope for growth (Figure 33), an index which considers environmental stressors that pose a cost for physiological functioning, limiting growth and reproduction of the organisms in a particular area (Kostylev and Hannah 2007). Scope for growth is a continuous variable scaling from ‘adverse’ (low scope for growth) to ‘benign’ (high scope for growth), based on food availability, average annual bottom temperature, temperature variability, and oxygen saturation (Kostylev and Hannah 2007). A general east-west gradient in scope for growth is observed in the Gulf of Maine and on the Scotian Shelf, with the western part showing high scope for growth, and low scope for growth in the east. Based on Kostylev and Hannah (2007), the majority of the AOI shows high scope for growth, particularly on Browns Bank and Georges Basin. A relatively lower scope for growth is shown towards the continental slope where natural disturbance varies with sediment type. Disturbance is a variable representing the ratio of characteristic friction velocity to critical shear stress (a function of grain size) required for sediments to move and thus alter the habitat; it does not consider episodic events such as anthropogenic disturbances. Areas of low disturbance are present within the Northeast Channel and correspond with the presence of deep water corals (Figure 33) (V. Kostylev, DFO, pers. comm., May 2018).

# INVERTEBRATES

## Diversity of the Fundian Channel-Browns Bank

Ward-Paige and Bundy (2016) identified the Northeast Channel as being an area of consistently high fish and invertebrate diversity, suggesting this ecosystem may be resilient to disturbance and change. Similarly, Browns Bank was also characterized by high invertebrate richness and evenness relative to other areas on the Scotian Shelf. Nearly 340 species and 100 genera of macrobenthic invertebrates have been recorded from Browns Bank (Wildish et al. 1990, Wildish et al. 1989). Kostylev et al. (2001) and Todd et al. (2006) report general trends on benthic megainvertebrates on Browns Bank. Suspension feeders, including Atlantic Sea Scallop, Sea Cucumber, and sabellid worms are predominant on the western, shallower part of the bank. Deposit feeders, including nothriid worms, are more abundant with increasing depth towards the eastern portion of the bank (Kostylev et al. 2001). Complex gravel habitats with a wide range in grain size in the central and eastern parts of the bank showed the highest diversity and abundance of sessile epifauna. These epifauna include several species of sponges (*Halichondria panicea, Myxilla* sp., *Cliona* sp.), brachiopods (*Terebratulina septentrionalis*), and tunicates (Molgulidae). At deeper parts of Browns Bank (> 100 m) are covered predominantly by a thin layer of mud creating habitat for leafy bryozoans (*Flustra foliacea*), sponges, and tunicates. Barnacle tests were also found in deep portions of the bank (Todd et al. 2006). Sandy portions of the bank were relatively barren, with solitary hydroids (*Corymorpha pendula*) and sand dollars being the most common epifauna (Kostylev et al. 2001). Kostylev et al. (2001) divide Browns Bank into six habitats based on sediment type, depth, and the benthic community, which are summarized in Table 5.

Murillo et al. (2018) provide a report on the benthic invertebrates in the Maritimes Region based on the summer RV Survey from 2017 on board the CCGS *Alfred Needler* (NED2017020). This survey sampled NAFO divisions 4VWX and the Canadian portion of 5YZ at depths between 49 and 1,348 m. Two hundred and sixty-one fishing stations were completed during the survey, with 17 of these designated as a null set either due to net damage or the trawl being cut short, for a total of 244 valid sets. Several general trends emerged in the vicinity of the AOI. First, while the biomass of demersal fish generally outweighed that of invertebrates in the majority of trawl sets, invertebrate biomass was higher than demersal fish on Browns Bank and some sets in the Bay of Fundy. Benthic biomass (kg/station) was highest on Browns Bank, Georges Bank, Banquereau Bank, and the northern side of the Bay of Fundy.

Within the AOI, on Browns Bank, within the Fundian Channel, and in Georges Basin, arthropods represented the majority (approximately 98%) of the composition of total benthic invertebrate biomass in the 2017 RV Survey. This arthropod biomass is primarily the result of large lobster catches, which account for 87% of the total arthropod biomass (Murillo et al. 2018). In terms of other invertebrates, molluscs were more abundant on northwestern Georges Bank, while chordates (tunicates) were most abundant in central Browns Bank. Cnidarians were more abundant on southern Browns Bank and in the Fundian Channel and Georges Basin, though annelid worms were also abundant in some sets in Georges Basin. Few bryozoans were caught within the AOI, as these were most abundant in the Bay of Fundy (Murillo et al. 2018).

A total of 9 fishing stations were completed within the AOI during the 2017 survey. Benthic invertebrate biomass ranged between 4.7 and 98.5 kg per station, with a mean (± SD) 25.8 ± 31.7 kg across the 9 stations. At least 41 benthic invertebrate taxa were preliminarily identified from these stations, representing 9 different phyla. Estimated species richness by phylum showed a different pattern in dominance, when compared to biomass. Sponges were the most diverse phylum (10), followed by echinoderms (8), arthropods (8), cnidarians (6), and molluscs (4). The rest of the phyla encountered constituted the remaining 5 species.

### Corals, Sponges, and Megaepifauna

Cold-water corals, also known as deep-water corals, are commonly found throughout Atlantic Canada typically between 200–1,500 m in depth along the continental shelf edge, in submarine canyons and in channels between fishing banks including the Fundian Channel. These areas may be associated with strong, relatively warm currents, higher concentrations of nutrients and hard substrate for larval attachment, which collectivity create ideal habitat for deep-water corals. Cold-water corals are able to survive without light and in temperatures ranging from 4–13°C (Gordon Jr and Kenchington 2007).

Corals provide complex biogenic habitat, contribute to species richness and biodiversity, and provide a place for marine animals to rest, feed, spawn and seek shelter. In deep water, coral and sponge communities may be the only habitat feature on the seafloor. Buhl-Mortensen and Mortensen (2005) investigated fauna associated with two species of cold-water corals (*Paragorgia arborea* and *Primnoa resedaeformis*) from five areas along the continental shelf and slope off Atlantic Canada (300–600 m). Of the 25 samples, 13 were from *Paragorgia arborea* and 12 were from *Primnoa resedaeformis*, a total of 114 species and 3,915 individuals were recorded.

The existence of cold-water Gorgonacea (horny corals) and Scleractinia (stony corals) corals in Atlantic Canada has been known for decades primarily due to incidental catches by fishers and historical surveys. The two most common species of large gorgonian corals in Atlantic Canada are *Paragorgia arborea* and *Primnoa resedaeformis* (Mortensen and Buhl-Mortensen 2004) and in certain areas like the Northeast Channel can form dense forest-like habitats. Recently, visual studies conducted by government and university scientists have confirmed areas of coral importance including the Northeast Channel (Kenchington et al. 2016a). Biomass surface of large gorgonian corals found in the Northeast Channel were predicted to have moderate to high biomass with the top predictor being slope (Kenchington et al. 2016a).

In the Maritimes Region, the Northeast Channel Coral Conservation Area (NECCA - 424 km$^2$) has been a primary focus of coral conservation since the 1990s and was established to protect high densities of corals (Campbell and Simms 2009). The conservation area is divided into two zones where 90% of bottom fishing is prohibited and only 10% is open to longline gear.

Because corals are limited by their habitat and have variable reproductive strategies, they are vulnerable to a wide range of impacts including invasive species, temperature, ocean acidification and anthropogenic activities such as fishing, offshore oil and gas exploration, and subsea mining and cables (Campbell and Simms 2009). Cold-water corals are long-lived and slow growing and consequently, once disturbed, will mean lost opportunity to learn more about their importance (Breeze et al. 1997) and more importantly, a reduction in habitat for many associated species.

Beazley et al. (2016), Kenchington et al. (2016a), and Beazley et al. (2017) used species distribution models (SDMs) and kernel density estimates to predict the presence or absence of benthic invertebrates, including sponges, corals, tunicates, sand dollars, and sea pens in the

Maritimes Region. Sponges were distributed throughout the AOI, but were particularly dense in the Browns Bank portion of the AOI. The Russian Hat Sponge (*Vazella pourtalesi*) was detected in deeper waters, including the Northeast Channel and into the Gulf of Maine, with a high probability of occurrence based on a random forest model in the deep portions of the Fundian/Northeast Channel (Beazley et al. 2016). Sea pens (Pennatulacea) are concentrated in deep basins and along the continental slope, with a high probability of occurrence along the slope and in deep, offshore waters. Sea pens are distributed within both the Georges Basin and Fundian Channel portions of the AOI (Lacharité and Metaxas 2018), but in lower densities than corals. Large gorgonian corals are concentrated along the continental slope, with a particularly high abundance within the Northeast Channel portion of the AOI. In fact, the highest abundance of large gorgonians in the Maritimes Region occurs within the Northeast Channel portion of the AOI, where they co-occur with *V. pourtalesi.* Small gorgonians are similarly distributed along the continental slope, including in the Northeast Channel (Beazley et al. 2016).

### Patterns in the Distribution and Abundance of Deep-water Corals and Other Megaepifauna in the Fundian Channel-Browns Bank AOI

Soft coral gardens include *Gersemia rubiformis, Anthomastus grandiflorus, Dulva florida* and *Drifa glomerata*, have been observed near the slope in the Northeast Channel, along the continental slope, and off Cape Breton. Finally, cup corals (*Flabellum alabastrum, F. angulare,* and *F. macandrewi*) reach high densities along the Scotian Slope, but do not form biogenic habitat and thus do not meet Ecologically and Biologically Significant Area (EBSA) criteria (Kenchington 2014). Cup corals are distributed between 180 m and 3,200 m, but these have not been found within the AOI (Beazley et al. 2017).

Two prominent deep-water corals in the AOI are the Alcyonacea *Primnoa resedaeformis* and *Paragorgia arborea*. SDMs have predicted areas of suitable habitat to occur on steeply sloping regions along the shelf break and shallow continental slope for *P. arborea*, but wider swaths that extend onto the shelf for *P. resedaeformis* (Bryan and Metaxas 2007). In practice, the locations of known occurrences of these two species are fewer than predicted (Bryan and Metaxas 2006). Some of the densest aggregations of the two taxa on the Scotian Slope are found in the NECCCA established to specifically protect them. Although abundance of these corals can vary greatly across different sections within the NECCCA, it generally increases with depth from an average of 4.8 and 0.6 colonies 100 $m^{-2}$ at depths < 500 m for *P. resedaeformis* and *P. arborea,* respectively, to 12.8 and 2.5 colonies 100 $m^{-2}$, respectively, at depths > 500 m (Mortensen and Buhl-Mortensen 2004, Watanabe et al. 2009). Deeper than 500 m, the abundance of *P. resedaeformis* decreases monotonically to the bottom of the canyons at approximately 910 m, whereas that of *P. arborea* remains unchanging but variable and low (Bennecke and Metaxas 2017, Watanabe et al. 2009). Outside the NECCCA on the westernmost canyon of Northeast Channel, abundance of these two species is almost negligible at depths 500–800 m (Watanabe et al. 2009), but both species were found at depths approximately 900 m (Bennecke and Metaxas 2017). Coral abundance in these aggregations has increased slightly between 2001 and 2014 (Bennecke and Metaxas 2017). Within the AOI, sparse colonies of *P. arborea* and *P. resedaeformis* were also found during a dive in Fiddlers Cove, at depths between 620 and 691 m. Only two dives with a remotely operated vehicle have been at the deeper reaches of the NECCCA, covering a total of 846 $m^2$. Coral abundance was low at the deepest (1,230–1,520 m depth) but 12 taxa were identified in the shallower one (1,000–1,200 m); the most abundant of these were *Anthomastus*, with *Acanella*, Isididae and *Halipteris* also being relatively abundant. *Anthomastus* and Nephtheidae were also the most abundant taxa, at depths 680–1,020 m, southwest of the boundary of the NECCCA (Bennecke and Metaxas 2017).

The corals observed in the NECCCA vary in size from small recruits (< 5 cm in height) to 140 cm and 230 cm, for *P. resedaeformis* and *P. arborea,* respectively (Watanabe et al. 2009). For *P. resedaeformis,* mean and maximum height decreases with depth from 550 to 950 m, whereas for *P. arborea,* it increases (Watanabe et al. 2009). Using photogrammetry, the growth rate of *P. arborea* was determined *in situ* to be up to 4.0 cm $yr^{-1}$ for colonies < 65 cm in height and 0–0.7 cm $yr^{-1}$ for a colony 165 cm in height (Bennecke et al. 2016). For *P. resedaeformis*, growth rates of approximately 2 cm $yr^{-1}$ were recorded. This suggests that some of the largest colonies observed in the NECCCA are hundreds of years old. Colony size for *P. resedaeformis* was greatest in 2014 compared to 2001, 2006, and 2010, and for both species, the largest colonies were found in 2014 compared to the other years (Bennecke and Metaxas 2017). These patterns suggest that protection from fishing may have had some impact by allowing continued growth of existing colonies.

Rates of recruitment vary across the Northeast Channel and are higher in shallower depths (658–671 m) amongst the coral thickets than on the floor of the canyon (860 m depth) where only a handful of colonies are present (Lacharité and Metaxas 2013). The pattern could be the result of short dispersal distances and localized larval supply, gregarious settlement or hydrodynamics within the broader canyon. Within the coral thickets, recruitment rate was on the order of 300 colonies $m^{-2}$ $yr^{-1}$ (Lacharité and Metaxas 2013), a rate more than six orders of magnitude greater than coral abundance in the NEC. Size frequency distributions changed little between 2001 and 2014, and attached small colonies (< 5 cm) were few and only at a single site in NECCCA (Bennecke and Metaxas 2017). These results suggest that for corals in the NEC (1) the populations are not limited by larval supply, (2) mortality is extremely high at the early life history stages after settlement, and (3) consequently, it will take > 13 years to detect significant changes in the population that can be attributed to protection from anthropogenic activities.

### Sponges and other Megaepifauna

Megaepifauna other than deep-water corals are for the most part sparsely distributed across the regions of the AOI that have been sampled visually (remotely operated vehicle ROPOS and drop-camera CAMPOD). On Sewell Ridge and Georges Basin, epifauna cover was < 3%, and in two locations in Browns Channel it reached 16 and 34% (Lacharité and Metaxas 2018). Overall, cnidarians (mainly anemones) and sponges dominated the fauna in these regions. In Browns Channel, one species of ophiuroid and an encrusting sponge were the most abundant, whereas on Sewell Ridge, the same encrusting sponge, as well as a solitary anemone, the sea pen *Pennatula aculeata*, and the brachiopod *T. septentrionalis* showed the highest abundance. A crinoid, the sponge *Stylocordila borealis,* and an ophiuroid were the most abundant morphotaxa in Georges Basin (Lacharité and Metaxas 2018). Oceanographic properties, geomorphology, and substrate complexity were the factors that explained most of the variance in megafaunal cover (Lacharité and Metaxas 2018).

Southern Browns Bank is an area of significant sponge concentrations as defined by Kenchington et al. (2016b). Sponges dominated by the family Polymastiidae were present in all stations sampled during the 2017 RV survey within the AOI. In some samples up to 7 specimens of the glass sponge *V. pourtalesi* (Russian Hat Sponge) were recorded. Additionally, several branches of the gorgonian *Paramuricea* sp. were recorded in one station in the northwest of the area, together with several colonies of the sea pen *Pennatula aculeata*, which was also found in higher abundance in another station constituting a significant catch as defined by Kenchington et al. (2016b).

Within the NECCCA, dense aggregations of the ophiuroid *Ophiacantha abyssicola* (390–1,200 individuals $m^{-2}$) are present, likely because of reduced predation and increased particle supply (Metaxas and Giffin 2004). It is possible that the disturbance from movement and feeding of these aggregations is responsible for the high early life history mortality suggested for deep-water corals (Lacharité and Metaxas 2013). Anemones (including *Actinuage verilli* and *Bolocera tudiae*) and an encrusting white sponge can also be quite abundant at 10–150 individuals $m^{-2}$ (Metaxas and Davis 2005). Actinaria and hexactinnelid sponges recruited on colonization substrates at rates of 100s $m^{-2}$ $yr^{-1}$, again suggesting high post-recruitment mortality as for the deep-water corals (Girard et al. 2016).

Some surveys done on the Northeast Fan have detected low substrate complexity at 2,100 and 2,500 m depths, but high complexity at 2,900 m, lower species diversity and evenness at 2,100 m than the other two depths and no differences in species richness (Lacharité and Metaxas 2017). At 2,500 and 2,900 m, the most abundant taxa were holothuroids, asteroids, and ophiuroids, with some Alcyonacean corals (*Chrysogorgia* and *Nephtheidae* spp.) (Lacharité and Metaxas 2017); total abundance was related to depth but not substrate type. Species diversity and richness were highly associated with substrate complexity as a result of faunal aggregations on sporadic features such as boulders scattered across a relatively homogeneous soft-sediment seafloor. These features may provide important stepping stones for taxa such as corals and sponges that require hard substrate for attachment.

Based on Beazley et al. (2017), Stalked Tunicates *(Boltenia ovifera*) are not predicted to be highly abundant in the AOI but have been collected intermittently on Browns Bank and Georges Bank. Sand Dollars (*Echinarachnius parma*) are present on Browns Bank and Georges Bank, but are more common on the ESS.

## Lobster

### Geographic Range and Habitat Preferences

American Lobster are a decapod crustacean distributed throughout the northwest Atlantic, ranging from the coast of North Carolina to southern Labrador to North Carolina. Lobster generally inhabit coastal waters (< 50 m depth), but can be found deeper (> 500 m) in areas where warm slope water is persistent year round. These warm, deep water habitats have been documented from North Carolina to Sable Island, specifically along slopes and in basins of the WSS (Pezzack et al. 2015a) and in the vicinity of the AOI (Figure 34). Deep water habitat is not prevalent on the ESS, outer Gulf of St. Lawrence, or off Newfoundland, where warm deep waters are not a persistent feature.

Evaluating connectivity and larval recruitment patterns has been a focus of research for deep water Lobster populations, with specific focus on evaluating the linkages between these discrete deep water habitats and the broadly inhabited coastal zone. Understanding inshore-offshore connectivity was of particular importance for managers to evaluate the influence, if any, of offshore fisheries on those inshore, and vice versa (Pezzack 1992). It is known that spawning does occur in these deep water habitats (Harding et al. 1987), generally in waters up to 100 m depth (Harding et al. 2005), with some surveys suggesting abundance of early stage larvae could be as much as 2.5 times higher than in the coastal zone (Harding and Trites 1988). Ontogenetic migration of ovigerous female Lobsters to shallower and warmer bank habitat (e.g., Browns and Georges Banks) to spawn was thought to be a behavioural mechanism to place hatched larvae into more suitable developmental conditions (Campbell 1986). Correspondingly, ichthyoplankton surveys from the Scotian Shelf noted that the majority of larval Lobster captured offshore were found in the vicinity of Browns and Georges Banks (Watson and Miller 1991).

Biophysical models have been used to describe larval connectivity from deep water populations and have demonstrated that offshore spawning could provide significant recruitment subsidies to inshore stocks. In particular, simulations of dispersal of larvae originating from Browns and Georges Banks suggested significant recruitment to southwestern Nova Scotia (Harding and Trites 1988). These offshore larval subsidies are likely an important factor regulating the persistence of inshore stocks (Fogarty 1998) and recruitment from southern gulf of Maine and highlight the importance of source-sink dynamics to the conservation and management of Lobster stocks. Using biophysical hindcasted trajectories, Harding et al. (2005) found that coastal spawning from the southern Gulf of Maine was likely an important source of late stage larvae to Browns and Georges Banks. Collectively, these studies highlight a dynamic and connected relationship between inshore-offshore socks achieved through larval production and ontogenetic migration. Recent genetic surveys agree with this narrative, finding little evidence of significant genetic exchange and genetic structure among Lobster sampled coastally and offshore in the WSS (Stanley et al. 2018). Overall, the influence of increased surface temperatures (e.g., Figure 13) on larval dispersal and population connectivity is unknown, though it is likely that changes in pelagic larval duration will influence the recruitment dynamics between inshore and offshore populations.

Temperature also plays an important role in the adult and juvenile life history of American Lobster. Processes such as behaviour, habitat preference, moulting, growth rate, gonadal development, and egg development have all been linked to temperature and temperature variability (e.g., Lawton and Lavalli 1995, Mills et al. 2013). Overall, thermal preferences for Lobster are broad and vary seasonally, with juvenile and adult Lobsters associated with temperatures between 0–25°C across their range. Range-wide genetic surveys suggest Lobster on Browns and Georges Bank cluster broadly with those Lobsters sampled on the WSS and Gulf of Maine (approximately 45 °N and lower; Stanley et al. 2018) and thus temperature tolerances for Lobsters within and adjacent to the AOI should be similar to those Lobsters in the Gulf of Maine and Bay of Fundy. Habitat modelling for offshore populations of the WSS suggests that Lobsters are most frequently associated with temperatures of 5 and 15°C (Cook et al. 2017). Historic tagging studies note that behaviour is linked to seasonal changes in temperature, with Lobster moving off the banks (Browns and Georges) to deep, presumably warmer water (200–400 m) in the winter (Pezzack and Duggan 1986). Given changes in bottom temperature and Lobster abundance in deep water habitats, it is unknown whether this seasonal migratory behaviour remains (Cook et al. 2017).

Of Lobster collected within the AOI by the RV Survey, 77% were collected on Browns Bank, 18% were collected in Georges Basin, and 5% from within the Fundian Channel. The weighted mean depth and temperature at which Lobster were collected within the AOI are 73 m and 9.2°C, respectively.

### Biology

Reproductive potential of American lobster is related to the frequency of spawning and fecundity, which both scale positively with body size (Currie and Schneider 2011, Waddy and Aiken 1986). Size structures for offshore populations, including those of the WSS, are generally larger than those of inshore populations. Maintaining the high reproductive potential associated with this size structure is an important component of management and conservation for the area (Cook et al. 2017).

Lobsters are generalist feeders, preying on a variety of marine organisms including crab, sea stars, worms, shellfish and fish. Predators for Lobsters include Spiny Dogfish, Sea Ravens, wolffish, Haddock, and hake (Lavalli and Lawton 1996), whom are all likely to inhabit the areas within and surrounding the AOI. Diet analyses of groundfish sampled during the DFO RV Survey over several decades (1960s-2009) suggest that predation on Lobster is likely low (< 0.0001% of 160,580 samples) (Cook et al. 2017). The natural mortality of adult Lobster is generally assumed to be between 10 and 15% per year (Gendron and Gagnon 2001) and likely decreases with size. However, there remains no definitive estimate of natural mortality for the species.

### Population or Stock Definitions

Offshore Lobster fishing in Lobster Fishing Area (LFA) 41 occurs within the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4X (Browns Bank and adjacent slope and basins) and within Canadian waters of 5Z (Georges Bank). The AOI overlaps with approximately half of LFA 40 and parts of LFA 41. LFA 40 was closed to fishing in 1979 as a measure to conserve egg production by protecting a broodstock believed to inhabit upper Browns Bank (Cook et al. 2017). Offshore Lobster populations have been shown to have a higher proportion of large, ovigerous female Lobsters than observed in the inshore. Lobsters have been observed aggregating in high abundance within LFA 40, at least in the summer months.

### Fisheries and Other Human Activities

Lobster have been commercially harvested since the 1800s, with fishing activity primarily focused in coastal waters between the Gulf of Maine and the Gulf of St. Lawrence. LFA 41 is managed under the Integrated Fisheries Management Plan with one Enterprise Allocation offshore Lobster license and a Total Allowable Catch (TAC) of 720 t (Cook et al. 2017, DFO 2017j). In 2010, the offshore fishery received certification for being a sustainable and well managed fishery from the Marine Stewardship Council (MSC). Bycatch species that occur most frequently in the LFA 41 Lobster fishery include Jonah Crab, Cusk, Atlantic Cod, Red and White hake, and Haddock; however, bycatch has decreased from 126 t to 19 t between 2006 and 2015, with Cusk making up 6.7 t of bycatch in 2015 (Cook et al. 2017). Lobster fishing remains closed within LFA 40, approximately 50% of which resides within the AOI.

### Status and Trends

The Maritime Region Summer Ecosystem Surveys in NAFO division 4X show that over the last 36 years (1980–2016) the stratified mean number of Lobsters per tow was the highest ever recorded with pronounced increases in 2014 (

Figure 35). Offshore American Lobster populations, in particular within LFA 40, have been shown to have a higher proportion of large, ovigerous female lobsters than observed inshore. Abundance in the offshore varies seasonally with peaks in the summer months associated with the onset of spawning. Abundances of lobster recorded in the vicinity of the AOI during the Summer RV Survey is consistently amongst the highest on the Scotian Shelf. Based on the 2018 stock status update (DFO 2019b), the LFA 41 Lobster fishery is in the Healthy Zone.

### Sources of Information

Data sources for offshore Lobster on the WSS include logbook data, dock side monitoring, at-sea monitoring, bycatch, Maritime Region Summer Ecosystem Survey, , and NEFSC bottom trawl surveys (see Cook et al. 2017 for detailed description of data sources). For the purposes of this overview, results from the DFO summer RV Survey were used to describe recent, fisheries independent trends.

### Sources of Uncertainty

Re-evaluating connectivity between offshore areas and adjacent stocks was identified as a key knowledge gap in the recent review of offshore (LFA 41) Lobster (Cook et al. 2017). Previous tagging studies (e.g., Pezzack and Duggan 1986) noted seasonal movement of adult Lobsters. It is unclear whether this migratory behaviour and resultant connectivity is still prevalent given changes in environment (generally warmer bottom temperatures) and abundance (Cook et al. 2017). Moreover, it remains unclear whether any consistent pattern of connectivity or dependency (e.g., inshore to offshore or vice versa) characterizes the area.

The influence of warming temperatures associated with stochastic incursions of the Gulf Stream (see Physical Oceanography section) or long-term variations associated with the North Atlantic Oscillation Index and the Atlantic Multidecadal Oscillation on the biology of offshore Lobsters is unknown. Understanding how productivity may respond to warming temperature should be a focus of future monitoring and management of Lobster stocks within and adjacent to the AOI.

## Atlantic Sea Scallop

### Geographic Range and Habitat Preferences

Atlantic Sea Scallop (*Placopecten magellanicus,* hereinafter Scallop) is a bivalve mollusc that supports the second largest commercial fishery in the Maritimes region. Atlantic Sea Scallop are found from North Carolina to the Strait of Belle Isle, Newfoundland. This species is generally found at depths up to 110 m, though populations are known to occur at depths in excess of 300 m (Merrill 1959, Shumway and Parsons 2016). Scallop tend to be found in large aggregations (beds); these beds can be transient or long lasting with some beds having supported commercial fisheries for decades. Adults are predominately found on coarse sand, gravelly, cobble bottom (Hart and Chute 2004).

In the Maritimes Region, Atlantic Sea Scallop are distributed across Georges and Browns banks, in the Bay of Fundy, the offshore mid Scotian Shelf, and sporadically throughout the region (Figure 36). Of Atlantic Sea Scallop collected within the AOI by the RV Survey, 96% were collected on Browns Bank, and 4% from within the Fundian Channel. The weighted mean depth and temperature Sea Scallop were collected within the AOI are 65.5 m and 7.8°C, respectively.

### Biology

Atlantic Sea Scallop are broadcast spawners with separate sexes. This species is highly fecund and females can produce tens of millions of eggs each year; they can show evidence of maturation during their first year and their fecundity increases rapidly with individual size (Langton et al. 1987). Spawning is typically synchronous and generally occurs in the late summer or early fall, although there is regional variability in the timing (Shumway and Parsons 2016).

The Browns Bank North stock assessment model indicates that instantaneous natural mortality rates for commercial sized scallop (≥ 95 mm) averaged 0.15 and varied between 0.07 and 0.27 from 1991 to 2012 (Hubley et al. 2013). Natural mortality is significantly higher for larval stages and generally declines with increasing size (Shumway and Parsons 2016).

Scallop are suspension filter feeders and primarily feed on phytoplankton and microzooplankton (Shumway and Parsons 2016). Detritus can also be an important source of nutrients (Shumway et al. 1987).

During their planktonic larval stage, Sea Scallop larvae are subject to predation by a wide range of filter feeders and small planktonic predators (Langton and Robinson 1990). Once in their adult form, Scallops contend with predation from numerous fish (Atlantic Cod, sculpins, flounder, etc.), decapods (lobster and various crab species), and several sea star species (Shumway and Parsons 2016). Scallop susceptibility to predation generally declines as the individual increases in size (Stokesbury and Himmelman 1995).

### Populations or Stock Definitions

Scallop in the Maritimes Region is managed in 20 separate management units split between the offshore (7) and inshore (13). The offshore management units generally separate populations found on different banks, although some of the management units separate contiguous populations within a single bank. The Browns Bank region of the AOI overlaps with two of the offshore management areas (Browns Bank north and Browns Bank south) which divides one contiguous scallop population. The AOI encompasses the entire scallop fishing area in Browns Bank south, while it overlaps with a portion of the Browns Bank north scallop fishing area.

### Fisheries and Other Human Activities

The fishery is managed on the basis of an enterprise allocation program in which each company receives a percentage share of the TAC. In 2017 there were 6 companies participating in the enterprise allocation program. The fishery is year round in both management areas and is managed by a TAC; in 2017 the Browns Bank north TAC was 750 t and on Browns Bank south the TAC was 50 t. There is a meat count regulation for each region, with the average number of scallop that make up a 500 gram sample not to exceed 40 on Browns Bank north and 60 on Browns Bank south.

### Status and Trends

The removals from Browns Bank south ranged between 0 and 22.8 t per year over the last decade (2008–2017), although at least 100 t of scallop were caught annually in this management zone between 1998 and 2004. In 2017, the removals from Browns Bank south 22.8 t which was the highest catch from this management zone since 2005. There is no assessment model for Browns Bank south and survey indices are used to assess stock status on Browns Bank south. The last survey in Browns Bank south occurred in 2018, and in 2016 the survey biomass index indicated that the commercial biomass (≥95 mm) in this region was slightly above the long term median biomass for the area in years in which a survey occurred (Figure 37).

In 2017 there were 768 t of scallop caught on Browns Bank north; this was above the median catch in this management unit. This management unit is assessed using a stock assessment model; the model results for 2018 indicate that the biomass in Browns Bank north declined by approximately 40% and was below the long term median for the management unit (DFO 2018i). The 2017 survey identified high abundance patches of small Scallop (20–40 mm in size) in a southern portion of Browns Bank north slightly north of the boundary of the AOI.

#### *Abundance/Biomass in the AOI*

The mean catch (kg/tow) of Scallop within the AOI from the summer RV Survey is generally higher on average than the rest of the bioregion, but shows similar trends across time (Figure 38). The mean kg/tow was high in the early 2000s, before declining to < 1 kg/tow within the AOI from 2004–2010. The mean catch then increased following 2010 through 2017.

Based on the DFO Maritimes Offshore Scallop Survey, the mean abundance of Scallop per standardized tow for each year surveyed (all size classes) was calculated for each grid cell. For analysis purposes, the survey domain was gridded into 1-minute by 1-minute cells. These yearly values were then aggregated across all years into a mean abundance of Scallop per tow for each grid cell (Figure 36). Years in which there were no survey tows in a grid cell were excluded from mean calculations for that grid cell.

The spatial index of Scallop abundance showed that abundance was generally higher outside of the AOI on Browns Bank north (BBn); however, there have been relatively large aggregations of Scallops on Browns Bank south (BBs) within the AOI. The maximum mean abundance per tow for a grid cell inside the AOI was 2,435 (located on Browns South); the median grid cell value was 153. Outside the AOI, the maximum mean abundance per tow for a grid cell was 10,476 (located on Browns North); the median grid cell value was 364.

### Sources of Information

The DFO Maritimes Offshore Scallop Science Survey is the primary source of information for Sea Scallop. The Offshore Scallop Survey has occurred on Browns Bank North annually from 1991–2018, and on Browns Bank South 18 times between 1985 and 2018; both surveys use a stratified random sampling design. The surveys provide abundance data at a high spatial resolution and can provide information on the Scallop distribution in the region.

Fishery dependent data (catch, catch per unit effort [Catch, CPUE], etc.) is also available within this region, and the RV Survey also records Scallop species and distributions.

### Sources of Uncertainty

While the population status of scallop in the region is generally well understood, there is uncertainty regarding the life history and movement of the early pelagic stages. Bycatch composition and trends within the Scallop fishery are not well understood.

## Squid

### Geographic Range and Habitat Preferences

Two species of squid occur in Canadian waters – the Longfin Squid (*Loligo pealeii*) and the Shortfin Squid (*Illex illecebrosus*) (Dawe et al. 2007). Both species have short (annual) life cycles and form an important component of the coastal and offshore food webs. These squid prey on euphausiids and mysids, and are an important forage species for seals, marine birds, and pelagic fishes (Johnson et al. 2011, Macy 1982, Staudinger 2006). Ranges for both species extend north to Newfoundland, however Longfin Squid are rarely observed north of Browns Bank on the Scotian Shelf. Shortfin Squid spawn offshore below the surface of the Gulf Stream where their eggs are neutrally buoyant, while Longfin Squid spawn in nearshore coastal zones in the spring and summer. Both species are highly variable in abundance on an interannual basis (Dawe et al. 2007, Lange and Sissenwine 1980). Warming water temperatures predicted under climate change may favour northward expansion of Longfin Squid, while at the same time reducing suitable oceanic conditions for Shortfin Squid (Dawe et al. 2007). From 1970–2006, Shortfin Squid were consistently observed along the continental slope, the central and Western Scotian Shelf, and within the Fundian Channel (Horsman and Shackell 2009).

### Populations or Stock Definitions

Shortfin Squid are considered a single stock along their range. This species inhabits the continental shelf and slope, migrating southward in the late fall (Kennedy et al. 2011). Abundance of Shortfin Squid in appears cyclical in nature. For example, a periods of relatively low abundance between 1970–1975 and 1982–2004 were permeated by a period of higher abundance in NAFO Division 4. Similar, cycles in abundance are also apparent in NAFO Divisions 5 and 6 (Kennedy et al. 2011). Cycles in abundance in Newfoundland and on the Scotian Shelf, have been related to southward or northward displacement of the Gulf Stream Front (Dawe and Colbourne 1997).

Longfin Squid are a schooling species that inhabit the continental shelf and slope to depths of 400 m. This species typically moves to deeper waters in winter, and in summer and fall are found in warm coastal waters at depths of 6–28 m (Kennedy et al. 2011). These migrations are seasonal and related to bottom temperatures (Jacobson 2005). Relative abundance is affected by variation in oceanography each year, but declined between 2002 and 2005.

### Fisheries and Other Human Activities

Both species of squid may be found within the AOI and are landed either in directed summer-fall fisheries or as bycatch, but no trends in abundance are available specific to this region and no assessments on stock status have been conducted. Historically, annual variability in Shortfin Squid catch was lowest for the shelf fishery in the USA, while variability is higher in Newfoundland and on the Scotian Shelf (Dawe and Colbourne 1997).

Seismic exploration could potentially alter the behaviour of squid, who both demonstrate a strong startle response to air-gun start up and a significant alteration of behaviour in response to seismic sound sources at distances up to 5 km air-gun seismic sources (McCauley et al. 2000).

### Sources of Uncertainty

There are no regular stock assessments for squid in the Maritimes, and thus the biomass of squid on the Scotian Shelf or in the vicinity of the AOI remains unknown. Currently, there is no known stock structure for either species. Investigation of stock structure (i.e., genetic structure) may help inform management of these species, particularly if any structure corresponds to environmental conditions (e.g., genetic separation between stocks on the eastern and western scotia shelf associated with gradients in temperature – Stanley et al. 2018). Given the presence of both species on the Shelf and in the vicinity of the AOI is closely tied to environment (namely temperature), this information could provide important insight into how current and potential future climate conditions will influence the presence of both species in the region.

## Other Invertebrates

### Echinoderms

Asteroid (sea stars), echinoid (sea urchins and sand dollars), ophiuroid (brittle and basket stars), crinoid (sea lilies), and holothuroid (sea cucumbers) echinoderms can be found within the AOI. These species provide important food for demersal fish, such as wolffish (*Anarhichas* spp.) (Nelson and Ross 1992). Within the AOI, sea cucumbers and sand dollars are primarily found on Browns Bank, brittle stars are primarily found in the Fundian Channel and Georges Basin, crinoid species are typically only observed within Georges Basin, and sea stars of different species found sparsely throughout the AOI.

Dense aggregations of the brittle star *O. abyssicola* (390–1,200 individuals per m$^2$) have been observed within the NECCCA. Density estimated for the central channel near the shelf break (site: Hell Hole West) was 2–3 times greater than areas sampled east and west of this site (Metaxas and Giffin 2004).

Sand Dollars are abundant on parts of Browns Bank (Kostylev et al. 2001). Sea Cucumber and Green Sea Urchin are found primarily on the northern portion of Georges Bank and parts of Browns Bank, but have not been reported from the Fundian Channel portion of the AOI.

In a survey in the eastern Gulf of Maine, Lacharité and Metaxas (2018) report that an unidentified crinoid and a morphospecies of brittle star were found in the highest abundance in the muddy, fine-grained substrates of Georges Basin. Blood Stars (*Henricia* spp.) appeared ubiquitous in the eastern Gulf of Maine and were observed within Georges Basin (Lacharité and Metaxas 2018).

### Decapods

Other species of decapods that are found within the AOI include Jonah Crab (*Cancer borealis*), Rock Crab (*C. irroratus*), Red Crab (*Chaceon quinquedens)*, other crabs including *Lithodes mya,* Snow Crab (*Chionectes opilio), Hyas araneus, H. coarctatus,* and shrimps including Northern Shrimp (*Pandalus borealis)*, *P. montagui*, hermit crabs (*Paguridae sp.*), and the Pink Glass Shrimp (*Pasiphaea multidentata*) (Tremblay et al. 2007).

Jonah Crab are found on Browns Bank and within Georges Basin, and are caught as bycatch in the Lobster fishery (M. Greenlaw, DFO, pers. comm.). Rock Crab are found predominantly in the shallower portion of the AOI on Browns Bank.

Red Crab are at their northern limit in southern Nova Scotia and are commonly found at depths of 300–900 m on hard or muddy bottom. Catch rates for Red Crab on Browns Bank declined from 1984 to 1997 and this population may be depleted, though this species has not been assessed since 1997 (DFO 1998).

The AOI represents the extreme southern range limit for Snow Crab and they may in fact no longer be found in this region at all. Suitable habitat for Snow Crab is highly dependent on temperature, and it is likely that the conditions of the WSS are too warm and thus unsuitable for this species. Observations of Snow Crab within NAFO 4X have been restricted to small incursions of cold water from the Nova Scotia Current into LaHave and Roseway basins, south of the AOI (Zisserson and Cook 2017). Currently no stations from the Snow Crab survey overlap with the AOI.

The Gulf of Maine is the extreme southern range limit of Northern Shrimp (*P. borealis*) (Hardie et al. 2018). Northern Shrimp prefer high salinity environments and temperatures from 0 to 5°C. Northern Shrimp are most common between 50 and 500 m, and especially so on muddy substrates from 10–300 m (Hardie et al. 2018). They provide food for many groundfish species, including Atlantic Cod, hake, redfish, and flounders. The AOI is in Shrimp Fishing Area 16, which is not regularly assessed. The stock in the Gulf of Maine appears highly variable, fluctuating based on temperature anomalies and fluctuations in predator abundance (Hardie et al. 2018). Interestingly, Northern Shrimp in the Gulf of Maine move inshore to spawn due to deep water temperatures becoming too warm in the fall, and then return to deep water in the spring; this contrasts with more northern populations, which do not undergo extensive migrations (Hardie et al. 2018).

#### Invasive Tunicates

Four species of invasive, colonial tunicates have been detected in the Gulf of Maine, including *Botryllus schlosseri, Botrylloides violaceus, Diplosoma listerianum,* and *Didemnum* sp. (Dijkstra et al. 2007). Though most of these species are common in shallow, coastal areas, the non-indigenous colonial tunicate *Didemnum vexillum* has been detected on Georges Bank, but not Browns Bank (Vercaemer et al. 2015). This species overgrow rocks, bivalves, and seaweeds, and grows in dense mats, smothering benthic organisms (Vercaemer et al. 2015). *D. listerianum* can also be found on subtidal rocks in deep, offshore sites (Dijkstra et al. 2007). Expansion of these invasive species could be facilitated by ongoing warming associated with climate change, and thus monitoring on Browns Bank may be advisable.

#### Brachiopods

The brachiopod *Terebratulina septentrionalis* is found on structurally complex gravel and boulder habitat at depths of around 90 m on Browns Bank. This species has a short larval duration and limited dispersal. The larvae of this species actively seek low-light areas, suggesting that areas of high complexity with rocks and crevices attract higher recruitment (Kostylev et al. 2001). This species has undergone steep population declines in the United States (U.S.). and is highly vulnerable to climate change. Brachiopods are also caught as bycatch in commercial trawls which may result in local extinction (SGCN 2016).

## FISH

### Fish Diversity

Biological diversity is defined by the Convention on Biological Diversity (CBD) as "*the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems*". Fish diversity on the Scotian Shelf has long been a focal point of research for many DFO scientists (see Table 1 in Ward-Paige and Bundy 2016). For the purposes of this review, we summarize existing studies of diversity and rely particularly on the most recent assessment of fish diversity in the area provided by Ward-Paige and Bundy (2016). We will focus descriptions of diversity to the waters within and immediately surrounding the AOI including Browns Bank, Georges Basin and the Fundian Channel, with broader reference to the WSS (NAFO divisions 4X and Canadian waters of 5Ze). Where appropriate, we also describe particular diversity features using the RV survey data (described in section 3.1).

In the AOI there have been 71 species observed in 360 RV survey sets since 1970 (Table 6). This species richness varied among the AOI components (65 and 40 for the Northeastern Channel-Browns Bank and Georges Basin, respectively). Within the Northeastern Channel-Browns Bank component, species richness was lower in the channel (46) versus Bank (58; < 200 m depth). Based on the species accumulation curves, it appears that the number of unique species has not leveled off and continues to increase within each of the AOI sub-components (Georges Basin and the Northeastern Channel-Browns Bank) and the AOI overall (Figure 38). Based on these species sampling relationships, and a first-order Jackknife extrapolation (Oksanen et al. 2018), it is estimated that approximately 91.9 ± 4.6 (mean ± se) fish species could be present within the AOI. Extrapolated fish diversity among the components is estimated at 48.8 ± 3.8, 56.8 ± 3.5, and 74.9 ± 4.6 (mean ± se) fish species for Georges Basin, the Northeastern Channel, and Browns Bank, respectively.

### Fish Community

Of the 71 fish species recorded during the RV survey within the AOI boundaries, the top 20, including Haddock, Atlantic Cod, Silver Hake, Yellowtail Flounder, and Pollock, comprised nearly 80% of all observations (Figure 39). Haddock and Silver Hake were both the most frequently observed and abundant fish within the AOI (Figure 40). For the other species, frequency of occurrence was high whereas the median abundance and biomass (per trawl) was relatively low (i.e., Yellowtail flounder, Pollock, Atlantic Halibut and American Plaice; Figure 40) suggesting a widespread but sparse distribution in the AOI.

To identify any substructure within the fish community, species counts were converted to binary (presence-absence) matrices and analyzed using the R package *vegan* (Oksanen et al. 2018). K-means cluster partitioning revealed the fish community within the AOI boundaries is delimited into two distinct groups based on the Calinski criterion (Caliński and Harabasz 1974). This partitioning was estimated to occur at approximately 207 m depth based on a logistic regression of site group assignment and depth (Figure 41). Non-metric multidimensional scaling (nMDS) was used to visualize the distribution of these partitions based on presence-absence data and a Jaccard dissimilarity index (Figure 42). Species centroids in nMDS space also agree with the recorded depth preference for the species within the AOI (See Fish Depth Preferences Section; Figure 43). Partitioning identified by k-means was clearly differentiated in nMDS space, with the Browns Bank fish community distinct from the Fundian Channel and Georges Basin. Overall, group dispersion (ß-diversity) is significantly lower in Georges Basin compared to the Fundian Channel and Browns Bank (permutation test for constrained correspondence analysis – $p < 0.0001$ for each comparison) agreeing measurements of species richness and species accumulation trajectories for the each partition and the nMDS projection (Figure 38 and Figure 42, respectively).

### Fish Depth Preferences

Habitat preferences for finfish species is a combination of depth, temperature, and to a lesser extent sediment type (Fisher et al. 2011, Mahon and Smith 1989). The AOI is characterized by a diverse seascape of depth and temperature. With warm water inflows through the Fundian Channel and over Browns Bank, and rapid transitions of depth associated with the northeastern side of the channel. Community assemblages on the bank, correspondingly change as a function of depth (see section 3.5.1.1).

For some species, depth is an important defining characteristic of habitat as evidenced by narrower observed depth ranges. For example, Haddock, Atlantic Cod and Yellowtail Flounder are restricted primarily to Browns Bank at depths shallower than 200m, Greenland Halibut (*Reinhardtius hippoglossoides*) and species of Hake (White and Smooth) are generally found deeper (> 250m) and Redfish species and Spiny Dogfish can be found across a broad depth gradient (Figure 43).

Variations in depth range associated with size, age, and ontogeny, is common place in marine species. On the Scotian Shelf, Frank et al. (2018) demonstrated that the distribution of fishing activity likely plays an important role regulating the age-depth distribution of fishes (specifically Atlantic Cod in their study). Based on length frequency information collected by the summer RV Survey for the ten most frequently observed species in the AOI (Table A4-1), there appears to be a size based zonation for Atlantic Cod, Haddock, Atlantic Halibut, Atlantic Argentine (*Argentina silus*, hereinafter Argentine), American Plaice, and Yellowtail Flounder among Bank, Channel, and Basin areas (Figure 44).

Ontogenetic shifts in habitat use can also be associated with reproductive fitness, whereby species migrate to areas for spawning, placing larvae in optimal growth and survival (i.e., the ‘match-mismatch hypothesis’; Cushing 1990). Spawning on banks like Browns Bank, with associated circulation gyres could be a strategy to maximize the survival of larvae by co-locating them with food-rich water masses. Correspondingly aggregations of spawning Haddock have been observed on Browns Bank. Currently there is a seasonal spawning fisheries closure implemented on Browns Bank to protect this spawning aggregation.

The RV survey provides an important source of information on groundfish communities. However, of the 360 sets recorded within the AOI boundaries since the 1970s, the depth range has only encompassed 70 to 360 m (median 115 m) compared to the AOI which encompasses depths of 65 to 2,251 m (median 235 m) (Figure 19, Figure 45). There is currently no survey sets for the southern portion of the channel and the deepest areas of the AOI on the Scotian Shelf slope. There are also no assigned sampling strata for the southwestern corner of the AOI (Figure 19). Lack of data in these areas is likely in part due to bottom type, depth restrictions, and particularly the presence of cold-water corals (Don Clark, personal communication). This void limits a complete evaluation of how species and diversity are distributed with depth throughout the AOI.

### Deep Water Community Structure

While no deep water strata exist within the AOI for the Summer RV Survey, the community composition can be inferred from adjacent deep water strata. Exploratory sets along the shelf edge at depths of 750 – 1,800 m revealed similar catch sizes but very distinct community composition. In 2010, 126 vertebrate species and 64 invertebrate species were recorded from these deep catches (Clark and Emberley 2011). The most frequently captured fish species included Stout Sawpalate (*Serrivomer beanii*), Gray’s Cutthroat Eel (*Synaphobranchus kaupii*), Lanternfish (*Lampanyctus macdonaldi*), and Blue Hake (*Antimora rostrata*). The fish species contributing most to weight caught included Roundnose Grenadier (*Coryphaenoides rupestris*), Black Dogfish (*Centroscyllium fabricii*), Agassiz’s Smooth-head (*Leptochilichthys agassizii*), and Portuguese Shark (*Centroscymnus coelolepis*). The most frequently captured invertebrate species were a caridean shrimp (*Acanthephyra pelagica*), *Sabinea* spp., jellyfishes, and

Gnathophausia. Sand dollars, Red Deepsea Crab (*C. quinquedens*), *A. pelagica*, and sea urchins contributed the most to invertebrate catch weight (Clark and Emberley 2011).

Catches in deep water strata 501-504 had similar weights to the shelf strata, but with higher species diversity (see Fig. 4 in Clark and Emberley 2011). Catches on the shelf edge had similar diversity to other shelf strata, but the aver number of species caught per tow was higher in deep strata. Greenland Halibut was the only species that was widely distributed across both shelf and deep water sets (Clark and Emberley 2011).

As noted in the sections on corals and sponges, ROV studies have been conducted in deep portions of the AOI including the continental slope and Northeast Fan. The corals *P. resedaeformis* and *P. arborea* abundance in the Northeast Channel depths between 500–800 m is low, though both species are found at depths up to 900 m. Coral abundance overall is low at depths between 1,200 and 1,520 m, but 12 taxa were identified between 1,000–1,200 m (Bennecke and Metaxas 2017). At depths between 2,500–2,900 m the most abundant taxa are sea cucumbers, sea stars, and brittle stars, with some Alcyonacean corals (Lacharité and Metaxas 2017).

### Fish Biodiversity Hot Spots

Areas of historical high fish diversity in the Maritimes region include the Bay of Fundy, eastern Gully, the continental slopes, Western Bank, and the northeastern shelf, based on data from the summer RV survey between 1970 and 2000 (Shackell and Frank 2003). High species richness was found to be associated with larger areas and a greater depth range, but Shackell and Frank (2003) were unable to estimate total fish diversity on the Scotian Shelf as the species accumulation curves from had not yet (at the time of analysis) plateaued. Cook and Bundy (2012) supplemented data from the summer RV Survey with stomach content data from a length-stratified sample of finfish and found that the addition of stomach contents increased both the number and size range of species observed, especially invertebrates and small finfish. In total, Cook and Bundy (2012) observed 330 species in the trawl and stomach surveys from 1998 to 2008; 294 of these were observed in the trawl surveys, while an additional 36 species were observed only in the stomach contents, though these were entirely invertebrates. The highest finfish diversity, including observations from both trawl and stomach survey, was found in the Bay of Fundy, Browns Bank, and on the northeastern shelf, whereas the lowest finfish diversity was observed on Banquereau and Sable banks, and in NAFO division 4W (Cook and Bundy 2012).

More recently, Ward-Paige and Bundy (2016) investigated species diversity on the Scotian Shelf and Bay of Fundy using three biodiversity indices: species richness, the exponential of Shannon-Wiener Index (ESW), and Heip’s Evenness Index. Their study found that areas with high ESW values occur in the same locations as areas with a high Heip’s Evenness Index, while areas of high species richness occur in different areas from the other two indices. Ward-Paige and Bundy (2016) analyzed data from the DFO summer RV Survey over 44 years (1970–2013), as well as recent data from the Shelf edge (edge sets and deep sets, sampled since 1995 and 2010, respectively) to calculate their biodiversity indices. The results of this study are summarized below.

In the early 1970s, the areas of highest fish species richness occurred in the Bay of Fundy, off southwest Nova Scotia, and other areas on the WSS and along the edge of the Laurentian Channel. Areas of low and high species richness shifted over subsequent decades and increased in size. In the 2000s, the highest species richness moved northwest into the Bay of Fundy and northwards to coastal areas on the Scotian Shelf with mixed depths. Areas of high ESW were generally found throughout the Scotian Shelf across all years, but were higher in the Bay of Fundy in the 1970s and 80s relative to more recent years. High values of Heip's Evenness Index shifted eastward over time to the north and east of NAFO divisions 4VW (Ward-Paige and Bundy 2016).

When all three indices were combined across all years, small areas of high diversity ('hotspots') were observed throughout the Bay of Fundy, the deeper waters of the Northeast Channel and Georges Basin, pockets along the shelf edge, the shallow coastal zone, and areas in northern 4VW. These areas were persistent over time and also showed high co-location of all three biodiversity indices. Areas of low fish diversity included the portion of NAFO 4X centered on the LaHave basin, the upper reaches of the Bay of Fundy, and in general the large basins of the Scotian Shelf. Fish diversity was highest in deep strata (edge and deep shelf sets) compared to the Scotian Shelf (12.5–22.4 mean species richness for edge and deep strata respectively, compared to 9.5 species on the Scotian Shelf), though there was less data for these deep strata overall.

The abundances of key species were compared with areas of high biodiversity indices. Atlantic Herring were most abundant in the Bay of Fundy and inshore WSS and were highly associated with high species richness in both areas. High abundances of Atlantic Cod overlapped with Heip's Evenness Index primarily on the ESS. High Haddock abundance was spread across the banks of 4WX, including Browns Bank, and some overlap with the top 20% quantile for species richness in the outer reaches and middle of the Bay of Fundy. High abundances of White Hake occurred in the Bay of Fundy and deeper waters along the shelf edge, overlapping with areas of high species richness. Red Hake (*Urophycis chuss*), Silver Hake, and Atlantic Mackerel showed high abundances in the Bay of Fundy and WSS, overlapping with areas of high species richness in the Bay of Fundy, and areas of high evenness on the Scotian Shelf. Pollock abundance was highest in 4WX in the deeper waters approaching the Bay of Fundy, overlapping with the high species richness of the Bay of Fundy. Atlantic Halibut were most abundant on Browns Bank, an area of relatively low species richness and evenness, and on German Bank, an area of high species richness. Various other species, including Cusk, Spiny Dogfish, Smooth Skate and Winter Skate showed high abundances approaching the Bay of Fundy and in deep waters in 4X, including Georges Basin. Species that showed the highest abundances in the ESS (4V) included Northern Sand Lance (*Ammodytes dubius*), Capelin (*Mallotus villosus*), American Plaice, Witch Flounder, and Atlantic, Spotted, and Northern wolffish, though Atlantic Wolffish were also highly abundant in the Bay of Fundy (Ward-Paige and Bundy 2016).

Several studies have evaluated biophysical variables that relate to benthic fish diversity. In particular, it has been noted that transitional or high-energy habitats are generally associated with higher diversity (Cook and Bundy 2012). Indeed, strata that encompass steep bathymetric transitions (slopes) consistently show among the highest diversity of finfish species (Themelis 1996) as they span a variety of depth gradients and thus potential fish habitats. The Bay of Fundy is undoubtedly one of the most high-energy areas on the Scotian Shelf and correspondingly has been shown to have consistently high fish and invertebrate diversity (Cook and Bundy 2012, Shackell and Frank 2003, Ward-Paige and Bundy 2016). The AOI has examples of both transitional and high-energy habitat and like the Bay of Fundy has been noted as an area of higher diversity. Bathymetric complexity associated with steep and rapid (> 1 km) transitions from shallow bank habitat (200 m) to the channel (300 m) provide habitat for a variety of species. The Northeastern Channel is also an area of dynamic circulation and like the Bay of Fundy is characterized by high tidal energy (Chen et al. 2011). Fisher et al. (2011) used the RV survey data to relate species diversity to habitat template model based on oceanographic, hydrographic, and benthic-data layers. This template model produces two unitless orthogonal axes that describe broad scale habitat characteristics; *scope for growth* (estimate of local energy available for growth and reproduction) and *natural disturbance* (a local characteristic of the sea floor; see Kostylev and Hannah 2007 for details). They report that diversity was most strongly related to natural disturbance, whereby intermediate values of natural disturbance were related to higher diversity (Fisher et al. 2011). Natural disturbance estimated for the AOI is within this intermediate range (0.2–0.6) averaging 0.41 ± 0.09 (mean ± SD) associated with higher diversity (Figure 33).

The spatial distribution of finfish species richness (number of species per set) shows that for the areas sampled during the RV survey, the most species dense sets appear to be located on Browns Bank and Georges Basin (Figure 46); however there does not appear to be any clear patterns or gradients in diversity and there does not appear to be any clear relationship between depth and diversity, with all intervals distributed between 70 and 360 m. Given the depth distribution of samples within the AOI it is unlikely that this information gives a clear picture of the depth – fish diversity patterns of the AOI.

Habitat complexity is often associated with fish diversity. In particular, the availability of biogenic habitats (i.e., corals and sponges) is consistently related to high fish diversity. Boundaries for the AOI encompass the NECCA, which was established in 2002 to protect a significant concentration of deep water corals. These corals create physical structure and complexity to the bottom and thus provide shelter and feeding places to a wide variety of fish and invertebrate species. Species richness and abundance is often higher within these complex biogenic habitats than compared to adjacent non-reef areas (Costello et al. 2005, Linley et al. 2015). Increases in fish diversity and abundance have also been recorded with glass sponge reefs (*V. pourtalesi*) (Hawkes et al. 2019), which have been observed in the Northeastern Channel and which is predicted to contain highly suitable habitat (Beazley et al. 2018). Within the AOI it is likely that fish diversity will be highest in areas within and immediately surrounding these deep water biogenic habitats. Redfish (*Sebastes* spp.), in particular, have been noted in close association with Gorgonian corals in the Northeast Channel (Mortensen et al. 2005). A full evaluation of the relative contribution of these coral habitats to the fish and invertebrate diversity of the AOI will require more targeted research (e.g., Costello et al. 2005).

Overall fish diversity is higher in the Bay of Fundy and in the vicinity of the AOI, particularly the deeper portions in Georges Basin and on the continental slope, relative to the ESS and areas in the WSS (Shackell and Frank 2003, Ward-Paige and Bundy 2016). Areas with steep bathymetric transitions, high scope for growth, and intermediate natural disturbance, all of which can be found in the AOI, have been found to be associated with high diversity. Additionally, habitat complexity enhanced by biogenic habitat (corals and sponges) found in portions of the AOI are also associated with high fish diversity.

### Larval Fish Diversity

Synoptic surveys of larval fish diversity were conducted from 1978–1982 by the Scotian Shelf Ichthyoplankton Program (SSIP). This program sought out to evaluate the spatial-temporal patterns of fish egg and larval abundance across the Scotian Shelf in relation to environmental covariates. From these surveys several areas emerged as having high diversity near the AOI. In particular, southern Browns Bank was consistently characterized by high larval diversity between April and October (Figure 47) (Shackell and Frank 2000). Specifically, American plaice, Haddock, and Redfish were noted has having high abundance of larvae in the waters within and adjacent to the AOI (Figure 48). Larval Silver Hake were also identified immediately adjacent to, but not within, the AOI. Across the region, Western and Emerald Island Banks were consistently noted as areas of high fish diversity (Figure 47, Figure 48). The presence of a persistent gyre over this bank was attributed as a potential mechanism influencing the concentration and abundance of larvae (Shackell and Frank 2000). Similarly it is possible that the persistent gyre noted over Browns Bank (Figure 9) could potentially influence larval abundance; however, updated larval sampling would be required to fully evaluate how circulation features on Browns Bank and the Northeastern Channel would influence larval abundance. Moreover, updated ichthyoplankton sampling is required to understand the seascape of larval fish diversity and potential distribution of important spawning areas across the Scotian Shelf and within the AOI.

## Warm Water Species

Species more commonly observed in warmer waters south of the Scotian Shelf bioregion, in the Gulf of Maine and on Georges Bank, have been increasingly observed in catches of the summer RV Survey (for species list see Table 7). Average bottom temperatures recorded during the summer RV Survey (NAFO subdivisions 4VWX) have been variable but with an overall increasing trend since the 1970s (Figure 49, Figure 50). The warmest bottom temperatures are generally associated with the Northeast Channel, along the edge of the Scotian Shelf, the central Scotian Shelf, and shoals near Sable Island (Figure 10). Not surprisingly, warm water species are closely associated with these waters (Figure 49, Figure 50) and their prevalence has increased over the past decade (Figure 51). During the most recent summer RV Surveys (2016–17), the total biomass of warm water species sampled exceeded 3,000 t (DFO 2018a). Whereas this biomass is a small fraction of the total estimated groundfish biomass, it nonetheless has increased significantly over the past decade and since the beginning of the survey. Across the region, the increased presence of these species is most pronounced on the WSS, in the vicinity of the AOI (Georges and Browns banks - Figure 50, Figure 51). This increased prevalence is a product of both the expansion of warm species recorded since the beginning of the RV Survey (1970s; e.g., American John Dory (*Zenopsis ocellata*), Stout Beardfish (*Polymixia nobilis*), and Atlantic Torpedo Ray (*Torpedo nobiliana*) and the introduction of new warm water species such as the Black Scabbard Fish (*Aphanopus carbo*), Thorny Tinselfish (*Grammicolepis brachiusculus*), Silver-rag Driftfish (*Ariomma bondi*), Deep-bodied Boarfish (*Antigonia capros*), Atlantic Moonfish (*Vomer setapinnis*), and Fawn Cusk Eel (*Lepophidium profundorum*) over the past decade; the latter two species having been recorded within the AOI boundaries (Table 7). In addition to these warm water species, the frequency of capture of Tomcod (*Microgadus tomcod*), Gulf-Stream Flounder (*Citharichthys arctifrons*), Four-Spot Flounder (*Paralichthys oblongus*) and Brill (*Scophthalmus aquosus*) has increased significantly over the past decade. These species are typically captured in warmer waters (> 8°C) but were rarely recorded at the beginning of the survey in the 1970s (DFO 2018a).

## Preferred Habitat Mapping

Horsman and Shackell (2009) identified important habitat for a variety of fish species on the Scotian Shelf, including forage species, predators, depleted species, and other dominant species observed in the summer RV Survey. Forage species and influential predators represent Type 1 Ecologically Significant Species (DFO 2006), while dominant species occurred in > 10% of all RV survey sets. The approach used by Horsman and Shackell (2009) was independent of changes in abundance of each species, and identified areas of persistently high biomass. Time blocks were split into 1970–77, when foreign fleets were active in Canadian waters; 1978–85, the establishment of the 200 mile EEZ and recovery of domestic stocks; 1986–93, a period of increased fishing pressure; and 1994–2006, the collapse and absence of recovery of several groundfish species on the ESS Biomass of each species for each time period was defined as the observed weight per tow, which was interpolated across the bioregion. The preferred habitats for each species included in Horsman and Shackell (2009) are discussed in the following sections.

## Atlantic Cod

### Geographic Range and Habitat Preferences

Atlantic Cod are a bottom dwelling fish found from Georges Bank to northern Labrador in Atlantic Canada. In the southern portion of their range, Cod reach maturity at 2–3 years of age, and females produce between 300,000 and 500,000 eggs at maturity, though larger females may produce millions of eggs (COSEWIC 2010a). Juvenile Cod prefer heterogeneous, three-dimensional habitats, including Eelgrass (*Zostera marina*), macroalgae, and cobble and boulder substrates to provide shelter and protection from predators (COSEWIC 2010a, Laurel et al. 2003, Tupper and Boutilier 1995). Offshore, juvenile Cod have been observed amongst deep-sea corals, presumably for protection from predators. Cod were historically distributed across the inshore and offshore of the Bay of Fundy and Scotian Shelf. However, Cod along the Scotian Shelf have disappeared from the shelf edge, and are now concentrated almost exclusively on Browns, LaHave, Roseway, and Baccaro banks (

Figure 52) (Andrushchenko et al. 2018). Browns Bank is a persistent top quintile habitat for Atlantic Cod across the past four decades (Horsman and Shackell 2009).

Spring spawning is geographically and seasonally broadly distributed in the Southern Designatable Unit (DU), but Browns Bank is a major spring spawning ground for 4X5Yb Cod. Fall spawning tends to occur along coastal Nova Scotia (Clark et al. 2015). Peak concentrations of Cod eggs are found on Georges Bank in January/February and on Browns Bank in March/April (Frank et al. 1994).

Cod are generalist feeders and prey preferences vary by life stage. Larval Cod feed on zooplankton, especially *Pseudocalanus* and *Paracalanus* sp. copepods (McLaren and Avendaño 1995). Based on analyses of stomach contents collected on the RV summer survey between 1999 and 2016, Cod < 37cm in length primarily feed on krill (35.27% of stomach contents), while Northern Sand Lance and shrimp make up most of the remainder of stomach contents. Cod ≥ 37 cm primarily feed on Herring, crabs, and Silver Hake, with stomach contents of 35.97%, 12.83%, and 6.80%, respectively (Andrushchenko et al. 2018). Cod are preyed upon by larger Cod, seals, whales, seabirds, and other large fish such as halibut and Monkfish (*Lophius americanus*).

Of Atlantic Cod collected within the AOI by the RV Survey, 80% were collected on Browns Bank, 9.5% from Georges Basin, and 11% from within the Fundian Channel. The weighted mean depth and temperature Cod were collected within the AOI are 66.5 m and 6.6°C, respectively.

### Populations or Stock Definitions

Cod in NAFO division 4X and 5Z are part of the endangered Southern DU (COSEWIC 2010a). Historically one of the most socioeconomically important fish in Atlantic Canada, the Southern DU has declined by 64% over the past three generations as of 2010. The Southern DU is assessed as two separate management units – the southern Scotian Shelf and Bay of Fundy (NAFO divisions 4X and the Canadian portion of 5Yb), and Eastern Georges Bank (NAFO division 5Zjm) (Clark et al. 2015).

Cod in the Bay of Fundy have a higher growth rate than those on the Scotian Shelf portion of 4X (which includes the AOI). Bay of Fundy Cod reach an average length of 77cm by age 5, while Cod from the Scotian Shelf reach an average length of 65cm by age 5 (Andrushchenko et al. 2018).

Cod on Browns Bank, Georges Bank, and in the Bay of Fundy are distinguishable genetically, consistent with the persistent gyres and bathymetry separating these areas (i.e., the Fundian Channel; Ruzzante et al. 1998). Using 1,536 single nucleotide polymorphisms, (Bradbury et al. 2014) revealed genetic differences between Scotian Shelf and Gulf of Maine Atlantic Cod from the Gulf of St. Lawrence and other northern populations. This was reinforced in a recent study by Stanley et al. (2018) who revealed a cryptic multispecies genetic break near Halifax, with Cod below this latitude being of a warm water ecotype. Within the Gulf of Maine, Barney et al. (2017) used whole genome sequencing and revealed strong genetic differences between Cod on Georges Bank and winter spawning Cod in the western Gulf of Maine. Sampling of additional regions using these large genomic datasets may reveal additional cryptic population structure that could be important for understanding gene flow and potential conservation and management of Cod.

### Fisheries and Other Human Activities

Cod are a historically exploited groundfish in Atlantic Canada and those from divisions 4TVW have been under a moratorium since 1993. A TAC was first set for Cod in 4X in 1975, but only applied to the offshore portion of 4X, excluding Browns and LaHave banks (Andrushchenko et al. 2018). Following a rapid decline in Cod in both inshore and offshore areas, quotas dropped continuously throughout the 1990s, with a decline in fishing effort primarily in the Scotian Shelf component of 4X5Y (Figure 53) (Andrushchenko et al. 2018). In division 4X, Cod are caught primarily as bycatch in a mixed fishery that includes Haddock, Pollock, Winter Flounder, and redfish (DFO 2018g). A restrictive TAC exists in division 4X, and landings have been below the TAC since the mid-1990s (DFO 2018g).

Bycatch associated with the Cod-directed mobile gear fishery in 4X5Y primarily includes Haddock, Pollock, and Winter Flounder, though Cod-directed trips have decreased significantly over the past decade (see Table 7 in Andrushchenko et al. 2018). Haddock, Cusk, Pollock, White Hake, and Atlantic Halibut make up the majority of bycatch in fixed-gear Cod-directed trips (Andrushchenko et al. 2018).

A recreational fishery for Cod within 4X5Y also exists, but catches are not recorded (Andrushchenko et al. 2018).

### Status and Trends

In 2003 Cod in the Maritimes DU were assessed as a species of Special Concern. In 2010, the Maritimes DU was split into the Laurentian South DU and the Southern DU, at which point the Southern DU, encompassing the AOI, was designated Endangered (COSEWIC 2010a).

Trends in survey biomass show a decline since the mid-1990s; though survey biomass increased from 2,058 t in 2013 to 3,068 t in 2017, these biomass estimates are the lowest in a time series since 1970 (DFO 2018g). The total biomass of Cod in 4X5Y appears to have stabilized at this low level in 2010. The 4X stock has been in the Critical Zone since 2011, and biomass has remained low since this time, with very low recruitment (Clark et al. 2015, DFO 2018g). Fish counts in 4X from the summer RV Survey show relatively high numbers of Cod in the Bay of Fundy and on Browns Bank until 2009, followed by a large decrease in the number of Cod observed after 2009. Individuals are primarily found on Browns Bank, with some, generally larger, individuals caught in the Fundian Channel and into Georges Basin (Figure 44) (Clark et al. 2015).

The number of mature individuals remains below pre-1992 levels (Clark et al. 2015). An increase in total mortality on Cod in the 4X portion of the DU has contributed to the decline and subsequent lack of recovery for this stock. Although the cause of the increase in mortality is not known, it may include predation by Grey Seal (*Halichoerus grypus*) and unreported bycatch from other fisheries (Clark et al. 2015, DFO 2018g).

### Sources of Information

The DFO summer RV Survey is used to examine the distribution of Cod and provide estimates of abundance since 1970. Commercial landings and bycatch data are also available to estimate fishing mortality and help understand the distribution of Cod in the Maritimes Region.

### Sources of Uncertainty

The reason for an increase in natural mortality in Cod in divisions 4X is not well understood. Unreported bycatch, increased predation, or shifts in the environment and overall community in this region are thought to be potential contributors. The recoverability of Cod in the Maritimes Region is unknown; there are no mitigation measures for increased natural mortality, while reductions in fishery removals is the only factor that can be potentially reduced (Clark et al. 2015). The role of habitat within the AOI for Atlantic cod populations on the WSS (e.g., as an area of offshore juvenile recruitment or as a spawning area for Atlantic cod) remains unresolved.

The distribution and abundances of major prey species of juvenile Cod (krill, shrimp, and Sand Lance) and adult Cod (Herring, crabs, and Silver Hake) are not well quantified in 4X5Y. Adult Herring and Silver Hake biomass indices exist, but no reliable estimates of biomass for krill, sand lance, or crabs that make up the preferred prey of Cod exist (Andrushchenko et al. 2018).

## Haddock

### Geographic Range and Habitat Preferences

Haddock occur on both sides of the North Atlantic and are a commercially important species that range from Cape Hatteras to southern Greenland in the western Atlantic. This demersal species is most commonly found in cool, temperate waters at depths of 46–228 m and at bottom temperatures above 2ºC. Haddock show strong association with coarser, sandy sediments with diminishing catch rates as the bottom type decreases in grain size (Scott 1982).

Horsman and Shackell (2009) identified Browns Bank, Emerald-Western Bank, LaHave Bank, and the mouth of St. Marys Bay as among the most important Haddock habitat in the Maritimes Region from 1970 onward. This is reinforced by the recent 2016 summer RV Survey which showed the highest catches in the Bay of Fundy, Georges Basin, Browns Bank, Georges Bank, and Emerald-Western Bank (Figure 54) (DFO 2017a).

Of Haddock collected within the AOI by the RV Survey, 76% were collected on Browns Bank, 15% from Georges Basin, and 9% from within the Fundian Channel. The weighted mean depth and temperature Haddock were collected within the AOI are 62.5 m and 7.6°C, respectively.

### Populations or Stock Definitions

A major stock exists in NAFO divisions 4X5Y, overlapping with the AOI. Browns Bank is a major spawning ground, and spawning occurs from April to May (Page and Frank 1989), or earlier if conditions allow (Head et al. 2005). Because of this spawning period, a spawning closure is implemented from February 1st to June 15th in this region (Halliday 1988, O'Boyle 2011).

Growth rates of Haddock in the Bay of Fundy are higher than those on the WSS (including the AOI) and as such separate age length keys are used to calculate the fishery catch-at-age (DFO 2018j, Hurley et al. 1998).

Begg (1998) examined a range of Northwest Atlantic Haddock stock identification techniques (i.e., tag-recapture, demographics, spawning/recruitment patterns, meristics, morphometrics, parasites, and genetics) and concluded that the Scotian Shelf had a complex stock structure. At least two groupings were likely on the Scotian Shelf, eastern (4TVW) and western (4X), but as many as four may exist. Structure between these groupings and Haddock residing inshore from southern Scotian Shelf and Bay of Fundy remains uncertain (Begg 1998).

Lage et al. (2001) used microsatellites to examine temporal trends (40 years) in genetic diversity of Haddock on Georges Bank, revealing little change in allelic diversity over time. This suggests that stock sizes remained large enough over this time period to maintain genetic diversity despite increased fishing pressure. The same study found significant differences among Georges Bank, Browns Bank, the Scotian Shelf, and Nantucket Shoals spawning aggregations (Lage et al. 2001). Given these observations, an analysis of population structure using high-throughput DNA sequencing would be warranted, as these techniques provide a more detailed and potentially fine-scale view of cryptic population structure using thousands to millions of genetic markers.

### Fisheries and Other Human Activities

4X5Y Haddock are harvested as part of a mixed, multispecies fishery that also targets Atlantic Cod, Atlantic Halibut, Redfish, Pollock, White Hake, and flounders, with the mobile gear sector accounting for most (80%) of the landings of 4X5Y Haddock (DFO 2017b). Fixed-gear (longline) accounts for the other 20% of the landings over the past 10 years (DFO 2017b). In contrast, Haddock on the Scotian Shelf in NAFO divisions 4TVW have been under a moratorium since 1993 (Mohn and Simon 2004).

Landings within 4X5Y have remained below the TAC since 1994 and have remained under 4,000 t since 2012, averaging 3,719 t from 2010 to 2015. Landings from 4Xp, within which the

AOI is found, reached 2,400 t in 2007, but have remained below this level in subsequent years. High catches of Haddock within 4Xp are thought to reflect periods when above average year classes (i.e., 2000 and 2003) from Georges Bank (NAFO 5Z) expanded into the Fundian Channel (Wang et al. 2017). The increase in landings from 4Xp also reflects directed fisheries for larger Haddock in the deeper waters of the Fundian Channel (Finley et al. 2018). While a paucity of at-sea observer coverage over the past decade precludes an estimation of bycatch rates, bycatch in the Haddock fishery is generally considered low, consisting primarily of dogfish, lobster, and skates (Wang et al. 2017). The bycatch of Atlantic Cod in the Fundian Channel tends to be lower than in other units within NAFO division 4X (Finley et al. 2018).

### Status and Trends

Biomass estimates based on the DFO summer RV Survey were 69,900 t and 62,700 t in 2015 and 2016, respectively (DFO 2017b), but declined to 37,850 t in 2017 (DFO 2018j). The estimated spawning stock biomass in 2016 was 33,770 t, which is above the biomass limit reference point of 19,700 t and long-term average of 32,258 t (DFO 2017b). The 2017 biomass index is well below the short- (5 year; 49,967 t) and long-term (since 1970; 52,161 t) averages. 2013 was an exceptional year-class for Haddock, with five times the number of hatched haddock that survived one year than in 1985, the second highest year on record. The mean number of Haddock per tow in the RV Survey shows a general increase within the AOI and is generally higher than the mean catch per tow in the rest of NAFO 4X5YZe (Figure 55).

There has been a declining trend in weight-at-age and length-at-age from the 1990s to mid-2000s. Though this period of decline was somewhat muted in recent years, the lowest weight-at-age estimated for the WSS occurred in 2016 (DFO 2018j).

Eastern Georges Bank (5Zjm) haddock is a transboundary stock managed jointly by Canadian and American regulatory bodies. The fishing season begins on Jan 1st to Dec 31st with a seasonal spawning closure from early February to the end of May. Haddock on eastern Georges Bank has shown positive signs of productivity including increased abundance for older ages, broad spatial distribution, and large biomass. This stock has produced six notably strong year classes in the last 15 years. On the negative side, condition has decreased, growth has declined, recruitment from the large biomass has been extremely variable and mortality may be increasing on older ages.

### Sources of Information

Industry logbooks and dockside monitoring provides landed weight information. Port and observer sampling provides detailed data (length frequency, collect aging information) about the catch. The DFO summer RV Survey provides an annual biomass index as well as length, weight, and aging information.

### Sources of Uncertainty

It is not clear what causing the declining trend in weight-at-age and length-at-age, the effect on stock productivity is significant and has been discussed in previous assessments (Hurley et al. 2009, Mohn et al. 2010).

High natural mortality of older fish in recent years could be aliasing fish moving to adjacent areas or deeper waters where the fishery or survey cannot catch them. Research on a possible mechanism for high natural mortality on older ages would aid in the understanding of the population dynamics of 4X5Y Haddock. Noteworthy is that the adjacent Haddock stock on

Eastern Georges Bank also shows high total mortality on older (Age 8+) fish (Stone and Hansen 2015).

## Pollock

### Geographic Range and Habitat Preferences

In the northwest Atlantic, Pollock (*Pollachius virens*) are found from southwestern Greenland to Cape Hatteras, North Carolina and spawn offshore in several identified areas on the Scotian Shelf and one major area in the western Gulf of Maine (Stone 2012). Pollock are semi-pelagic and found at depths of 35–550 m and at bottom temperatures ranging from 5–8°C. Pollock can live up to 23 years, reaching lengths of 116 cm and weights of 17 Kg (DFO 2011b). Juveniles feed on small crustaceans, while adults feed on euphausiids, squid, Sand Lance, Herring, and Silver Hake. Predators include Monkfish, White Hake, Atlantic Cod, and Grey and Harbour seals (DFO 2011b). Areas of high Pollock abundance include NAFO 4WX in general, the deeper waters approaching the Bay of Fundy, and along the shelf edge (Figure 56).

Of Pollock collected within the AOI by the RV Survey, 58% were collected on Browns Bank, 28% from Georges Basin, and 14% from within the Fundian Channel. The weighted mean depth and temperature at which Pollock were collected within the AOI are 119 m and 7.7°C, respectively.

### Populations or Stock Definitions

Two management areas in the Maritimes Region exist for Pollock within the NAFO division management unit 4VWX5 and include 4VW and 4X5 (Canadian waters only). Within this management unit there are two population components: a slower-growing Eastern Component (4VW and 4Xmn) and a faster-growing Western Component (4Xopqrs and Canadian portions of Area 5) which overlaps with the AOI.

### Fisheries and Other Human Activities

The Western Component has contributed, on average, 95% of total landings since 2000 where fish harvesting has averaged 4,900 t/year. Landings from the Western Component come mostly from 4Xpq and 5Zj (Georges Bank), which overlap with the AOI. Landings from 5Zj have been increasing in recent years while landings have declined in other areas such as the Bay of Fundy and 4Xo (DFO 2011b).

### Status and Trends

The DFO summer RV Survey provides a long-term biomass index for Pollock extending from 1984–2017. The biomass index exhibits high inter-annual variability, which reflects the semi-pelagic schooling behavior of Pollock and changes in interaction with bottom trawl gear used in the survey. In general, there has been a declining trend in the Western Component Pollock index since the late 1980s, an increasing trend from 2003–2007, followed by another decline to 2012 (Figure 57). Since 2012, the survey biomass index has generally remained low (DFO 2018d).

### Sources of Information

The DFO summer RV Survey time series for Western Component Pollock extends from 1984–2017 thus far, which is a period when the same survey design and bottom trawl have been used annually (DFO 2018d). The biomass index exhibits strong year-effects that stem from the semi-pelagic schooling behaviour of Pollock and their differing distributions in the water column during the survey. A three-year geometric mean provides a long-term trend by smoothing year-effects to provide monitoring data and calculating future catch limits (DFO 2018d).

### Sources of Uncertainty

The high variability in biomass and recruitment indices makes it difficult to determine trends in abundance, adding uncertainty to the assessment of Pollock. In 2010, a Management Strategy Evaluation (MSE) process involving industry, science, and outside representatives was initiated by Resource Management for the Western Component (4Xopqrs5) (DFO 2011b). The goal of the MSE was to consider uncertainty surrounding stock assessment assumptions and models, and compare consequences of management objectives.

## Silver Hake

### Geographic Range and Habitat Preferences

Silver Hake (*Merluccius bilinearis*) are a species of widely distributed gadoid fish that range from Cape Hatteras to the Grand Banks including the Gulf of St. Lawrence. The distribution of these demersal-pelagic fish are closely associated with bottom water temperatures between 5–12°C for juveniles and 7–10°C for adults (DFO 2018k). A self-reproducing population occurs on the Scotian Shelf with depth preferences over 120m in the Northwest Atlantic Fisheries Organization (NAFO) divisions 4VWX (Rikhter et al. 2001).

Adult Silver Hake within these NAFO divisions predominantly aggregate along the warm slope waters of the shelf, the approaches to the Bay of Fundy, and inside the Emerald and LaHave basins (Figure 58) (Horsman and Shackell 2009, Ward-Paige and Bundy 2016). From July to September, Silver Hake migrate to shallower (30–40 m), warmer (> 10°C) waters surrounding the Emerald and Sable Island banks for spawning (Rikhter et al. 2001). Although most spawning occurs on the Scotian Shelf, eggs and/or larvae have been observed on northeastern Georges Bank, Bay of Fundy, western 4X, and Browns Bank and may or may not be part of the same stock structure (DFO 2013).

Silver Hake reach maturity by age 2, with females growing faster than males, and can reach a maximum age of 12 years. The main prey items of Scotian Shelf Silver Hake are shrimp, sand lance, and krill. Older fish also demonstrate piscivory, and although they exhibit cannibalism, this no longer appears to be a major contributor to the overall mortality of Silver Hake on the Scotian Shelf.

> *Of Silver Hake collected within the AOI by the RV Survey, 63% were collected on Browns Bank, 31% from Georges Basin, and 6% from within the Fundian Channel. The weighted mean depth and temperature at which Silver Hake were collected within the AOI are 71.3 m and 10.7°C, respectively.*

### Populations or Stock Definitions

Silver Hake in the Maritimes Region are assessed as a single stock (Scotian Shelf 4VWX), though Silver Hake in the Bay of Fundy likely represent a portion of the Gulf of Maine/Northern Georges Bank stock rather than the Scotian Shelf stock (Showell 1998).

### Fisheries and Other Human Activities

Foreign fleets (predominantly from Russia, Japan, and Cuba) dominated the Silver Hake fishery across the Scotian Shelf from the 1960s up until the mid-1990s when Canadian trawlers began participating in the fishery commercially in 1995 (Showell and Cooper 1997). Since 2004, all landings of Silver Hake in 4VWX have all come from Canadian mobile gear fleets using bottom trawls with 55 mm square mesh cod-ends to limit capture of small fish. The TAC has been set at 15,000 t since 2003, but landings only averaged 7,600 t from 2012 to 2016 (DFO 2018k).

### Status and Trends

The most recent framework and assessment for Silver Hake occurred in 2012. Biomass indices from the DFO summer RV Survey peaked in the early 1980s followed by a downward trend until 2008 (Figure 59). From 2009 to 2014, biomass indices increased to 60,400 t, the highest observed level since the 1980s; however, biomass trends have decreased since then to 46,074 t in 2016. Population biomass is estimated from a logistic biomass dynamic model (Cook 2013). Trends in biomass estimates by the model follow biomass indices from the summer survey. Based on the model, the stock remains in the Healthy Zone (DFO 2018k).

### Sources of Information

The summer RV Survey provides biomass indices for Silver Hake on an annual basis. This survey provides information on Silver Hake numbers, biomass, and estimates of year-class strength and recruitment.

### Sources of Uncertainty

Only RV Survey strata 440–483 are used to estimate biomass in the Silver Hake update, which excludes data from the Bay of Fundy. The stock boundary between the Scotian Shelf and Bay of Fundy stocks is imprecise and varies from year to year. Better delineation of these stocks could provide information on migration patterns in Silver Hake, as well as be used to estimate the biomass of Silver Hake in the Maritimes region as a whole.

The logistic biomass model may not closely track the dynamics of the actual population, as the model assumes mean recruitment and growth across projected years and does not account for variability in year-class strength (DFO 2018k). Therefore, the model may be unable to provide accurate estimates of biomass more than one year ahead.

The usage of the AOI by Silver Hake also remains unknown. Browns and Georges Banks may be used as spawning sites.

## White Hake

### Geographic Range and Habitat Preferences

White Hake (*Urophycis tenuis*) are a demersal fish species that are caught in all groundfish fisheries in NAFO divisions 4VWX5Zc. White Hake are found from North Carolina to Labrador, with the highest abundances in the Gulf of Maine and on Georges Bank (COSEWIC 2013b). On the Scotian Shelf, White Hake are show the highest abundances in the Bay of Fundy and along the deep waters of the shelf edges (Figure 60) (Ward-Paige and Bundy 2016). White Hake co-occur with Red Hake in the WSS, for which they are often misidentified.

Adult and juvenile White Hake are commonly found on fine substrates, such as mud at the bottom of basins on the Scotian Shelf. White Hake are found over a wide range of depths

(50– 325 m), but prefer warmer, more saline waters with a temperature range of 5–9°C (Scott 1982, Simon and Cook 2011). Larger individuals generally occur in deeper waters. In the southern portion of their range, individuals move towards shallower water in warmer months and disperse to deep water in colder months (Chang et al. 1999, Musick 1974).

White Hake are highly fecund pelagic spawners with buoyant eggs. Juveniles remain in the upper water column for up to three months, and are more common in coastal shallow areas, while adults are found offshore in deeper waters (COSEWIC 2013b).

Of White Hake collected within the AOI by the RV Survey, 28% were collected on Browns Bank, 65% from Georges Basin, 1% from the continental slope, and 5% from within the Fundian Channel. The weighted mean depth and temperature at which White Hake were collected within the AOI are 156.6 m and 8.0°C, respectively.

### Populations or Stock Definitions

White Hake are divided into two DUs based on genetic and life history differences: the Southern Gulf of St. Lawrence population and the Atlantic and Northern Gulf of St. Lawrence population. The AOI is part of the Atlantic and Northern Gulf of St. Lawrence DU, which is considered Threatened due to a decline in adults by approximately 70% over the past three generations (COSEWIC 2013b). Within this DU, the ESS and the WSS, encompassing the Bay of Fundy and northern Georges Bank, are treated as two separate management units, and as such White Hake within the AOI are part of the WSS/Bay of Fundy/Georges Bank management unit. Much of this decline took place before the mid-1990s, and the population has remained stable since 2004, as overfishing of this species has ceased (COSEWIC 2013b, Guenette and Clark 2016).

### Fisheries and Other Human Activities

A TAC was introduced in 1996, and since 1999 White Hake are caught as bycatch in longline, gillnet, and otter trawl fisheries. White Hake are more susceptible to bruising and mortality compared to other gadoids when caught as bycatch and released (COSEWIC 2013b).

### Status and Trends

#### *Stock Status*

The abundance of White Hake in 4X5Zc is currently slightly higher than the proposed recovery target of 6,867 t (Guenette and Clark 2016). Despite a high natural mortality in 4X5Zc, there is an 84% probability of maintaining the spawning stock biomass above the recovery target under current mortality estimates (Guenette and Clark 2016). Recent declines in Atlantic Herring abundance in the WSS and Bay of Fundy could influence recovery trajectories, since Herring are a key prey species (Guenette and Clark 2016).

Horsman and Shackell (2009) show Georges Basin and the deep basins of the Gulf of Maine and Bay of Fundy, and Emerald and LaHave basins and the continental slope as being important habitat for White Hake consistently since 1970. This is supported by the 2016 RV Survey which shows the highest catches of White Hake in deep basins in the Gulf of Maine and Scotian Shelf, and along the continental slope (DFO 2017a). The short-term (2011–2015) average biomass index from the RV Survey (8,155 t) is less than half the long-term average (17,889 t) in division 4X. However, these biomass indices remain above the Scotia Fundy Groundfish Advisory Committee (SFGAC) defined lower reference point (DFO 2017a). The mean kg/tow of White Hake in the summer RV Survey within the AOI shows a similar trend of overall decline as the rest of the Scotian Shelf bioregion, though there are relatively high interannual fluctuations (Figure 61).

### Sources of Information

The DFO summer RV Survey provides biomass indices and information on the distribution of White Hake in the Scotian Shelf bioregion and Bay of Fundy on an annual basis.

### Sources of Uncertainty

The stock structure of White Hake remains unknown, particularly within the large Atlantic and Northern Gulf of St. Lawrence DU. Roy et al. (2012) used microsatellites to identify three genetically distinct populations of White Hake; these included the southern Gulf of St. Lawrence, southern Newfoundland, and the Scotian Shelf, including the Bay of Fundy and northern Gulf of St. Lawrence. However, stock structure on the Scotian Shelf is thought to be complex, and thus investigation of fine-scale structure in this population is warranted. Additionally, the precise timing of spawning on the Scotian Shelf is unclear, either occurring in spring (Kulka et al. 2005, Markle et al. 1982), summer (Bundy and Simon 2005), or both (Markle et al. 1982).

## Wolffish

### Geographic Range and Habitat Preferences

Three species of wolffish occur in the Northwest Atlantic and include Atlantic Wolffish (*Anarhichas lupus*), Northern Wolffish (*A. denticulatus*), and Spotted Wolffish (*A. minor*). Atlantic Wolffish are the most abundant of the three species, and are likely the only species to range as far south as the AOI. Both Spotted and Northern wolffish are observed infrequently in the AOI, and are more common in NAFO division 4V and further north (Collins et al. 2015). Spotted Wolffish have only been caught in 22 of 7,200 research tows on the Scotian Shelf as of the time of their COSEWIC assessment (COSEWIC 2012e). Atlantic Wolffish are found in the Gulf of Maine (Collins et al. 2015), which represents the southern extreme of their range (COSEWIC 2012a). On the Scotian Shelf, Atlantic Wolffish are most abundant on the ESS (4V), in the Bay of Fundy, and on Roseway, LaHave, and Browns Banks (Figure 62) (Ward-Paige and Bundy 2016). Atlantic Wolffish are found both inshore and offshore preferring temperatures between 0.5–3°C and depth between 100–500 m. Atlantic Wolffish can be found on various substrates types including sand, gravel, large rocks and boulders (Novaczek et al. 2017). Atlantic Wolffish grow to be 150 cm in length and primarily feed on brittle stars, sea urchins, crabs, and shrimp.

All three species deposit their eggs on the bottom and larvae tend to stay close to the nest, leading to little dispersal potential (O'Dea and Haedrich 2001, Scott and Scott 1988). Wolffish dens are predicted to be associated with relatively shallow depths and in areas of suitable rocky substrate (Novaczek et al. 2017). Templeman (1984b) reports limited movement in all three species, with individuals only moving an average of 8 km in a tagging study conducted between 1962 and 1966 off Newfoundland and Labrador. However, some migrations over long distance (hundreds of kilometres) have been observed in the Northwest Atlantic (Templeman 1984b).

### Populations or Stock Definitions

Each species of wolffish is genetically distinct at mitochondrial and nuclear markers (McCusker and Bentzen 2010b) and are considered single DU within Canadian waters. McCusker and Bentzen (2011) provide no evidence of population structuring of Spotted or Northern wolffish in

Canada despite the limited dispersal potential of these species. McCusker and Bentzen (2010a) found evidence of up to three genetically distinct populations of Atlantic Wolffish in Canada, but there is no evidence to merit their recognition as separate DUs. As such, each species is considered a single stock within Canadian waters.

### Fisheries and Other Human Activities

The primary threat to Atlantic Wolffish is bycatch in fisheries that target other species, such as flounder or shrimp. Because of their current listing under SARA, a Management Plan was published in 2008 (Kulka et al. 2007) with the intent to increase population levels and distribution of Atlantic Wolffish towards the long-term viability of the population. Most landings of Atlantic Wolffish occur in NAFO Division 4X, particularly between Browns Bank and coastal waters of southwestern Nova Scotia (McRuer et al. 2000). Historically, Atlantic Wolffish have been caught in high densities in the spring on Browns Bank (Nelson and Ross 1992, Ward-Paige and Bundy 2016).

There is mandatory release of both Spotted and Northern Wolffish in Canadian waters, and as such landings consist solely of Atlantic Wolffish. Survival of released individuals is variable and depends on various factors including physiological stress incurred by varying water temperatures and water pressure, handling, and trawl tow duration (Collins et al. 2015).

### Status and Trends

#### *Stock Status*

In the Maritimes Region, Northern and Spotted Wolffish are rarely found in DFO research surveys (Horsman and Shackell 2009) and Atlantic Wolffish abundances have remained below the long-term average since 2009 in divisions 4VWX5Y. Areas of highly persistent Atlantic Wolfish habitat partially overlap with the north eastern boundary of the AOI (based on Horsman and Shackell 2009). COSEWIC (2012a) estimated that there are 49 million Atlantic Wolffish in Canadian waters, including 5 million mature adults. There have been steep declines in both the abundance and distribution of all three species, though there have been more recent increases in abundance of all three species in southern Newfoundland and southern Labrador (COSEWIC 2012a, c, e).

In the vicinity of the AOI, Northern and Spotted wolffish are rare. On Georges Bank in division 5Z Atlantic Wolffish abundance has remained low since 2006. However, higher concentrations of Atlantic Wolffish occur on the WSS in division 4X and ESS in division 4V (Collins et al. 2015). In 2016, the summer RV Survey recorded the highest catches of Atlantic Wolffish on Browns Bank and Banquereau Bank. Biomass indices for Atlantic Wolffish in NAFO 4X are variable across years, but the short-term mean of 238 t is well below the long-term mean biomass of 1,978 t (DFO 2017a). In general there has been a decline in the abundance per tow of Atlantic Wolffish within the AOI over time, though this decline has been more precipitous across the rest of the Scotian Shelf as a whole.

#### *Species at Risk Considerations*

Significant declines (> 90%) in the 1980s and early 1990s led to all three species being listed under SARA. In 2012, COSEWIC re-evaluated the status of Wolffish in Canada and concluded that Atlantic Wolffish continue to meet the criteria for a species of Special Concern under SARA whereas the Northern and Spotted Wolffish continue to meet the criteria for Threatened under

SARA (COSEWIC 2012a, c, e). The distributions of each species have undergone substantial reductions over the past several generations (Collins et al. 2015).

### Sources of Information

The DFO summer RV Survey provides estimates of biomass in surveyed areas. Data on the distribution of wolffish is also provided by commercial landings data, and observer coverage (Collins et al. 2015).

### Sources of Uncertainty

As with most species of groundfish, the fine-scale stock structure of each species remains unknown. Each of the three species of wolffish in Canada are treated as a single stock. Previous genetic studies have provided no evidence to split the populations into multiple DUs (McCusker and Bentzen 2010b, 2011). However, current high-throughput sequencing techniques that utilize thousands of genetic markers could resolve fine-scale population structure and environmental associations, should any exist.

## Redfish

### Geographic Range and Habitat Preferences

Two species of redfish occupy the Northwest Atlantic: Deepwater Redfish (*Sebastes mentella*) and Acadian Redfish (*S. fasciatus*). Deepwater Redfish are found on both sides of the Atlantic, but in the Northwest Atlantic they do not range as far south as the AOI. In contrast, Acadian Redfish are found exclusively in Canadian Atlantic waters and range from the Gulf of Maine, including the AOI, to the Gulf of St. Lawrence and Newfoundland (DFO 2012a). Acadian Redfish are comprised of two populations (designatable units): Atlantic and Bonne Bay, but only the Atlantic population is relevant to the AOI. A juvenile redfish area known as the “bowtie” is located to the north of Browns Bank and is closed to redfish fishing (Figure 2).

Larval *S. mentella are* planktivorous feeding primarily on small pelagic crustaceans and fish eggs until settling to the seafloor. Juvenile and adult redfish feed on copepods, krill, and small fish (DFO 2012a). Redfish are preyed on by Haddock, Pollock, Cod, and Grey Seals on the Scotian Shelf.

The preferred temperature for adult southern area (Unit 3) Acadian Redfish is 5.5–7.0°C (Sévigny et al. 2007). Redfish exhibit slow growth and can live up to 75 years and reach 60 cm in length (DFO 2012a). Females grow faster than males, and growth rates are typically faster in southern areas (DFO 2012a). Females are viviparous and carry the young until as many as 1,500–107,000 larvae are released at the end of spring and beginning of summer (COSEWIC 2010b). Recruitment is variable and can range from 5–12 years between major year classes (Sévigny et al. 2007).

Acadian Redfish primarily live along continental slopes and in deep channels at depths of 150–300 m (COSEWIC 2010b) and are the most frequently observed fish taxa associated with cold-water corals (Gordon Jr and Kenchington 2007). Buhl-Mortensen and Mortensen (2005) found that in the Northeast Channel, redfish were almost four times as common in video sequences that contained corals. The Fundian Channel is an area of importance to deep-water corals that provide complex biogenic habitat for fish species such as Redfish. According to Horsman and Shackell (2009), the Georges Basin component of the AOI and the portion approaching the continental slope are also important habitat for Redfish. More recent abundance data from Ward-Paige and Bundy (2016) show relatively high abundance of redfish in the deep waters of the shelf edges, especially the Northeastern Shelf edge, the Gully, and in mid-depth waters along the WSS (Figure 63).

### Populations or Stock Definitions

*S. fasciatus* is divided into three stocks: the Scotian Shelf stock (Unit 3, includes NAFO divisions 4WX5Y and the AOI), the Gulf of St. Lawrence and Laurentian Channel (Units 1+2), and the Labrador Shelf population (NAFO divisions 2+3K) (DFO 2012a). The Scotian Shelf (Management Unit 3) is made up of NAFO subdivisions 4X and 4Wdehlk whereas the Gulf of Maine is comprised of NAFO Division 5 (primarily located in American jurisdiction). Despite declines of up to 99.7 % in some parts of the southern range, abundance indices in the Scotian Shelf show no consistent positive or negative trends. While exhibiting declines in some areas, the abundances of Redfish has also increased in the Gulf of Maine, bolstered by several significant year classes (COSEWIC 2010b).

### Fisheries and Other Human Activities

Targeted fishing and incidental bycatch from other fisheries are the main threats to Acadian Redfish. Redfish are managed by DFO in terms of catch limits, minimum legal catch sizes and minimum mesh sizes. On Browns Bank there is a protected area for juvenile Acadian Redfish.

### Status and Trends

#### *Stock Status*

A time series of biomass indices for Unit 3 Acadian Redfish shows large interannual fluctuations. Smoothing of this time series shows a general decline from 1970 to 2000, but a general increase from 2000 onward. The estimated biomass has never fallen below the limit reference point, calculated as 40% of the mean time series (1970–2011) biomass (DFO 2012a). The mean kg/tow of redfish within the AOI shows high interannual variability, with a general increase from 1980 to 2010, followed by a decrease; in comparison, mean catches on the Scotian Shelf bioregion have appeared relatively stable over time, with a slight increase between 2007 and 2012 (Figure 64).

#### *Species at Risk Considerations*

In 2010, the Atlantic designatable unit (DU) of Acadian Redfish was assessed as Threatened because of a decline in abundance of mature individuals by 99% over two generations (COSEWIC 2010b). Acadian Redfish are long-lived, late-maturing, and highly vulnerable to mortality from human activities. A time series of biomass indices for Unit 3 Acadian Redfish shows large inter-annual fluctuations. Smoothing of this time series shows a general decline from 1970 to 2000 but a general increase from 2000 onward, remaining above the upper stock reference point since 2004 (DFO 2019c). Since the 1990s, there has been no long-term trend in any one area, though it seems that the populations have been stable or shown slight increases since the initial decline (COSEWIC 2010b).

### Sources of Information

The RV summer Survey provides a biomass index for Acadian Redfish from 1970 onward in the Maritimes region. Other seasonal surveys are used in other DFO regions. In all regions, mature biomass is used as the estimate of biomass and biomass reference points.

### Sources of Uncertainty

*Sebastes* spp. are known as episodically recruiting species, where large year-classes may occur only once a decade or less. This episodic recruitment makes modeling population abundances problematic. The influence of these periodic high recruitment years could mean the stock grows faster than is modelled, but the true effects of episodic recruitment on the stock unit abundances is unknown (DFO 2012a). Further, the catchability of *Sebastes* spp. in the RV Survey is thought to be high, but remains unresolved. As such, the reliability of the biomass indices calculated from the RV Survey also remains unknown (DFO 2012a).

## Winter Skate

### Geographic Range and Habitat Preferences

Winter Skate (*Leucoraja ocellata*) are found in the Northwest Atlantic and in Canada are found in three main concentrations, including the Gulf of St Lawrence, ESS/Southern Newfoundland, and the WSS/Bay of Fundy. Because their Canadian range is so broad it is possible Winter Skate found within the AOI (WSS/Bay of Fundy) may be genetically distinct from the other areas they are found in (COSEWIC 2015). Winter Skate are bottom-dwelling typically found on sand and gravel and usually at depths < 111 m. The majority are caught in waters between 5–16°C. Winter Skate found within the AOI would mature at 75 cm and at 13 years (COSEWIC 2015). Long-term monitoring from fisheries independent surveys showed no discernable trend in Winter Skate abundance on the WSS/Bay of Fundy area where the AOI is located, though the Bay of Fundy, Georges Bank, Browns Bank, the Gully and Banquereau Bank are areas of persistent high abundance (Figure 65) (COSEWIC 2015, Ward-Paige and Bundy 2016). Within the AOI, Browns Bank is the only area of persistent high abundance of Winter Skate across the past four decades (Horsman and Shackell 2009)

### Populations or Stock Definitions

Winter Skate are considered three DU in Canada – the Gulf of St. Lawrence population, the ESS – Newfoundland population, and the WSS – Georges Bank population (COSEWIC 2015).

### Fisheries and Other Human Activities

Skates in general are particularly vulnerable to overfishing because of their large body size, slow growth, late maturation, and low fecundity relative to bony fishes (Dulvy and Reynolds 2002). However, it has been shown that fishing mortality has not caused a decline in the WSS – Georges Bank DU since the 1970s (COSEWIC 2015).

### Status and Trends

#### *Stock Status*

Long-term monitoring from fisheries independent surveys showed no discernable trend in species abundance on WSS/Bay of Fundy area where the AOI is located. The DFO summer RV Survey shows an increase in estimated Winter Skate biomass from 206 t in 2014 to 1,134 t in 2015 (DFO 2017a). The recent five year average (970 t; 2011–2015) is comparable to the long-term average (1970–2015) of 985 t in NAFO 4X (DFO 2017a). The majority of Winter Skate biomass caught in the 2016 survey was located on Georges Bank, with relatively less kg/tow in the Bay of Fundy, on Browns Bank and in the Fundian Channel, and low catches on the Scotian Shelf (DFO 2017a). As such, the short-term average (266 t) of Winter Skate in divisions 4VW is significantly lower than the long-term average (3,354 t). However, Winter Skate abundance has been noted to be particularly high around Browns Bank in previous studies (Ward-Paige and Bundy 2016). Over time, the mean kg/tow of Winter Skate caught in the summer RV Survey has increased within the AOI, as opposed to a more general decline in Winter Skate catch in the rest of the Scotian Shelf (Figure 66). Winter Skate abundance on Georges Bank increased dramatically in the 1980s following declines of commercially important species. This increase coincided with a decline of Winter Skate on the Scotian Shelf, which was hypothesized to be the source of Winter Skate on Georges Bank (Frisk et al. 2008). It remains unknown whether this shift in abundance was because of competitive release or a migration because of unfavourable conditions on the Scotian Shelf (Frisk et al. 2008).

##### *Species at Risk Considerations*

The Gulf of St. Lawrence and ESS – Newfoundland DUs have undergone declines of 99% over the last three generations and 98% over the last 2.4 generations, respectively. COSEWIC re-assessed Winter Skate in 2015 and because of their decline in the latter two areas they were designated Endangered. The WSS – Georges Bank population was also re-assessed and designated Not At Risk (COSEWIC 2015). This Not At Risk assessment is based on no apparent decline in the abundance or area occupied by Winter Skate since the 1970s (COSEWIC 2015).

#### Sources of Information

The DFO summer RV Survey provides biomass indices and information on the distribution of Winter Skate in the Scotian Shelf bioregion and Bay of Fundy on an annual basis.

#### Sources of Uncertainty

It is possible that the Fundian Channel might represent a bathymetric barrier to movement for Winter Skate between Georges Bank and Browns Bank, but little information exists on movement patterns or deep-water habitat usage for this species in the area (COSEWIC 2015). Winter Skate are occasionally captured in the Fundian Channel at depths greater than 200 m in both the summer RV Survey and bottom trawl surveys conducted by the U.S., suggesting the populations on these banks are not entirely isolated.

The three main concentrations of Winter Skate in Canada are separated by large distances (> 100 km), and little is known about migration and mixing patterns among these populations. The habitat separating these concentrations is considered suitable for Winter Skate, and so these may represent genetically discrete populations (COSEWIC 2015).

### Smooth Skate

#### Geographic Range and Habitat Preferences

Smooth Skate (*Malacoraja senta*) are endemic to North America and found from Labrador to Cape Cod. Smooth Skate prefer soft mud and clay substrates with the densest concentrations between 150 m and 550 m, though they may also be found on sand, gravel, and pebbles on the offshore banks in the Gulf of Maine (COSEWIC 2012d). The preferred temperatures for Smooth Skate are 3–10°C (Kulka et al. 2006), though they have been captured in waters between 1–10°C in the summer RV Survey (Simon et al. 2012). The densest concentrations of Smooth Skate in Canada occur in the basins and troughs surrounding offshore banks where temperatures are warmer. The narrow temperature tolerances of this species may explain the disjunct distribution of the species, as Smooth Skate are often not found on banks that are shallow, sandy, and with temperatures < 2°C (COSEWIC 2012d).

Horsman and Shackell (2009) show portions of Georges Basin, Browns Bank, and the Bay of Fundy as persistent habitat for Smooth Skate, in addition to the slope along the Laurentian Channel (Figure 67). Canadian and US trawl surveys also suggest high abundances within the Fundian Channel, Georges Basin, and Browns Bank relative to other portions of the Scotian Shelf, with the highest catch being located in Georges Basin since 2010 (COSEWIC 2012d, DFO 2017a, Ward-Paige and Bundy 2016).

Smooth Skate primarily prey upon crustaceans, including shrimps and krill, and occasionally fish. Predators of Smooth Skate are unknown. Smooth Skate has not been observed in the stomach contents of over 156,000 fish predators sampled from the Scotian Shelf (Simon et al. 2012)

### Populations or Stock Definitions

There are four DU of Smooth Skate in Canada, including the Hopedale Channel population, the Funk Island Deep population, the Nose of the Grand Bank population, and the Laurentian-Scotian population. Smooth Skate within the AOI are part of the Laurentian-Scotian DU, which was designated as Special Concern by COSEWIC (2012d). This DU represents approximately 70% of this species' range in Canada, but since the 1970s both the abundance and area of occupancy of Smooth Skate have declined steeply. Overall, approximately 80% of the global population of Smooth Skate occurs in Canada (COSEWIC 2012d).

Of Smooth Skate collected within the AOI by the RV Survey, 22% were collected on Browns Bank, 71% from Georges Basin, and 7% from within the Fundian Channel. The weighted mean depth and temperature at which Smooth Skate were collected within the AOI are 139.3 m and 7.9°C, respectively.

### Fisheries and Other Human Activities

In Division 4X, fishing mortality was low until 1985 but increased to a high in the late 1980s and early 1990s. Fishing mortality then fell to low levels comparable to the early 1970s (Simon et al. 2012). There are no directed fisheries for Smooth Skate, and bycatch is relatively low in this DU (COSEWIC 2012d). Smooth Skate grow relatively slowly and produce 40–100 egg capsules per year, suggesting a potentially long recovery time of the population.

### Status and Trends

#### *Stock Status*

The mean kg/tow of Smooth Skate caught in the summer RV Survey has recently returned to levels comparable to the 1980s within the AOI; a similar trend is also observed in the mean catch across the Scotian Shelf, though the mean kg/tow is lower relative to within the AOI (Figure 68). In NAFO division 4X biomass estimates of Smooth Skate have recently returned to a level comparable to the long-term average, but are below estimates from the mid-1970s. Abundances of mature Smooth Skate increased in 2013–2015 from the series low in 2012, while abundances of immature skate are highly variable over time based on the summer RV Survey (DFO 2017h). In 2016, the estimated biomass rose to 476 t in 4X, which was slightly higher than the long-term average (471 t) (DFO 2017a). In 5Z, the biomass of Smooth Skate remains low relative to short-term and long-term averages. The abundance of both immature and mature Smooth Skate in 5Z has generally been declining since a peak in abundance in 2004 (DFO 2017h). At-sea observer coverage (0–5% annually in most groundfish fisheries) is too low to estimate the total bycatch of skate, but post-discard mortality is thought to be high, with mortality rates of at least 50% from bottom trawls, 100% from longlines, and 100% from gillnets (DFO 2017h).

#### *Species at Risk Considerations*

The Laurentian-Scotian population of Smooth Skate historically represents 90% of the species' abundance and 70% of its range in Canada. Both the overall abundance and area of occupancy of this species have declined since the 1970s (COSEWIC 2012d) with some spatial-temporal variability.

### Sources of Information

The DFO summer RV Survey provides biomass indices and information on the distribution of Smooth Skate in the Scotian Shelf bioregion and Bay of Fundy on an annual basis. Between 1970 and 2010, 1,489 sets of 7,200 (20.7%) from the summer RV Survey captured Smooth Skate (Simon et al. 2012).

### Sources of Uncertainty

Fine-scale genetic population structure within the Laurentian-Scotian DU is unknown. Populations have likely become more fragmented as abundance has declined. This fragmentation could lead to changes in connectivity and thus an updated evolution of fine-scale genetic structure would be warranted.

## Thorny Skate

### Geographic Range and Habitat Preferences

In the northwest Atlantic, Thorny Skate (*Amblyraja radiata*) are distributed from Greenland to South Carolina, USA. Thorny Skate are found in the greatest densities on the Grand Banks, and are less abundant in southern areas such as the WSS. Horsman and Shackell (2009) suggest the ESS and the Bay of Fundy are important habitat for Thorny Skate, with highly persistent habitat for the species restricted to the Georges Basin component of the AOI (Figure 69). This species has been detected on Browns Bank and the Fundian Channel/Georges Basin portions of the AOI, but this area does not appear to be of particular importance for Thorny Skate (DFO 2017a).

This species is found at depths of 18–1,200 m at temperatures of 0 to 10°C. Thorny Skate mature at 11 years and lay 6–40 eggs per year (COSEWIC 2012f).

Of Thorny Skate collected within the AOI by the RV Survey, 61% were collected on Browns Bank, 28% from Georges Basin, and 11% from within the Fundian Channel. The weighted mean depth and temperature at which Thorny Skate were collected within the AOI are 112.2 m and 7.5°C, respectively.

### Populations or Stock Definitions

Thorny Skate are considered a single DU in Canadian waters despite substantial variation in the mitochondrial DNA sequences shown among Canadian samples (Coulson et al. 2011). This DU was designated Special Concern as a result of severe population declines over the southern part of their historic distribution, which have ultimately lead to some range contraction

(COSEWIC 2012f). This decline has continued in the southern portion of their range despite a reduction in fishing mortality; in contrast, abundance seems to be increasing at higher latitudes (COSEWIC 2012f).

### Fisheries and Other Human Activities

There is no directed fishery for Thorny Skate in 4X5YZc. Thorny Skate, in addition to Barndoor Skate (*Dipturus laevis*) and Winter Skate, show the among the highest fisheries discard by weight. Bycatch for Thorny Skate does not appear to be primarily attributed to any particular fishery, as is more often observed.

### Status and Trends

#### *Stock Status*

In 4X, biomass indices for Thorny Skate were highest between 1970 to 1985, with declines until 2000. After 2000, the estimated biomass remained well below the long-term average of 3,742 t (1970–2015), but rose slightly above the five year average (2010–2014) in 2014 (DFO 2017h). In 2015, biomass estimates increased, but declined severely in 2016 to 69 t, well below the long-term average (DFO 2017a). An increase in immature Thorny Skate abundance was observed from 2013–2015, but declined again in 2016. Overall, the short-term mean biomass estimate is below 20% of the long-term biomass estimates (DFO 2017a). The DFO summer RV Survey shows that Thorny Skate remain at low levels in NAFO divisions 4VWX, with no real indication of recovery. Specifically within the AOI, there has been a general decline in the mean kg/tow of Thorny Skate caught in the summer RV Survey over time, which coincides with a general decline across the entire Scotian Shelf (Figure 70).

#### *Species at Risk Considerations*

Thorny Skate are a species of Special Concern in Canada, as they are a slow growing, late-maturing fish that have undergone severe population declines in the southern part of their range (COSEWIC 2012f).

### Sources of Information

The DFO summer RV Survey provides biomass indices and information on the distribution of Thorny Skate in the Scotian Shelf bioregion and Bay of Fundy on an annual basis.

### Sources of Uncertainty

The reasons for the continued decline of Thorny Skate are not well understood. Fishing mortality in 4X has declined, but there is still bycatch in the scallop and other flatfish fisheries (COSEWIC 2012f). Like Smooth Skate, observer coverage is too low to estimate bycatch rates for Thorny Skate, but post-discard mortality is assumed to be very high (50–100% mortality depending on gear type) (DFO 2017h).

## Atlantic Halibut

### Geographic Range and Habitat Preferences

Atlantic Halibut (*Hippoglossus hippoglossus*; hereinafter Halibut) are the largest of the flatfishes in Atlantic Canada. Females attain a larger maximum size than males, to a maximum length of 3 m and live up to 50 years. Halibut range from Virginia to northern Greenland in the Northwest Atlantic. They are most abundant at depths of 200–500 m in deep-water channels between banks and along the edge of the continental shelf (DFO 2018h). Small halibut (< 30 cm in length) feed primarily on invertebrates, while larger individuals feed on invertebrates and other fish (COSEWIC 2011b). Atlantic Halibut are strong swimmers and are considered to be semi-pelagic. Adult Halibut prefer temperatures of 4.7°C, but are found across a range of 1.2–11.8°C (Armsworthy et al. 2014). Juvenile Halibut prefer summer bottom temperatures between 4.2 and 8.7°C, and winter bottom temperatures between 3.7 and 7.7°C in Nova Scotia and U.S. waters (French et al. 2018). French et al. (2018) further demonstrate that areas of highly suitable juvenile habitat are highly associated with adult production, suggesting recruitment and overall productivity is tightly linked with nursery areas NAFO divisions 4X and 4W have the greatest proportion of suitable habitat for juvenile Halibut (53% and 39% suitable habitat, respectively) and high juvenile abundance, while divisions 5Y, 5Ze, and 5Zw have lower juvenile abundance despite adequate habitat suitability; this is thought to reflect either fine-scale stock structure, or overfishing in NAFO Division 5 (French et al. 2018). These results support the "nursery size hypothesis", where the amount of suitable juvenile habitat is related to adult production (French et al. 2018).

Spawning sites for Halibut are unknown in the Northwest Atlantic, and data on egg and larval distributions is lacking (French et al. 2018). However, the AOI is an area of persistent juvenile Halibut abundance (Figure 71), suggesting this area, along with the Gully MPA, are potential Halibut nursery areas (Boudreau et al. 2017, Shackell et al. 2016). These regionally unique persistent hotspots of high juvenile abundance are thought to offer protection from commercial fishing, and this protection has contributed to the stock rebounding (Boudreau et al. 2017). Boudreau et al. (2017) also suggest that these two areas are core high abundance juvenile refugia where density-dependent habitat selection is occurring.

In the 2016 DFO RV summer Survey, Halibut were primarily caught on Browns and Georges banks, in the Bay of Fundy, and relatively evenly across the Scotian Shelf to the Laurentian Channel (DFO 2017a). Ward-Paige and Bundy (2016) show relatively high abundance of Halibut on Browns Bank and German Bank, along the shelf edge, and in the Gully. Of Halibut collected within the AOI by the RV Survey, 98% were collected on Browns Bank and 2% from within the Fundian Channel. The weighted mean depth and temperature at which Halibut were collected within the AOI are 71.2 m and 7.6°C, respectively. The Industry-DFO Longline Halibut Survey which uses longlines is thought to be more representative of the distribution of mature Halibut, which is shown in Figure 72.

### Populations or Stock Definitions

Halibut are managed as two discrete stocks in Canada; the larger of these is the Scotian Shelf – southern Grand Banks management unit (NAFO Divs. 3NOPs4VWX5Zc), and the smaller stock is in the Gulf of St. Lawrence (NAFO Divs. 4RST) (Boudreau et al. 2017). The management units were defined based on the variation in life history characteristics and extensive tagging studies (Stobo et al. 1988). However, the relatively discrete high density patches of juvenile Halibut suggest that population dynamics may occur on a smaller scale than the management units (Shackell et al. 2016).

### Fisheries and Other Human Activities

The fishery for Halibut was unregulated until 1988, when a TAC was implemented and the minimum legal size limit (≥ 81 cm total length) was introduced (DFO 2018h). The fishery operates year-round, and since the introduction of the minimum size, more than 90% of Halibut landed in the Scotian Shelf – southern Grand Banks unit come from longline (Themelis and den

Heyer 2015). Halibut landings in Atlantic Canada have been steadily rising since the early 2000s (DFO 2018h), with the TAC on Scotian Shelf and southern Grand Banks in 2017 set at 3,621 t.

Areas within and immediately adjacent to the Fundian Channel AOI are among the most heavily fished for halibut in the stock area as identified by the number of observed halibut directed trips in the Industry Survey Database Relative numbers of observed trips are a good proxy for the total number of directed trips, and the fact that these data are only observed trips underestimates the total fishing pressure in this area. Observer coverage for the fishery ranges from 4–13% in NAFO Area 4, and 15–87% in NAFO Area 3 (Themelis and den Heyer 2015). Retained bycatch includes Atlantic Cod, White Hake, and Cusk, while the main non-retained species are Spiny Dogfish, Thorny Skate, Barndoor Skate, other skates, and wolffish (Hurley et al. 2019, Themelis and den Heyer 2015). The proportion of non-target species in the Halibut directed fishery has been decreasing, though continued increases in the TAC could increase the catch of non-target species.

It should be noted that the Industry-DFO Halibut Longline Halibut Survey also conducts sets within the AOI. While the number of stratified random sets will change each year (2018 stations shown for example only; Figure 21), the fixed stations will be fished for the next few years and are key to calibrating the stratified random and fixed station surveys (Cox et al. 2018).

### Status and Trends

In Canada, Halibut are experiencing a period of high recruitment and population growth (DFO 2018h). The mean numbers of Halibut per tow in the 2017 summer RV Survey are tied for the fifth highest over the past 10 years and the Halibut Longline Survey biomass index has increased since 2004, with the 2017 standardized catch rate being the highest in the 20-year time series. The summer RV Survey shows a general increase in the mean kg/tow of Halibut within the AOI, and a more consistent increase on the Scotian Shelf as a whole over time. The Scotian Shelf and southern Grand Banks unit is Marine Stewardship Council certified, but is declared a Species of Concern in the United States under the US Endangered Species Act (French et al. 2013). Halibut were also assessed as Not At Risk by (COSEWIC 2011b).

### Sources of Information

The DFO RV Survey provides an index of abundance of recruitment for the stock, while the Industry-DFO Longline Halibut Survey on the Scotian Shelf – southern Grand Banks unit provides an index of exploitable (legal size) Halibut (DFO 2018h).

DFO and Atlantic Halibut fishing industry have collaborated on an annual longline survey since 1998. The protocols have changed over this time, and a new Stratified Random survey which features increased standardization of fishing protocol and 15 depth and area strata was introduced in 2017. The surveys take place between May and July each year. There are five Fixed Station survey stations within the AOI that will be continued to be fished for the next few years as the Fixed Station survey catch rates are calibrated to those of the Stratified Random. In 2018, there were three Stratified Random survey stations within the AOI, but this number may change from year to year given the random survey design (Figure 21).

### Sources of Uncertainty

The reasons why the Gully and areas in the vicinity of and overlapping with the AOI are persistent juvenile nursery areas remain unknown (Boudreau et al. 2017). Environmental conditions in these areas seem to be optimal for settlement and survival of Halibut, and/or these areas may be refugia from fishing or predators, and/or there may be particularly abundant prey in these areas. Additionally, the persistence of these areas as juvenile hotspots under climate change remains uncertain.

## Flounders

### Geographic Range and Habitat Preferences

A number of flounder species are found within the AOI, including Yellowtail Flounder (*Limanda ferruginea*), Witch Flounder (*Glyptocephalus cynoglossus*), Winter Flounder (*Pseudopleuronectes americanus*), and American Plaice (*Hippoglossoides platessoides*). Witch Flounder are a forage species, while American Plaice are influential predators (Horsman and Shackell 2009). Both Witch Flounder and American Plaice are primarily found on the ESS and in the Bay of Fundy (Figure 73), but are also found on Browns Bank (DFO 2017a, Horsman and Shackell 2009). Yellowtail Flounder are commonly found on Sable Island Bank, Banquereau Bank, and Browns Bank (Figure 74), while Winter Flounder are common on Georges Bank, Browns Bank, Sable Island Bank, and in the Bay of Fundy (DFO 2017a, Horsman and Shackell 2009).

Adult American Plaice are benthic and often bury in the sediment to avoid predation. This important behaviour suggests sediment composition (sandy and silty substrates) is likely an important attribute of habitat for American Plaice. American Plaice prefer depths of 100–300 m (Bowering and Brodie 1991) and sampling caught few American Plaice below the 200 m contour of the Laurentian and Esquiman Channels which may suggest American Plaice prefer depths shallower than 200 m in the Fundian Channel. Scott (1982) found American Plaice had a preferred temperature of 1–4°C on the Scotian Shelf with fish to the south having a higher preferred temperature. American Plaice are opportunistic feeders preying on invertebrates and smaller fish so their habitat is likely not dependant on specific prey.

Of American Plaice collected within the AOI by the RV Survey, 75% were collected on Browns Bank, 21% from Georges Basin, and 4% from within the Fundian Channel. The weighted mean depth and temperature at which American Plaice were collected within the AOI are 93.3 m and 7.4°C, respectively.

Of Witch Flounder collected within the AOI by the RV Survey, 66% were collected on Browns Bank, 31% from Georges Basin, and approximately 1% from each of the Fundian Channel and slope habitat. The weighted mean depth and temperature at which Witch Flounder were collected within the AOI are 94.2 m and 7.5°C, respectively.

Of Yellowtail Flounder collected within the AOI by the RV Survey, 99% were collected on Browns Bank and 1% from the Fundian Channel. The weighted mean depth and temperature at which Yellowtail Flounder were collected within the AOI are 52.1 m and 7.0°C, respectively.

Of Winter Flounder collected within the AOI by the RV Survey, 99% were collected on Browns Bank and 1% from the Fundian Channel. The weighted mean depth and temperature at which Winter Flounder were collected within the AOI are 48.5 m and 7.8°C, respectively.

### Populations or Stock Definitions

Populations of flounder that are isolated across the offshore banks on the Scotian Shelf may represent distinct populations, and as such, flounder are typically divided into 4VW and 4X stocks that are distinct from those in the Gulf of Maine. American Plaice are divided into three DU within Canada: the Maritime population, the Newfoundland and Labrador population, and the Arctic population (COSEWIC 2009a).

### Fisheries and Other Human Activities

Flatfish have historically been harvested as a directed multispecies fishery using mobile gear. Since 2015/2016, only Winter Flounder are targeted in directed fisheries in 4X5Y, while American Plaice, Witch Flounder, and Yellowtail Flounder are caught as bycatch only. Yellowtail Flounder and American Plaice are limited to no more than 10% as bycatch in the mobile gear fishery, while Witch Flounder are limited to no more than 20% of bycatch. Catch of flounders in 4VWX5Y in fixed gear is also limited to bycatch only as the available quota for fixed gear is low. Aside from American Plaice, none of these species have stock reference points.

In 5Z there is a directed fishery for Yellowtail Flounder in the U.S. but there is only a small quota for Yellowtail on the Canadian portion of 5Z. Since 2013, Yellowtail Flounder are caught as bycatch only in 5Z.

### Status and Trends

Of these flatfish, the Maritime population of American Plaice, which ranges from Georges Bank north to the Gulf of St. Lawrence, is assessed as Threatened (COSEWIC 2009a). This listing is because of a 67% decline in mature individuals on the Scotian Shelf, primarily attributed to natural and fishing related mortality. American Plaice can be found on the Canadian portion of Georges Bank, but are not abundant in this area because the Fundian Channel may provide a partial barrier to mixing of American Plaice between Georges Bank and Browns Bank (COSEWIC 2009a). While American Plaice are found on Browns Bank, it is not a large spawning component (Busby et al. 2007). The mean kg/tow of American Plaice caught in the summer RV Survey has declined within the AOI over time; this pattern is also observed across the Scotian Shelf as a whole, although the mean kg/tow is generally higher on the Scotian Shelf (Figure 75).

Summer RV Survey data as of 2016 suggests that biomass indices for 4X Winter Flounder are greater than the long-term average of the time series (since the beginning of the survey). This may reflect the poleward movement of southern Gulf of Maine populations into more northern and offshore areas (Nye et al. 2009). The short-term mean biomass (over the past five years) is lower than the long-term average in 4X American Plaice, 4X Witch Flounder, and 4X Yellowtail Flounder, indicating a decline in biomass (DFO 2017a). The mean kg/tow of Yellowtail Flounder caught in the summer RV Survey has declined within the AOI; this contrasts with the Scotian Shelf Bioregion as a whole, which shows relatively stable catch over time (Figure 76).

### Sources of Information

Resource Management uses data from the summer RV Surveys in NAFO 4VWX5Y and winter RV Surveys in 5Z to provide information on trends in abundance and distribution of flounders in the Maritimes.

### Sources of Uncertainty

Seasonal movement patterns of flounders remain uncertain in the WSS and Gulf of Maine, as well as mixing with other flounder in other regions. The genetic stock structure of each species also remains unknown.

## Cusk

### Geographic Range and Habitat Preferences

Cusk (*Brosme brosme*) are demersal and range throughout the North Atlantic where the middle of their abundance lies in the Gulf of Maine and southern Scotian Shelf. Cusk are a solitary, slow-swimming species that prefer hard and rocky substrate so that they can take shelter under rocks (Bigelow and Schroeder 1953). Cusk are also commonly found among gorgonian corals, including those in the Northeast Channel. In the western north Atlantic, Cusk prefer intermediate depths with relatively warm water ranging from 2–12°C, or between 6 and 10°C in the Gulf of Maine specifically (Scott 1982, Scott and Scott 1988). Cusk have been found to range from 20–1,100 m (Andriyashev 1964, Cohen et al. 1990, Hareide and Garnes 2001), but are rarely found at depths less than 20–30 m (Svetovidov 1948). In the Industry-DFO Longline Halibut Survey off Nova Scotia and Newfoundland, Cusk are most frequently caught at depths of 400–600 m but have been caught at depths up to 1,185 m (Harris et al. 2018). This survey data reveals that the mouth of the Northeast Channel is a hotspot for Cusk abundance (Figure 77).

Runnebaum et al. (2017) developed a habitat suitability index for Cusk across the Gulf of Maine based on the NEFSC spring and fall bottom trawl survey data from 1980–2015 and the NEFSC spring and fall longline survey from 2014–2015. The model included included depth, temperature, and sediment type. Density plots based on survey data show that the Cusk population is densest within the central Gulf of Maine in both spring and fall, though the densities have constricted over time. The central GoM was revealed to be the most suitable habitat for Cusk in both spring and fall, and Georges Basin was also shown to be highly suitable despite its silt and mud substrate (Figure 78).

Harris et al. (2018) revealed that the Fundian Channel has among the highest probabilities of Cusk being present based on HIS landings and environmental variables (Figure 79). Harris et al. (2018) showed that the environmental variables that influenced Cusk habitat suitability included current stress, annual chlorophyll, winter total suspended matter, temperature and salinity. For example, Cusk are less prevalent in the Bay of Fundy because of the high levels of suspended matter in the waters, while suspended matter and temperature levels in the Fundian Channel are within the preferred ranges of this species. As such, protection of the Fundian Channel and Northeast Channel could contribute to recovery of this species.

Cusk are among the most fecund fish, with a range of 100,000 to approximately 4,000,000 eggs reported (Oldham 1966). Larvae hatch at approximately 4 mm and remain in the water column until they are about 50–60 mm at which time settle to the benthic environment (Collette and Klein-MacPhee 2002). Cusk are primarily preyed upon by Spiny Dogfish (Halliday 2006), but also Winter Skate, Atlantic Cod, Atlantic Halibut, White Hake, Atlantic Monkfish and possibly Grey Seals.

### Populations or Stock Definitions

Because the majority of the population is located in the Gulf of Maine and southwestern Scotian Shelf, Cusk are treated as a single DU (COSEWIC 2012b). There is no evidence of spatially separated populations of Cusk, and thus seem to form a continuous distribution from the Gulf of Maine to the Grand Banks (Harris et al. 2018).

Of Cusk collected within the AOI by the RV Survey (360 sets unadjusted among comparison areas), 35% were collected on Browns Bank, 43% from Georges Basin, and 22% from within the Fundian Channel. The weighted mean depth and temperature at which Cusk were collected within the AOI are 116.8 m and 8.4°C, respectively.

### Fisheries and Other Human Activities

Fishing related mortality has been identified as a threat to Cusk. Directed fishing has been non-existent since 1999, but approximately 120–150 t of Cusk are landed as bycatch in pelagic and groundfish fisheries annually. Of this, > 95% are landed by the groundfish longline fleet. Cusk are also captured as bycatch in the lobster fishery where they are discarded. Approximately 250–300 t annually are captured as bycatch in the lobster fishery annually and the mortality rates associated with this discard are thought to be high (COSEWIC 2012b). Conservation Harvesting Plans and bycatch caps are the primary regulatory tools for Cusk in Canada.

### Status and Trends

#### *Stock Status*

The DFO summer RV survey indicated from 1970–1985 Cusk were distributed all along the Scotian Shelf, but were primarily found off southwest Nova Scotia and were abundant in the Gulf of Maine. In contrast, in the 1990s–2000 Cusk became sparser in the same region (COSEWIC 2012b). Bottom trawl surveys by both DFO and US National Marine Fisheries Service indicate mature abundance over the last three generations shows a continuous decline. Despite declines in abundance, there is no evidence of a reduction in the range of Cusk (Harris et al. 2018).

#### *Species at Risk Considerations*

In 2012, Cusk were re-examined from their previous designation as Threatened and assessed as Endangered by COSEWIC COSEWIC (2012b). Cusk are currently under consideration for addition to Schedule 1 of SARA (Harris et al. 2018). The Industry-DFO Longline Halibut Survey indicates that Cusk is in the Cautious Zone, and has been for the past seven years (Harris et al. 2018). While their current population seems stable, Cusk are slow-growing and late to mature, suggesting that recovery may be prolonged.

### Sources of Information

The Industry-DFO Longline Halibut Survey is currently the best indicator of Cusk distribution and abundance. Cusk may be caught in the DFO summer RV Survey, but they are not readily captured by the gear type in this survey, and as such estimates of abundance cannot be made. Additionally, the RV Survey generally does not sample the preferred habitat of Cusk (Harris et al. 2018).

### Sources of Uncertainty

A number of uncertainties exist for Cusk, including its stock structure, spawning locations and nursery grounds, and its true range-wide abundance. No studies have been undertaken to compare life histories of Cusk caught in different locations, nor have any genetic studies been undertaken to delineate populations. Thus it remains unknown whether any genetically discrete stocks exist for Cusk.

## Atlantic Hagfish

### Geographic Range and Habitat Preferences

The Atlantic Hagfish (*Myxine glutinosa*) is found from Florida to Greenland on muddy or soft bottom substrates at depths greater than 30–50 m (Martini et al. 1997, Morin et al. 2017). Salinity, temperature, and substrate type are thought to be the primary determinants of Hagfish distribution. Hagfish spend much of their time in temporary burrows in soft sediments which collapse after they move through the substrate. Hagfish are abundant in benthic communities characterized by anemones, polychaete worms, sponges, nemerteans, tunicates, and *Pandalus* shrimp, which they prey upon (Martini et al. 1997). Hagfish play an important role in nutrient cycling, substrate mixing, and removal of dead organisms from the sea floor.

Of Hagfish collected within the AOI by the RV Survey, 32% were collected on Browns Bank, 63% from Georges Basin, and 5% from within the Fundian Channel. The weighted mean temperature at which Hagfish were collected within the AOI is 8.2°C.

### Populations or Stock Definitions

There is no existing assessment framework for Hagfish in the Maritimes Region. Data from the DFO Groundfish Survey shows increases in biomass around 1995 and 2006, and a slight increase from 2015 to 2017 in both biomass and mean number of Hagfish caught per tow (DFO 2018f). However, Hagfish are poorly captured in this gear type, and so these trends are likely not necessarily indicative of actual biomass in the Maritimes Region. On the Scotian Shelf, Hagfish are landed primarily in depths of 50–300 m, and are concentrated in the deep basins of the Gulf of Maine, along the continental slope, and in Emerald Basin (DFO 2018f). These landings areas are reinforced by distributions of Hagfish caught in the RV Survey, which as mentioned does not capture Hagfish well but is still thought to be representative of their overall distribution (DFO 2018f). From 1983 to 2017, the largest numbers of individual Hagfish caught in the Groundfish Survey were in the Bay of Fundy, Georges Basin, Emerald Basin, and along the continental slope (DFO 2018f).

The NEFSC spring and fall groundfish surveys reveal concentrations of Hagfish in the western Gulf of Maine from 1963 to 2002 (NEFSC 2003). Within the AOI, Hagfish are most prevalent in Georges Basin, with some individuals caught on Browns Bank and Georges Bank (NEFSC 2003). Hagfish were rarely caught in the winter surveys. Hagfish in general have low catchability in groundfish surveys, and so estimates of their abundance may not be reliable (NEFSC 2003).

### Fisheries and Other Human Activities

The Canadian directed fishery began in 1989 and was historically centred in NAFO Div. 4X in the 1990s, but has expanded eastward since 2000 (DFO 2018f). An exploratory fishery now exists in NAFO Div. 4T9 (Morin et al. 2017). In the Maritimes, this fishery is managed by limiting the number of licenses, vessel size, number of traps per license, and the size of trap escape holes (Morin et al. 2017). Hagfish are caught and used as bait, for food, and as ‘eelskin’ or fish leather.

### Status and Trends

*Stock Status*

The status of Hagfish in the Maritimes Region remains unknown. No reference points exist for the stock, but catch rates have been stable over time. High numbers of juveniles (44% and a recent increase to 69%) are caught in the offshore Hagfish fishery despite escape holes and extended soak times to potentially allow escapes. Discard of juveniles is not authorized, as the individuals are likely moribund due to the changes in temperature and pressure they experience. The impacts of this high catch rate of juveniles on the stock overall remains unknown (DFO 2018f). The Maritimes Hagfish population shows a variety of high risk factors, including low fecundity, long lifespan, late age of maturity, and poor knowledge of many aspects of their biology.

It is unknown whether catch rates are reflective of general population trends, as they may exhibit characteristics such as hyperstability (a phenomenon where catch rates remain high even though populations are declining), or population changes may be masked by rotational fishing practices. Although catch rate declines have not been seen in the last 20 years of the fishery, the life span of the species is expected to be long, with slow growth rates, which could create difficulties for sustainability in the future (M. Greenlaw, DFO, pers. comm.).

### Sources of Information

The main sources of information for Hagfish are from landings data, distributional data from the Groundfish Survey, and NOAA groundfish surveys in the Gulf of Maine (DFO 2018f, NEFSC 2003).

### Sources of Uncertainty

The overall status of the stock remains unknown. There is a lack of available data to characterize the population and distribution of Hagfish in Atlantic Canada. The longevity of Hagfish also remains unknown, as well as the relative distributions of juveniles versus adults. These uncertainties would require targeted studies and/or surveys to be implemented.

## Spiny Dogfish

### Geographic Range and Habitat Preferences

Spiny Dogfish are long-lived and slow growing small sharks, with low fecundity and low productivity. An average of six pups are born every two years after a gestation period of 18–24 months (COSEWIC 2010c). Females do not mature until approximately 14 years (DFO 2016c). Mating occurs in the fall and early winter.

Spiny Dogfish occur in temperate demersal and pelagic habitats from North Carolina to southern Newfoundland, and undergo seasonal migrations, migrating south in the winter and north in the summer (DFO 2016c). However, resident individuals may inhabit Scotian Shelf waters.

Spiny Dogfish are most commonly captured on the WSS and in the Bay of Fundy during DFO ecosystem surveys, and have become less common on the ESS (Figure 80). The waters approaching and including the Bay of Fundy are persistent top quintile habitat for Spiny Dogfish, with portions of Browns Bank being of relatively high habitat persistence as well since the 1970s (Horsman and Shackell 2009).

### Fisheries and Other Human Activities

Spiny Dogfish have historically been fished by handline, longline, and gillnet gear types in Canada, but landings have not exceeded 200 mt despite a 10,000 mt TAC set in 2015. There is currently no directed fishery in Canada, though a TAC of 4,000 mt for directed fishery and 4,000 mt for retained bycatch was set for 2018/19. This TAC is unlikely to be reached. The Spiny Dogfish fishery in the US is MSC certified where landings have increased since 2002. Spiny Dogfish may also be caught as bycatch in otter trawls and scallop dredges.

### Status and Trends

Spiny Dogfish show highly variable trends in biomass in the summer RV survey across NAFO divisions 4VWX. Estimated biomass was 133,384 t in 2014 but declined to 42,472 t in 2015 (DFO 2017a). The short-term biomass (2011–2015) for 4VWX Spiny Dogfish (100,608 t) is lower than both the mid-term (2001–2015) average of 149,521 t and the long-term (1970–2015) average of 125,805 t (DFO 2017a). The majority of the catch of Spiny Dogfish occurs in 4X and on Georges Bank, with concentrations on Browns Bank, Georges Basin, and the Bay of Fundy (DFO 2017a). Currently, US reference points are considered to be appropriate under the Canadian Precautionary Approach Framework. Under this framework, the biomass estimates for Spiny Dogfish in Canada are in the Cautious Zone since 2015.

The IUCN has assessed the global population of Spiny Dogfish as vulnerable, with a decreasing population trend (Fordham et al. 2016). In Canada, Spiny Dogfish are assessed as Special Concern under COSEWIC but have no SARA status (COSEWIC 2010c). These sharks have few natural predators, but are subject to both targeted fisheries and bycatch mortality, and discards from otter trawl, gillnet, and longline fisheries are the primary sources of fishing mortality. This mortality, coupled with their low fecundity, long generation time, and uncertainty regarding the abundance of mature females in Canadian waters warranted their Special Concern status. In Canadian and global waters, overfishing is considered the only threat to Spiny Dogfish to affect them at the population level (COSEWIC 2010c).

## Other Groundfish

A variety of other groundfish that are not regularly assessed can be found within the AOI. These include Sea Raven (*Hemitripterus americanus*), Ocean Pout (*Zoarces americanus*), Moustache Sculpin (*Triglops murrayi*), Longhorn Sculpin (*Myoxocephalus octodecemspinosus*), Red Hake (*Urophycis chuss*), Monkfish, Roundnose Grenadier, and others. Monkfish and Roundnose Grenadier are briefly discussed below, while the other species are not discussed due to a lack of available information.

Monkfish are a demersal species native to the western Atlantic, that generally inhabit warm slope waters (Kulka and Miri 2001). In Canada, Monkfish are found primarily on the Grand Banks, in the Gulf of St. Lawrence, on the Scotian Shelf and in the Bay of Fundy. Annual RV Surveys show Monkfish appear to be distributed across the Scotian Shelf with concentrations on the edges of the banks and in the basins, but small fish (10–30 cm) were consistently found inshore of LaHave Basin (DFO 2002). Monkfish are meroplanktonic with pelagic egg and larvae stages followed by a transition to benthic habitat during juvenile and adult stages they shift to benthic habitat (Steimle et al. 1999). Concentrations of Monkfish generally peak at depth ranges between 70–100 m but also in deeper waters up to 190 m, appearing most abundant between 3–9°C (DFO 2002). Monkfish are opportunistic feeders preying on a variety of benthic and pelagic fish, and invertebrates. Little is known regarding predation of Monkfish by other species, but records indicate they are eaten by predatory fish, sharks, skates and other Monkfish (Steimle et al. 1999). In the Maritimes Region, the current stock area consists of 4VWX and 5Zc with the fishery conducted nearly entirely in 4X. In the early 1990s, new markets and higher prices led to an increase in the number of trips targeting Monkfish, and therefore current landings are likely reflective of catches. In contrast, prior to 1986 when the Canadian market for Monkfish was limited, landings by the scallop and groundfish mobile gear fleets may not have been reflective of actual catches because of potential discarding (DFO 2002). In 2000, Monkfish underwent a full assessment review and the fishery continues as bycatch only. Evidence suggests improved immature abundance in 4X since 1992, but does not appear to be resulting in increased population biomass. Abundance of adult Monkfish in 4X remains at or below average and the proportion of large fish (> 70 cm) continues to decline and biomass remains low (DFO 2002). Because the stock structure of Monkfish is largely unknown (Kulka and Miri 2001), indicators for Monkfish in 4VW show similar trends to 4X, uncertainty exists among why there is an absence of large fish, and management suggests continuing to implement the cautious approach to harvesting until increases in immature abundance is reflected in mature biomass (DFO 2002). Monkfish have a patchy distribution in the Maritimes Region based on Horsman and Shackell (2009) with the most important habitat including deep basins on the Scotian Shelf and Georges Basin, as well as high concentrations along the continental slope in more recent years. The distribution of Monkfish from the 2016 summer RV Survey appears relatively evenly spaced across the Bay of Fundy, Browns Bank, Georges Bank, and the Scotian Shelf (DFO 2017a).

Roundnose Grenadier are a species of deep-water fish commonly known as rattails. In Atlantic Canada, Grenadier are found along the continental slope from Georges Bank to the Davis Strait. This species has been reported from depths of 200 to 2,600 m (Atkinson 1995), and are most abundant between 800–1,000 m (COSEWIC 2008) at temperatures between 3.5–4.5°C (Atkinson 1995). Grenadier are long-lived, reaching maturity at 10 years and a reported maximum age of 60 years. Their generation time is 17 years, and spawning is thought to occur throughout the year. Fecundity is relatively low compared to other fish, with females producing between 12,000 and 55,000 eggs (Scott and Scott 1988). Grenadier are assessed as Endangered by COSEWIC (2008) because of a decline in adult numbers by 98% from 1978 to 1994, and further decline between 1995 and 2003. This species is considered a single DU in Atlantic Canada (COSEWIC 2008). Roundnose Grenadier were subject to commercial fishing from the 1950s to early 1990s, but are now caught only as bycatch. Minimum trawlable abundance estimates in their Canadian range estimate that the number of adults fell from 44 million in 1996 to 2.5 million in 2003; however, the DFO summer RV Survey does not sample beyond the continental slope and thus these numbers are likely underestimates (COSEWIC 2008). The RV Survey is thus restricted to waters too shallow to provide accurate indications of abundance trends for Grenadier. Landings from the MARFIS database show bycatch occurring within the deep portions (≥200 m) of the Fundian Channel and Georges Basin, spanning from the interior Gulf of Maine to the continental slope. The local status of Roundnose Grenadier in the vicinity of the AOI remains unknown, and while this species is known to occur within the AOI, this is unlikely to be its preferred habitat.

## Atlantic Herring

### Geographic Range and Habitat Preferences

Atlantic Herring (*Clupea harengus*; hereinafter Herring) are a pelagic forage fish found on both sides of the North Atlantic. Herring are distributed from Labrador to Cape Hatteras, but their major spawning grounds generally lie between Cape Cod and Newfoundland (Scott and Scott 1988). Herring spawn in discrete areas, where they show a strong homing fidelity. Herring mature at three to four years of age and then undergo annual patterns of spawning, overwintering, and summer feeding, which involves large migrations, as well as mixing with other spawning groups (Singh et al. 2016). Both inshore and offshore regions (such as the central Gulf of Maine) act as nurseries for juvenile Herring, while offshore regions provide overwintering and feeding grounds (Townsend 1992).

Herring feed on phytoplankton, zooplankton, and ichthyoplankton. Herring are an Ecologically Significant Species, designated as a Type I forage species (DFO 2006). Herring represent an important prey item for a variety of organisms, including larger fish (Cod, tuna, sharks), marine mammals (seals, porpoises, dolphins and whales), and marine birds.

### Populations or Stock Definitions

Herring in the NAFO 4VWX management unit spawn in a number of areas that are located from the Bay of Fundy to Cape Breton, and spawning occurs in the spring or fall. There are four spawning components in 4VWX, including the Southwest Nova Scotia/Bay of Fundy spawning component, the offshore Scotian Shelf banks spawning component, the coastal Nova Scotia spawning component, and the southwest New Brunswick spawning component (Singh et al. 2016). Three stock complexes occur in the Gulf of Maine and Bay of Fundy region, including the aforementioned Southwest Nova Scotia/Bay of Fundy component (NAFO Div. 4X), coastal Gulf of Maine (NAFO 5Y), and Georges Bank (NAFO 5Z) (Melvin and Stephenson 2006). The Georges Bank component nearly disappeared in the 1970s, but recovered to 1960s levels by the late 1990s.In 2003, the Georges Bank component was estimated to have contributed up to 90% of the spawning stock biomass of the Gulf of Maine stock complexes (Melvin and Stephenson 2006).

It is unknown which spawning groups would utilize the AOI as a feeding ground or migration route. Feeding aggregations of herring undergo substantial migrations, and it is likely the AOI serves as part of a migration route from Georges Bank to the Scotian Shelf, and for herring moving from the Scotian Shelf to Georges Bank and into the Gulf of Maine (R. Singh, DFO, pers. comm.).

### Fisheries and Other Human Activities

Herring are historically an important commercial species in the Gulf of Maine and Maritimes region. Prior to its collapse in the late 1970s, Georges Bank supported the largest Herring fishery in the Western Atlantic (Melvin and Stephenson 2006). Fishing occurs around summer feeding, overwintering, and spawning aggregations of Herring, typically using purse seine, weir, and gillnet gear types (Singh et al. 2016). Some spawning grounds also support a directed Herring roe gillnet fishery during the spawning season. Herring are typically fished as bait, but also for consumption. Herring have not been landed in the Canadian portion of Georges Bank since 2004 (Singh et al. 2016).

### Status and Trends

#### *Stock Status*

Populations in the Gulf of Maine are known to fluctuate year to year (Townsend 1992). In the Maritimes Region Herring are assessed using acoustic spawning stock biomass estimates, which have some degree of uncertainty associated with them. In Southwest Nova Scotia/Bay of Fundy total spawning biomass decreased to 328,000 t in 2016 from 462,000 t in 2015 and was the lowest biomass index since 2010 (DFO 2017i).

In the Offshore Scotian Shelf Component, both landings and the mean number of Herring caught in the summer RV Survey declined in 2016 relative to 2015.

In the Coastal Nova Scotia component, spawning stock biomass decreased from 145,395 t in 2015 to 61,408 t in 2016 in the Little Hope/Port Mouton area, while the average spawning stock biomass was 68,034 t over the past five years (DFO 2017i). In the Halifax/Eastern Shore survey, spawning stock biomass decreased from 68,562 t in 2015 to 54,094 t in 2016; however, this spawning stock biomass is higher than the average over the past five years (28,556 t) (DFO 2017i).

### Sources of Information

Little information exists on Herring specific to the AOI, or which spawning component(s) would feed within or migrate through the AOI (R. Singh, DFO, pers. comm.). Herring biomass is estimated using acoustic surveys in the spawning grounds, but Herring are not representatively captured in other DFO surveys, such as the summer RV Survey.

### Sources of Uncertainty

It is unknown which spawning component(s) use the AOI for feeding or a migration route. There is no way to identify individual spawning groups once they have left their spawning grounds, as there is substantial mixing in feeding grounds and during migration (R. Singh, DFO, pers. comm.). The development of diagnostic genetic markers could be used to identify regions of origin from mixed-stock feeding grounds, as has previously been done for European Herring (Bekkevold et al. 2011).

## Atlantic Mackerel

### Geographic Range and Habitat Preferences

Atlantic Mackerel (*Scomber scombrus,* hereinafter Mackerel) are a fast swimming, pelagic schooling species. They are distributed from North Carolina to Newfoundland (Studholme et al. 1999). In spring and summer, Mackerel are found inshore, while in fall and winter they prefer deeper, warmer waters on the edge of the continental shelf (DFO 2017c). Adult Mackerel across this range are primarily found in open, offshore waters, though rarely beyond the continental shelf (Studholme et al. 1999). Horsman and Shackell (2009) show that the Fundian Channel region is ranked low in terms of important habitat, with the most important habitat for Mackerel in the Maritimes occurring on Emerald, Western, and Sable Island banks; this has been consistent since the 1970s.

Mackerel have been observed to be intolerant of temperatures < 5–6°C or > 15–16°C, at which point they increase their swimming speed, indicative of thermal avoidance. Mackerel from the northern portion of their range have been found in temperatures of 2.8°C (D'amours et al. 1990), suggesting there may be different temperature tolerances across their observed range. Based on NEFSC bottom trawl fall surveys, adult Mackerel are distributed from 10–340 m depth, though > 50% were caught at 60–80 m (Studholme et al. 1999). In winter however, > 50% of fish were found at depths of 20–30 m, and by spring fish were broadly distributed again to 380 m (Studholme et al. 1999).

Mackerel are opportunistic feeders that prey on plankton (Studholme et al. 1999). Mackerel larvae feed on copepod nauplii and adult copepods as they grow, while juveniles eat small crustaceans such as copepods, amphipods, mysids, and decapod larvae. The diets of adults are more varied, and may include other species such as shrimp, krill, chaetognaths, and polychaetes (Studholme et al. 1999). Large, mature Mackerel also prey on squid and fishes such as hake, herring, and sculpins (Bowman and Michaels 1984). Mackerel are prey for Swordfish, sharks, hake, tunas, Striped Bass (*Morone saxatilis*), Cod, squids, and marine birds.

### Populations or Stock Definitions

Mackerel are divided into NAFO subareas 3 and 4 in Atlantic Canada, where commercial landings have decreased significantly in recent years. Mackerel represent a transboundary stock that undergoes seasonal migrations between North Carolina and Atlantic Canada (Van Beveren et al. 2017).

### Fisheries and Other Human Activities

Landings of Mackerel increased significantly in the 1960s following the arrival of foreign fishing, with historical highs of 250,000 t per year between 1970 and 1976. Landings dropped in 1977 with the introduction of the 200 nautical mile EEZ. Landings again increased to 90,000 t in 1990 as a result of agreements with the U.S. and the Union of Soviet Socialist Republics (U.S.S.R.) Between 1987 and 2000, the TAC for the Northwest Atlantic was 200,000 t, but was lowered to 150,000 t from 2001 to 2009 because of low biomass estimates from egg surveys. These declines continued and the TAC was lowered to 36,000 t by 2012, but was never reached. In 2014, the TAC was set at 8,000 t, though science advice recommended that annual catches not exceed 800 t in subareas 3 and 4 (DFO 2017c). As of 2016, the TAC of 8,000 t was reached for the first time. In the U.S. landings have remained stable and below 6,000 t since 2012 (as of 2016). The dominant gear types used vary year to year, but include handline, small purse seine, and fixed gear types such as traps, gillnets, lines, and weirs (DFO 2017c).

Mackerel are used as bait in the Lobster, Atlantic Bluefin Tuna (*Thunnus thynnus*), Snow Crab, and Atlantic Halibut fisheries (DFO 2017c). Unreported catches are a significant issue for the Mackerel fishery, because a large portion of the commercially caught Mackerel are sold directly to other fishers and the bait industry for personal use. Catches from the recreational fishery are also not recorded. Van Beveren et al. (2017) suggest that total Mackerel catches, including from the bait fishery, recreational fishery, and discards, may be between 150 and 200% of reported catches.

### Status and Trends

Landings in US waters (NAFO divisions 5 and 6) have also decreased in recent years. Abundances of Mackerel are estimated from an egg survey in the southern Gulf of St. Lawrence, which is their primary spawning ground. Abundance indices reached their lowest level in 2012 (14,568 t) but increased to 52,667 t in 2016 (DFO 2017c). However, abundances are still substantially lower than estimates of over 750,000 t in the 1980s. NAFO division 4X is historically an important Mackerel fishing area, with landings being substantially higher relative to 4VW (DFO 2017c).

### Sources of Information

Mackerel abundance is estimated from an egg survey that takes place in the main spawning site in the southern Gulf of St. Lawrence. Taking into account water temperature, incubation time, and average weight and fecundity of female Mackerel, the egg densities are used to calculate a spawning biomass abundance index (DFO 2017c).

### Sources of Uncertainty

It is unknown if the AOI is important habitat for Mackerel, as they are a migratory pelagic species. Chemical and physical characteristics of the water, including salinity, nutrients, dissolved oxygen, and temperature have been shown to affect the distributions of Mackerel over Georges Bank, and so the biomass of Mackerel in a region is variable on annual basis (Garrison et al. 2002, Radlinski et al. 2013). Mackerel do prefer offshore waters in the fall and winter, and this area may serve as a feeding ground. It is likely that Mackerel would transit through the AOI during spawning migrations and during migrations southward, but the actual usage of the AOI remains unknown.

## Large Pelagic Fishes

A diversity of large pelagic fishes move through Atlantic Canadian waters year-round including tunas, billfishes, and sharks. Distinct oceanographic processes, including upwelling at the mouth of the Northeast Channel, internal waves generated within the Fundian and Northeast channels, and local gyres, in conjunction with dynamic features associated with the Gulf stream, concentrate plankton and forage species such as squid and Atlantic Herring, attracting large pelagic fishes, including various tuna species, to the AOI and continental slope.

Given the highly migratory nature of many of these species, which spend only part of the year in Canadian waters as they track prey and suitable temperature conditions, abundance trends are conducted on broad geographic scales.

### Sources of Information

Fisheries independent monitoring of large pelagic species is not regularly conducted in Atlantic Canada; however, a shark survey for Porbeagle Shark (*Lamna nasus*) was conducted in 2006 and 2007 and most recently in 2017 (Heather Bowlby, DFO, pers. comm.). Fisheries dependent data of landings and logbook data of direct and incidental catch are some of the only sources of data for some large pelagic species as are SARA logbook data for designated species.

Information on presence and distribution of large pelagic species from fisheries dependent catch data from the Canadian Swordfish harpoon and longline fisheries and the Canadian Maritimes Atlantic Bluefin Tuna fishery is presented here, without a focus on trends in the smaller geographic area of the AOI given the stock definitions and movement scales of these species. The distribution of landings of other tuna species are also shown, based on fisheries dependent data (Figure 81). Information on species presence within the AOI and known stock status of the species as reported in the International Commission for the Conservation of Atlantic Tunas (ICCAT) Report for the Biennial Period, 2016–2017, Part II (2017) - Report of the Standing Committee on Research and Statistics (SCRS) and its appendices (2018) are included. Additional information on large pelagic fishes is available on ICCAT’s website, an intergovernmental organization responsible for the management and conservation of tuna and tuna-like species in the Atlantic Ocean and adjacent seas[2].

## Albacore Tuna

### Geographic Range and Habitat Preferences

Albacore (*Thunnus alalunga*) is a temperate tuna widely distributed throughout the Atlantic Ocean and Mediterranean Sea. Geographical limits are from 45–50º N to 30–40º S, but they are less abundant in surface waters between 10º N and 10º S (Collette and Nauen 1983, ICCAT 2006–2016). The distribution of landings on the Scotian Shelf and within and around the AOI based on fisheries dependent data are shown in Figure 82 and Figure 83.

### Population or Stock Definitions

On the basis of the biological information available for assessment purposes, the existence of three stocks are assumed: a northern Atlantic and southern Atlantic stock (separated at 5º N) and a Mediterranean stock.

### Fisheries and Other Human Activities

The Canadian nominal landings of North Atlantic Albacore in 2016 was approximately 20 t, the Canadian quota was 200 t. Canada’s greatest year of landings of North Atlantic Albacore, since 1992, occurred in the year 2000 when 122 t was landed.

### Status and Trends

The status of the North Atlantic Albacore Tuna stock is based on the most recent analyses conducted in May 2016 using data available up to 2014. In 2016, a production model was used to assess the North Atlantic Albacore stock status. Similarly, in 2016, ICCAT established a TAC of 28,000 t and suggested that the biomass would continue to increase and was likely sustainable at this level; such that several provisions were included to allow the catch to exceed this established TAC. It was also noted that, since the establishment of the TAC in the year 2001, catch has remained substantially below the TAC in all but three years, including 2016, which may have accelerated rebuilding over the last decade.

## Bigeye Tuna

### Geographic Range and Habitat Preferences

Bigeye Tuna (*Thunnus obesus*) are distributed throughout the Atlantic Ocean between 50ºN and 45ºS, but not in the Mediterranean Sea (Figure 84, Figure 85). Bigeye Tuna are an epi- or mesopelagic species that inhabit open waters, preferring temperatures between 17°C and 22°C. However, this species has been known to dive and forage in deep waters in the 5°C range. Bigeye Tuna are typically found at depths of 50 m, but have been observed diving to depths exceeding 1,000 m (ICCAT 2006–2016).

### Population or Stock Definitions

Bigeye Tuna are treated as a single stock in the Atlantic Ocean (ICCAT 2006–2016).

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[2] ICCAT Website

### Status and Trends

The last stock assessment for Bigeye Tuna was conducted in 2015. The stock assessment used fishery data from the period of 1950 to 2014 and most indices of relative abundance used in the assessment were also constructed through 2014. Stock status evaluations for Atlantic Bigeye Tuna used several modeling approaches, ranging from non-equilibrium production models to integrated statistical assessment models. The Atlantic Bigeye Tuna stock was estimated to be overfished and that overfishing was occurring in 2014. Projections indicated that catches at the TAC level of 85,000 t would have around a 30% probability to recover the population to a level that is consistent with ICCAT's objectives by 2028. ICCAT's objectives for Atlantic Bigeye Tuna are to have the stock maintained at levels capable of producing its Maximum Sustainable Yield (MSY). Projections indicated that maintaining catch levels at a TAC of 65,000 t was expected to recover the stock status to the ICCAT objectives with a 49% probability by 2028. However, 2016 catches (72,375 t) exceeded the TAC of 65,000 t. Therefore, if future catches are maintained at the 2016 level, the probability of achieving ICCAT's objectives by 2028 was expected to decrease to around 38 %. The Canadian nominal landings of Atlantic Bigeye in 2016 was approximately 171 t, the Canadian quota was 1,575 t. Canada's greatest landings of Bigeye Tuna, since 1992, occurred in 2000 when 327 t was landed.

## Atlantic Bluefin Tuna

### Geographic Range and Habitat Preferences

Atlantic Bluefin Tuna have a wide geographical distribution but mainly live in the temperate pelagic ecosystem of the entire North Atlantic and its adjacent waters, for example the Gulf of Mexico, Gulf of St. Lawrence and the Mediterranean Sea. Bluefin tuna are a highly migratory species that seem to display a homing behavior and spawning site fidelity to primary spawning areas in both the Mediterranean Sea and Gulf of Mexico. Atlantic Bluefin Tuna migrate into Canadian waters between July and December. The commercial fishing period for individual fleets operates using different opening and closing dates, but the entire season runs from late spring to late fall with the majority of landings occurring between late July and early September.

Atlantic Bluefin Tuna have a lifespan of approximately 40 years and are believed to mature at 25 kg. By age 20, they can reach 270 cm and weigh 400 kg (ICCAT 2010). Atlantic Bluefin Tuna are highly migratory and frequently reach depths of 500–1,000 m (Maguire and Lester 2012). In the AOI, Atlantic Bluefin Tuna primarily prey on Atlantic Herring and Mackerel. Recent declines in prey species, particularly Mackerel, have not seemed to affect Atlantic Bluefin Tuna distribution or range in Canada. Occasional predators of adult Atlantic Bluefin Tuna include Killer and Pilot whales, and Mako Sharks (Scott and Scott 1988).

One major area in Canada where Atlantic Bluefin Tuna are primarily caught is at the entrance to the Fundian Channel between Browns Bank and Georges Bank, known as the "Hell Hole" (Figure 86, Figure 87). In the directed fishery, Atlantic Bluefin Tuna are caught using rod and reel, handlines, electric harpoon, and trap nets. Every fish harvested is required to be tagged and weighed at dockside.

Currently, the major anthropogenic cause of Atlantic Bluefin Tuna mortality in Canadian water is targeted and incidental fishing. From the 1970s to 1992, the spawning stock biomass for the western population of Atlantic Bluefin Tuna declined substantially, but after implementing a 20-year recovery plan in 1998 the spawning stock biomass appears to be improving.

### Population or Stock Definitions

Currently, the Atlantic Bluefin Tuna population is managed as two stocks, conventionally separated by the 45°W meridian, however, efforts to understand the population structure through tagging, genetic and microchemistry studies indicate that mixing is occurring at various rates in the eastern, western and northwestern Atlantic (ICCAT 2006–2016).

### Status and Trends

#### *Stock Status*

Bluefin Tuna are assessed approximately every 2 to 3 years. The last assessment was conducted in July of 2017; this recent assessment was open to revisions of the assessment methodology and parameterization. In 1998, ICCAT initiated a 20-year rebuilding plan, with recommended total allowable catches (TAC) of 1,900 t in 2009, 1,800 t in 2010, 1,750 t in 2011, 2012, 2013 and 2014 and 2,000 t in 2015 to 2017. In the 2017 western Bluefin Tuna stock assessment, two stock assessment models (virtual population analysis and Stock Synthesis) were considered sufficiently developed to provide advice on the stock status and results were equally weighted to formulate advice. The 2017 assessment did not provide management advice based on MSY reference points or evaluate if the stock is rebuilt. Instead, the focus was on giving short-term advice based on fishing mortality rate (F) reference point ($F_{0.1}$), a proxy for $F_{MSY}$, using recent recruitment assuming that near term recruitment will be similar to the recent past recruitment. The 2017 assessment advised that the TAC over 2018–2020 should not be greater than 2,500 t, which would be a 500 t increase in TAC. It was also noted that nearly all TACs greater than 1,000 t will result in an estimated decrease in biomass between 2018 and 2020. In addition to the TAC, Bluefin Tuna have an additional size management measure in place. Contracting Parties, Cooperating non-Contracting Parties, Entities, or Fishing entities shall take the necessary measures to prohibit catching, retaining on board, transhipping, transferring, landing, transporting, storing, selling, displaying or offering for sale Atlantic Bluefin Tuna weighing less than 30 kg. The Canadian nominal landings of Bluefin Tuna in 2016 was approximately 466 t, the Canadian quota was 506 t.

#### *Species at Risk Considerations*

Atlantic Bluefin Tuna in the western Atlantic were assessed by COSEWIC in 2011 as Endangered because of a 69% decline in adult abundance over the past 2.7 generations (COSEWIC 2011a, Maguire and Lester 2012). Bluefin Tuna are not listed under SARA, but are listed as Endangered by the IUCN with a decreasing population trend in the Atlantic.

## Yellowfin Tuna

### Geographic Range and Habitat Preferences

Yellowfin Tuna (*Thunnus albacares*) are epi- and mesopelagic fish widely distributed in tropical and subtropical waters of the Atlantic, Indian, and Pacific oceans, but are absent in the Mediterranean Sea (Collette and Nauen 1983, ICCAT 2006–2016). The geographical limits are between 45º–50º N and 45º–50º S. Their wide distribution explains the number and variety of fisheries that have developed throughout the world. The distribution in the Atlantic Ocean: in the eastern Atlantic is from the Netherlands to South Africa and in the western Atlantic from south of Canada to north of Argentina. Landings for the bioregion are aggregated in the WSS, particularly near the Fundian Channel, and waters offshore to the southeast(Figure 88, Figure 89).

### Population or Stock Definitions

Up to 1993, two differentiated stocks of Yellowfin tuna were considered in the Atlantic Ocean. Although the distinct spawning areas might imply separate stocks, or substantial heterogeneity in the distribution of Yellowfin tuna, observed transatlantic movements (from west to east) indicated Yellowfin are distributed continuously throughout the tropical Atlantic Ocean. Therefore currently, in the ICCAT Convention area there is only a single management unit of Yellowfin Tuna.

### Status and Trends

A stock assessment for Yellowfin tuna was conducted in 2016, at which time catch and effort data through 2014 were available. Based on the 2016 stock assessment, the Atlantic Yellowfin tuna stock was estimated to be overfished, but in 2014 the biomass was at 95% of the Biomass needed for the maximum sustainable yield. Maintaining catch levels at the TAC of 110,000 t was expected to maintain healthy stock status through 2024. However, 2016 catches exceeded the catch recommendation by 16%. The Canadian nominal landings of Atlantic Yellowfin Tuna in 2016 was approximately 19.5 t. Canada’s greatest landings of Yellowfin Tuna, since 1992 occurred in the year 2004 when 304 t was landed.

## Skipjack Tuna

### Geographic Range and Habitat Preferences

Skipjack Tuna (*Katsuwonus pelamis*) is a cosmopolitan species found in schools in tropical and subtropical waters of the three oceans. Its geographical limits are 55º–60ºN and 45º–50ºS. It is most abundant in the region of the equator all the year round and in the tropics during the warm season. This wide distribution accounts for the number and variety of fisheries that have developed all around the world. Distribution in the Atlantic Ocean: in the eastern Atlantic from Ireland to South Africa, and in the western Atlantic from Canada to northern Argentina.

### Population or Stock Definitions

Stocks can be divided into two distinct units in the East and the West of the Atlantic Ocean, separated by the meridian at 30º W (a dividing line set when fisheries were coastal). However, some migrations and longline fishery records have shown the presence of young Skipjack Tuna along the equator, west of 30º W and only 1,000 nautical miles from the Brazil fisheries, which could imply a degree of mixing (ICCAT 2006–2016).

### Status and Trends

Stock assessments for East and West Atlantic Skipjack were conducted in 2014 using catch data available to 2013. For the West Atlantic Skipjack Tuna stock, it was recommends that the catches should not be allowed to exceed the MSY. The model based on catches and the non-equilibrium surplus biomass production model have estimated, respectively, the MSY at 30,000 t–32,000 t. The average catch of Skipjack Tuna in the last ten years from the Western Atlantic stock has been 27,194 t. The stock has determined to be in a healthy state not overfished and not currently being overfished. The Canadian nominal landings of western Atlantic Skipjack Tuna in 2016 was approximately 0 kg. Canada’s greatest landings of Skipjack Tuna, since 1992 occurred in the year 2010 when 25 kg was landed.

## Swordfish

### Geographic Range and Habitat Preferences

Swordfish (*Xiphias gladius*) are distributed widely in the Atlantic Ocean and Mediterranean Sea. Swordfish may be found in coastal waters and have a broad temperature tolerance, from 5 to 27°C. Swordfish spawn at temperatures from 23 to 26°C, but may spawn all year round in the Northwest Atlantic (ICCAT 2006–2016). Tagging studies show Swordfish make extensive movements between tropical and temperate waters in the North and South Atlantic. The distribution of landings on the Scotian Shelf are primarily aggregated near the shelf break, with areas of high landings overlapping the southern portion of the AOI near the Fundian Channel (Figure 91 and Figure 92).

### Fisheries and Other Human Activities

Swordfish are fished using longline and harpoon in Nova Scotia. Effort between 2002 and 2010 decreased, with fewer vessels, sets, trips, and sea days in 2010 than in 2006 (Hanke et al. 2012). Effort had dropped by 50% as of 2011 in NAFO divisions 4WX, though landings have not declined (DFO 2011a). Bycatch associated with the Swordfish longline fishery includes tunas, Shortfin Mako, Blue Shark, Porbeagle Shark, Loggerhead Sea Turtle, and Leatherback Sea Turtle, though most of this bycatch occurs off the continental shelf and not within the AOI, except near the slope (DFO 2011a).

### Population or Stock Definitions

In the ICCAT Convention area, the management units of Swordfish for assessment purposes are a separate Mediterranean group, and North and South Atlantic groups separated at 5° N (ICCAT 2006–2016).

### Status and Trends

*Stock Status*

The status of the North and South Atlantic Swordfish stocks were assessed in 2017, using data available up to 2015. In 2010, the total allowable catch in the North Atlantic was reduced to 13,700 t from 14,000 t. The reported total catch since 2010 has averaged 11,682 t and only exceeded the TAC in one year (2012, 13,868 t). The current TAC of 13,700 t has a 36% probability of maintaining the North Atlantic Swordfish stock in the green quadrant of the Kobe plot by 2028 (which represents a healthy stock; overfishing is not occurring and the stock is not in a state of overfished;(Maunder and Aires-da-Silva 2011)), whereas a TAC of 13,200 t would have a 50% probability. In addition to the TAC, Swordfish have an additional size management measure in place. Each country has two choices for the allowable minimum size limits of landed Swordfish either: anything above 125 cm Lower Jaw Fork Length (LJFL) with a 15% tolerance for anything below, or anything above 119 cm LJFL with zero tolerance for anything less than that and evaluation of the discards. The Canadian nominal landings of Swordfish in 2016 were 1,547.9 t, which resulted in a quota underage of 492.3 t. The Canadian quota for 2016 was 2,040.2 t, which included transfers to Canada of 35 t from each of Japan and Chinese Taipei, 125 t transfer from Senegal. The current stock assessment however does recognizes that the above advice does not account for removals associated with the actual mortality of unreported dead and live discards, quota carryovers (15% in the North Atlantic), quota transfers across the North and South stock management boundaries nor that the total cumulative quota distributed would fall above the TAC if achieved.

## Blue Marlin

### Geographic Range and Habitat Preferences

Blue Marlin (*Makaira nigricans*) is one of the large billfish species. Blue Marlin display extensive movements in the Atlantic. Significant movement is observed between the US mid-Atlantic coast, and the Gulf of Mexico to Venezuelan waters with smaller amounts of transatlantic and trans-equatorial movements (ICCAT 2006–2016).

### Population or Stock Definitions

ICAAT manages the Atlantic as a single unit stock for Blue Marlin.

### Status and Trends

The most recent assessment for Blue Marlin was conducted in 2011. This assessment indicated that the stock remains overfished and is currently undergoing overfishing. At that time, it was noted that if catch levels of Blue Marlin (3,223 t in 2010) were not substantially reduced, the stock would continue to decline. The current management plan is believed to have the potential of recovering the Blue Marlin stock if properly conducted. In 2012, ICCAT established a TAC of 2,000 t. In 2016, the landings of Blue Marlin were only 1,295 t and Canada landed only approximately 100 kg of the species. In addition, currently, four ICCAT Contracting Parties (Brazil, Canada, Mexico, and the United States) mandate or encourage the use of circle hooks on their pelagic longline fleets. Recent research has demonstrated that in some longline fisheries the use of non-offset circle hooks resulted in a reduction of billfish mortality, while the catch rates of several of the target species remained the same or were greater than the catch rates observed with the use of conventional “J” hooks or offset circle hooks.

Blue Marlin are primarily caught in pelagic longline fisheries that target tunas, though they may be caught as bycatch in coastal gillnet fisheries.

## White Marlin

### Geographic Range and Habitat Preferences

White Marlin are widely distributed in subtropical and tropical waters of the Atlantic Ocean, and occasionally in Atlantic temperate waters and in the Mediterranean Sea. Geographical limits are from 55ºN to 45ºS, but they are less abundant in waters of the eastern central Atlantic and the south central Atlantic (ICCAT 2006–2016).

### Population or Stock Definitions

In the ICCAT Convention area there is only a single management unit of White Marlin.

### Status and Trends

The most recent assessment for White Marlin (*Kajikia albidus*) was conducted in 2012 through a process that included a data preparatory meeting in April 2011 and an assessment meeting held in May 2012. The last year of fishery data used in the assessment was 2010. Two models were used to estimate the status of the stock, a surplus production model (ASPIC), and a fully integrated model (SS3). The results of the 2012 assessment indicated that the stock remains overfished but most likely not undergoing overfishing. In 2012, ICCAT reduced the total harvest of White Marlin to 400 t to allow the rebuilding of the stock from the overfished condition.

In 2016, the landings of White Marlin were only 452 t and Canada landed only approximately 1 t of the species. Overall, catching above the 400 t TAC will likely cause the rebuilding of the stock to proceed more slowly. As with Blue Marlin, currently, four ICCAT Contracting Parties (including Canada) mandate or encourage the use of circle hooks on their pelagic longline fleets. Recent research has demonstrated that in some longline fisheries the use of non-offset circle hooks resulted in a reduction of billfish mortality, while the catch rates of several of the target species remained the same or were greater than the catch rates observed with the use of conventional "J" hooks or offset circle hooks.

## Other Pelagic Fishes

Several other species of pelagic fishes can be found within the AOI that are not regularly assessed. Two examples of these species are Mahi-Mahi (*Coryphaena hippurus*), caught incidentally by the pelagic longline fishery, and Atlantic Argentine, found in relatively high concentrations within and around the AOI.

Mahi-Mahi are a surface-dwelling pelagic fish that live in temperate, subtropical, and tropical waters, with their northern range extending to Nova Scotia. Mahi-Mahi are commercially fished, and landings in the Pacific, Atlantic, and Indian Oceans have undergone exponential increases since the 1950s (Whoriskey et al. 2011). Mahi-Mahi are landed within the AOI with the highest landings occurring on the continental shelf and beyond. No assessments have been conducted on Mahi-Mahi in Canadian waters and so trends in biomass in this region cannot be examined. Longline fishing associated with Mahi-Mahi, swordfish, and tunas has been implicated in sea turtle and elasmobranch bycatch in the tropics and temperate zones (Swimmer et al. 2010, Whoriskey et al. 2011).

Atlantic Argentine are small-mouthed bathypelagic fish found on both sides of the Atlantic Ocean (Emery and McCracken 1966). Argentine are found in depths of approximately 50 to 350 m and deeper, and prefer warm, (7–10°C), saline waters in the Gulf of Maine region (Scott 1982, Scott and Scott 1988). Argentine are concentrated within the Fundian Channel, along the continental slope, and in deep basins on the Scotian Shelf according to the MARFIS database and distribution data from the Summer RV survey (Figure 92). The Fundian Channel and Georges Basin as persistent habitats for Argentine (Horsman and Shackell 2009).

## Basking Shark

### Geographic Range and Habitat Preferences

Basking Sharks (*Cetorhinus maximus*) are filter-feeding sharks in the order Lamniformes that use gill rakers to filter zooplankton out of water passing over their gills through their open mouth. Basking Sharks are the second largest fish species, attaining a maximum length of over 15 m. Basking Sharks are found in most temperate shelf waters and occur in Canadian Atlantic and Pacific temperate waters where temperatures exceed 6-7°C (Campana et al. 2008). Individuals are most commonly observed in the Gulf of St. Lawrence, the Bay of Fundy, the Scotian Shelf, and Grand Banks. There are confirmed observations of Basking Sharks within the AOI consistently since the late 1970s (Campana et al. 2008).

Basking Sharks are most commonly observed on the Scotian Shelf in the summer and tend to aggregate in areas where oceanographic features concentrate zooplankton (COSEWIC 2009b). These features include fronts where water masses meet, areas with strong tidal flow, and areas of upwelling such as those identified within the AOI (Section 2.2).

### Populations or Stock Definitions

Basking Sharks in Atlantic Canada are treated as a single population under COSEWIC. Atlantic Basking Sharks are considered a distinct DU from Pacific Basking Shark. Population estimates range from approximately 5,000 to 10,000 individuals that inhabit Canadian waters, at least seasonally. While individuals living in the Northwest Atlantic were thought to be a shared population between the United States and Canada, there is evidence of European individuals migrating across the Atlantic to Canadian waters.

### Fisheries and Other Human Activities

There is no directed fishery for Basking Shark in Canada. However, Basking Shark fins are highly valuable in Asian markets, and this species is included under Appendix II of the Convention on International Trade in Endangered Species to regulate the shark fin trade. Basking Sharks may also be caught as bycatch in pelagic longline or gillnet fisheries.

### Status and Trends

The IUCN lists Basking Sharks as globally vulnerable, and endangered in the northeast Atlantic and north Pacific. The Atlantic population of Basking Shark is assessed as Special Concern by COSEWIC (COSEWIC 2009b) but has no SARA listing. Basking Sharks have extremely low productivity, late maturity, and gestation times of 2.6 to 3.5 years, and as such are highly vulnerable to human-induced mortality, such as bycatch and entanglements (COSEWIC 2009b). Ship collisions may be another threat to Basking Sharks because of their habit of their surface-feeding habits. There is a high degree of uncertainty in population models based on aerial surveys, bycatch data, and life history parameters, but overall there is a low probability of Canadian Basking Sharks declining to extinction levels over the next 100 years (COSEWIC 2009b).

## Blue Shark

The Blue Shark (*Prionace glauca*) is a highly migratory species, with complex movement patterns related to reproduction and to the distribution of its prey (Campana 2016). The species displays a seasonal movement towards higher latitudes related to the existence of highly productive areas of convergence (Nakano and Stevens 2008). Blue Sharks, like other large pelagics sharks, are highly mobile and regularly migrate thousands of kilometres over coastal and open oceans. Blue Shark are rarely found in waters less than 50 m deep, and tend to move to deeper waters in the winter (Campana et al. 2015b). Blue Sharks prefer ocean temperatures between 10 and 25°C. Mating, birthing, and nursery areas are believed to be in international waters to the south and east of Canada, and there are no known important habitats for Blue Shark in Canadian waters (Campana et al. 2015b).

Blue Sharks are one of the most productive elasmobranch species, with a capacity for population growth approximately six times greater than Porbeagle (Campana 2016). Litters typically consist of 25 to 50 pups after a 9-12 month gestation period (Campana et al. 2015b). Despite this relatively high capacity for population growth, Blue Sharks experience recruitment rates similar to Porbeagle, which suggests that if the stock is depleted, it will recover on the same time scale as other shark species (Campana 2016).

#### Fisheries and Other Human Activities

The most recent assessment for North and South Atlantic Blue Shark stocks was conducted in 2015 through a process that included a data preparatory meeting in March 2015 and an assessment meeting held in July 2015. For the North Atlantic stock, while all scenarios considered with the Bayesian surplus production model and the integrated model (SS3) indicated that the stock was not overfished and that overfishing was not occurring. The level of uncertainty in the data inputs and model structural assumptions was high enough to prevent a consensus being reached on a specific management recommendation for this species. ICCAT established a catch limit for Blue Sharks in the North Atlantic in 2017 of 39,102 t which was the average of the two previous consecutive years. The preliminary catch in 2016 was 42,117 t. The Canadian nominal landings of North Atlantic Blue Shark in 2016 was approximately 0.3 t.

The IUCN lists Blue Shark as Near Threatened globally, and it is not known if the global population is declining or increasing (Stevens 2009). Blue Shark are assessed as Not at Risk by COSEWIC and are not SARA listed in Canada.

Blue Sharks are primarily caught as bycatch in the pelagic longline fishery for Swordfish and tuna. Hooking and post-release mortality are substantial sources of mortality (Campana et al. 2015b). Bycatch ratios of Blue Shark to target species of tuna and Swordfish often exceeded 100% since 2000, and both immature and mature sharks are caught.

The recreational fishery for Blue Sharks is catch and release only, with the exception of shark derbies. Fishing derbies, which occur annually, primarily take place along the continental shelf and on Georges Bank. As of 2006, all Blue Sharks less than 240 cm were to be released alive, preferable after tagging (Campana et al. 2015b). Derby landings are capped at 20 mt.

### Porbeagle Shark

#### Geographic Range and Habitat Preferences

Porbeagle Shark are distributed widely in the Maritimes Region, including within the AOI (Campana 2016). In the North Atlantic, this large pelagic shark ranges from New Jersey to the northern coast of Newfoundland. Mating grounds for this species are believed to be the entrance to the Gulf of St. Lawrence and the area of the Grand Banks off southern Newfoundland (Campana et al. 2003). Although Porbeagle Sharks are found at preferred temperatures of 5–10°C, they are found at all depths (Campana et al. 2003).

#### Populations or Stock Definitions

Porbeagle Sharks in the northwest Atlantic are believed to be a single stock that carries out extensive migrations between the south of Newfoundland (Canada) in summer to at least Massachusetts (United States) in winter (ICCAT 2006–2016).

#### Fisheries and Other Human Activities

Directed fisheries for Porbeagle Shark were suspended in 2013, though they are caught as bycatch in the pelagic longline fishery for offshore tunas and in various other fisheries in Canadian waters (Gibson and Campana 2005) and with unrecorded mortality in international waters. The Canadian nominal landings of Northwest Atlantic Porbeagle Shark in 2016 was approximately 1.9 t. In addition to threats posed by fishing activities, other human related activities could pose a potential threat to Porbeagle habitat including noise associated with offshore petroleum exploratory seismic surveys, marine pollution caused by offshore petroleum exploration or development spills, and large scale marine development projects.

### Status and Trends

#### *Stock Status*

The most recent assessment for Porbeagle Shark stocks was conducted in 2009 through a process that included an assessment meeting held in June 2009. The Canadian assessment of the Northwest Atlantic Porbeagle stock indicated that biomass is depleted to well below the Biomass needed for Maximum Sustainable Yield (BMSY), but recent fishing mortality is below the mortality rate necessary to achieve MSY and thus the biomass appears to be increasing. Additional modelling using a surplus production approach indicated a similar view of stock status. The Canadian assessment projected that with no fishing mortality, the stock could rebuild to BMSY level in approximately 20-60 years, whereas surplus-production based projections indicated 20 years would suffice. Under the Canadian strategy of a 4% exploitation rate, the stock was expected to recover in 30 to 100+ years according to the Canadian projections. ICCAT determined that new targeted Porbeagle fisheries should be prevented, Porbeagle retrieved alive should be released following best handling practices to increase survivorship, and all catches should be reported.

#### *Species at Risk Considerations*

Porbeagle was re-examined and confirmed as Endangered by COSEWIC (2014). Porbeagle exhibit a delayed age at sexual maturation and very low fecundity relative to most other fishes, with a maximum intrinsic rate of population increase of 0.05 (Campana 2016). Globally, Porbeagle are assessed as Vulnerable by the IUCN with a decreasing population trend (Stevens et al. 2006).

### Sources of Information

Porbeagle populations are monitored with shark-directed scientific surveys that use catch rates with commercial gear to estimate population abundance and trends. The most recent survey was conducted in 2017, with the most recent survey results available from the previous survey in 2009. Porbeagle stock assessments have been undertaken regularly in recent years with the most recent assessment, a post-COSEWIC recovery potential assessment, published in 2015 (Campana et al. 2015a).

## Shortfin Mako Shark

The most recent assessment for North and South Atlantic Shortfin Mako (*Isurus oxyrinchus*) stocks was conducted in 2017 through a process that included a data preparatory meeting in March 2017 and an assessment meeting held in June 2017. This species is the fastest shark and is an active fish that is highly migratory. It has been observed that Shortfin Mako carry out extensive migrations of up to 4,542 km, but transatlantic and trans-equatorial migrations are not common for this species (ICCAT 2006–2016). Shortfin Mako can be found in summer and fall in waters off all of Atlantic Canada’s provinces, up to 50°N, and up to 60°N in the northeast Atlantic. Shortfin Mako occur offshore on the continental shelf break, on the continental shelf, and have been observed near shore (COSEWIC 2017). Browns Bank and the Fundian Channel have been identified as hotspots for the probability of Shortfin Mako catch (landings and discards) in the Canadian pelagic longline fishery between 2003–2013 (COSEWIC 2017, Godin et al. 2015).

Shortfin Mako have a low productivity relative to other North Atlantic shark species, with a generation time of 25 years. Their preferred water temperature is between 17–22°C, suggesting there are no resident individuals in Canadian waters (COSEWIC 2017). Their mating and pupping grounds remain unknown in Canada.

### Status and Trends

#### *Stock Status*

For the North Atlantic Shortfin Mako stock, nine stock assessment model runs were selected to provide stock status and management advice; however, projections could only be carried out with the BSP2JAGS production model. Projections indicated that catch levels (3,600 t, mean of 2011–2015) in the North Atlantic would cause continued population decline. The probabilities in the Kobe matrices indicate that to stop overfishing and start rebuilding, the constant annual catch should be reduced to 500 t or less. This will achieve the goal of stopping overfishing in 2018 with a 75% probability, but it only has a 35% probability of rebuilding the stock by 2040. Only a 0 t annual catch will rebuild the stock by 2040 with a 54% probability.

#### *Species at Risk Considerations*

While this species is not targeted in Canadian fisheries, it is caught and landed as bycatch. In 2006 the Atlantic population of Shortfin Mako were assessed as Threatened by COSEWIC, and re-examined in April 2017. The Atlantic population was then assessed as Special Concern as a result of its high vulnerability, which is in turn because of its long life span and low productivity (COSEWIC 2017). Shortfin Mako were referred to COSEWIC for reassessment in March 2019 following the autumn 2017 ICCAT assessment which presented new information not considered by COSEWIC. As of May 2019, Shortfin Mako are assessed as Endangered by COSEWIC due to continued overfishing of a depleted population. The IUCN has assessed the global population of Shortfin Mako as Endangered, with a decreasing population trend (Rigby et al. 2019).

## White Shark

### Geographic Range and Habitat Preferences

White Sharks (*Carcharodon carcharias)* are globally distributed in sub-tropical and temperate waters and are absent from cold polar waters. Canadian waters represent the northern edge of White Shark distribution. White Sharks have a long generation time (approximately 23 years) and low reproductive rates. Individuals may grow up to 6 m in length and potentially live up to 60 years.

### White Sharks in Fundian Channel-Browns Bank

The species is highly mobile, and individuals in Atlantic Canada are likely seasonal migrants belonging to a widespread Northwest Atlantic population; hence the status of the Atlantic Canadian population is considered to be the same as that of the broader population. White Sharks have been tracked moving through the AOI during their seasonal migrations into Canadian waters.

### Populations or Stock Definitions

The Atlantic and Pacific populations in Canada are isolated from each other and are considered separate DU.

### Fisheries and Other Human Activities

There is no fishery for White Shark in Atlantic Canada. Bycatch in the pelagic long line fisheries for tunas and Swordfish is considered to be the primary cause of increased mortality.

### Status and Trends

#### *Stock Status*

This large apex predator is rare in most parts of its range, but particularly so in Canadian waters No abundance trend information is available for Atlantic Canada. No abundance trend information is available for Atlantic Canada White Shark.

#### *Species at Risk Considerations*

White Sharks are assessed as Endangered under COSEWIC (2006a) and listed as such under SARA as of 2011 (Table 11). Numbers have been estimated to have declined by 80% over 14 years (less than one generation) in areas of the Northwest Atlantic Ocean outside of Canadian waters. The IUCN lists the global population of White Shark as Vulnerable, with an unknown population trend.

# SEALS

Grey Seals and Harbour Seals are the only seal species in Atlantic Canada that are likely to be found in the AOI.

## Harbour Seal

Movements of Harbour Seals (*Phoca vitulina*) generally seem to be limited to coastal areas (Thompson et al. 1996, 1998); however, more recent studies suggest that they are capable of longer distance movements (e.g., in the vicinity of a seasonally ice-covered area). As a coastal species that inhabits waters along the Newfoundland and Labrador coasts, the Gulf of St. Lawrence, and around Nova Scotia (Boulva and McLaren 1979); Harbor Seals may use waters in and/or adjacent to the AOI for foraging and/or travel. There is no current population estimate for this species and little is known of their movement and breeding distribution in eastern Canada; however, severe declines have been recorded on Sable Island (Lucas and Stobo 2000).

## Grey Seal

Given the known distribution, movement patterns and habitat preferences of Grey Seals (*Halichoerus grypus*), they are the most likely seal species to utilize the AOI for foraging and travelling.

### Geographic Range and Habitat Preferences

Grey Seals in Canadian Atlantic waters are found from the Gulf of St. Lawrence, Newfoundland, south to Georges Bank. Breeding populations occur in the southern Gulf on pack ice; on small coastal islands along the Eastern Shore of Nova Scotia; and on Sable Island, which has the largest breeding colony.

Beyond the breeding season, Grey Seals exhibit a wider distribution that varies by age, sex, and season and their distribution likely includes areas in and/or adjacent to the AOI, at least for some age/sex groups (Breed et al. 2006, Breed et al. 2009). Results from satellite telemetry studies of Grey Seals tagged on Sable Island, suggest that preferred foraging areas are mostly distributed heterogeneously across the ESS and over shallow banks, with large, deeper, unfavourable areas in between (Breed et al. 2009). In the summer, foraging locations tend to be close to haul-out sites, the trips are shorter, and individuals spend more time hauled out, whereas during the winter foraging locations tend to be deeper and more spread out. Compared with females, tagging indicates that males from Sable Island that forage in this area, as part of their large foraging areas, show a tendency to travel further, have fewer foraging locations, and seem more likely to use the AOI (Breed et al. 2009).

### Populations or Stock Definitions

Grey Seals in the northwest Atlantic are considered to be from a single stock (Boskovic et al. 1996); however, in Canada, three management units are recognized based on the location of breeding colonies: Gulf of St. Lawrence, Coastal Nova Scotia, and Sable Island.

### Fisheries

Although the main commercial species for the Canadian seal fishery is Harp Seals, Grey Seals are also harvested with a TAC set for the Gulf of St. Lawrence and the Scotian Shelf (DFO 2017k). There are no main areas for the commercial Grey Seal hunt near the AOI. Fulltime fishers may be awarded a nuisance seal licence to kill grey seals if they can demonstrate that their fishing operations are being detrimentally impacted by grey seal predation, subject to the National Nuisance Seal Licence Policy and Procedures (DFO 2017k).

### Status and Trends

The number of Grey Seal pups born on Sable Island has increased exponentially since 1962 (Bowen et al. 2003, 2007; den Heyer and Bowen 2017). The 2016 estimate of pup production for Sable Island was 83,600 with 95% confidence limits of 63,600 to 103,500 (den Heyer and Bowen 2017). Pup production on Sable Island has continued to increase, but at a slower rate than it did in the late 1990s and early 2000s. In addition to Sable Island, the sea ice and small islands in the southern Gulf of St. Lawrence, there are small Grey Seal breeding colonies on near-shore islands along the Atlantic Coast of Nova Scotia and in the Gulf of Maine, some of which have been established more recently and have increased rapidly (Mansfield and Beck 1977). The total estimated Canadian grey seal population in 2016 on the Scotian Shelf was 380,300 (95% CL = 234,000 to 517,200), and 44,100 (95% CL = 29,600 to 61,100), for the Gulf of St. Lawrence (DFO 2017k).

# CETACEANS

## Cetaceans of Atlantic Canada

At least 22 species of cetaceans are known to occur in the waters of Atlantic Canada including baleen whales, toothed whales, dolphins, and porpoise (Gomez-Salazar and Moors-Murphy 2014). Many of these species have been observed off the southwestern coast of Nova Scotia; however, no comprehensive systematic surveys on the occurrence or distribution of cetaceans in the AOI have been conducted, and the abundance of cetaceans has not been estimated for this area. Most of the sightings that do exist for this area are opportunistic in nature. A comprehensive analysis of any associated observational effort for these data is necessary to fully characterize cetacean distribution in the area over temporal and spatial scales. Baleen whales previously identified within the study area include Blue Whale (*Balaenoptera musculus*), Fin Whale (*Balaenoptera physalus*), Sei Whale (*Balaenoptera borealis*), Minke Whale (*Balaenoptera acutorostrata*), Humpback Whale (*Megaptera novaeangliae*), and North Atlantic

Right Whale (*Eubalaena glacialis*). Large odontocetes identified within the study area include Cuvier's Beaked Whale (*Ziphius cavirostris*), Killer Whale (*Orcinus orca*), Long-finned Pilot Whale (*Globicephala melas*), Sowerby's Beaked Whale (*Mesoplodon bidens*), and Sperm Whale (*Physeter macrocephalus*). Finally, small odontocetes identified within the study area include Common Bottlenose Dolphin (*Tursiops truncatus*), Atlantic White-sided Dolphin (*Lagenorhynchus acutus*), Short-beaked Common Dolphin (*Delphinus delphis*), Harbour Porpoise (*Phocoena phocoena*), and Risso's Dolphin (*Grampus griseus*).

This chapter summarizes information available from literature sources, visual sightings, acoustic detections, and modeled predictions of suitable habitat to identify cetacean species that are most likely to occur in the AOI. While numerous species have been identified in the study area, only those with information to support some degree of regular occurrence in or near the AOI are described here. Included among this group is the Northern Bottlenose Whale (*Hyperoodon ampullatus*), based on habitat preferences consistent with those found within the AOI and sightings made at the edge of the AOI boundary. The section below summarizes those sources of information used most consistently throughout the present chapter to characterize cetacean occurrence near and within the AOI. However, this section does not endeavor to describe every source of information; additional sources were used throughout the document to support species-specific conclusions about habitat preferences and possible or known occurrence near and within the AOI.

## Sources of Information

### Cetacean Surveys

Results from cetacean surveys conducted over previous years in both Canadian and American waters were consulted. These results can provide some information on distribution and density or abundance, but cannot be interpreted as comprehensive indices of abundance as they often do not cover the entirety of a species' range.

#### *Atlantic Marine Assessment Program for Protected Species (AMAPPS)*

Over the past number of years, the National Ocean and Atmospheric Administration's (NOAA) Northeast Fisheries Science Center (NEFSC) and Southeast Fisheries Science Center (SEFSC) has been a partner in the Atlantic Marine Assessment Program for Protected Species (AMAPPS), a U.S. federal government initiative that seeks to conduct fine-scale research on species and areas of particular interest in the U.S. waters of the Northwest Atlantic. This agreement came into force in 2010, and since then studies have been conducted each year to help achieve set goals related to the AMAPPS project. These studies have included dedicated research surveys for cetaceans along the eastern seaboard of the U.S. and up into Nova Scotian waters. Sightings and information presented in reports published by the NEFSC and SEFSC were used to support discussions of cetacean distribution in the Northwest Atlantic and in and near the AOI, where possible.

#### *Trans North Atlantic Sightings Survey (TNASS)*

Inspired by North Atlantic Sighting Surveys conducted in previous decades by European countries, the Trans North Atlantic Sightings Survey (TNASS) was conducted in 2007 in an effort to fill gaps in survey effort that existed in Atlantic Canadian waters. One of the goals of TNASS was to estimate abundance of different cetacean populations in the North Atlantic. Aerial surveys following specified line transects were conducted between northern Labrador down to the U.S. North Atlantic, collecting abundance and distribution information on various species of marine animals. Lawson and Gosselin (2009) used the results to estimate abundance of cetacean species in Atlantic Canadian waters for the areas encompassing the waters of Cape Breton, the Gulf of St. Lawrence and the Scotian Shelf. Results presented in Lawson and Gosselin (2009) were used to help inform cetacean species presence and abundance estimates throughout the Scotian Shelf. It is important to note that TNASS represents only a snapshot in time and therefore the resulting abundance estimates do not likely represent the entire population in question bur rather a minimum estimate at a certain point in time. The TNASS was repeated in 2016 and results from this second survey were mentioned when possible.

### Passive Acoustic Detections

#### *DFO*

Since 2012, marine mammal scientists of DFO's Ocean and Ecosystem Sciences Division, Maritimes Region, have been using stationary passive acoustic monitoring (PAM) to better understand and describe year-round cetacean presence throughout the Scotian Shelf Bioregion at specific recording sites. PAM instruments have been deployed in various locations throughout the Scotian Shelf and resulting data have contributed to a greater understanding of trends in species presence on the Scotian Shelf throughout the year. In 2018, an Autonomous Multichannel Acoustic Recorder (JASCO Applied Sciences, Inc.) was deployed for a one-year duration at the southern tip of Browns Bank to detect whale vocalizations, at the mouth of the Fundian Channel within the AOI boundaries. Acoustic data analysis from that deployment is underway and will provide more detailed information on the presence of cetaceans in the area. In 2019, a second one-year deployment was conducted in the same area, along with two additional yearlong deployments nearby: one in Corsair Canyon on the edge of Georges Bank, and another at the western entrance of the Fundian Channel, the latter of which falls within the current boundaries of the AOI. Data collected from these acoustic recorders will contribute to existing knowledge on cetacean presence in and around the AOI.

#### *Dalhousie University*

The Whitehead Lab of Dalhousie University has been conducting research on cetaceans in the Northwest Atlantic since 1986. Long-term population studies of the resident Scotian Shelf population of Northern Bottlenose Whales are ongoing. Research effort on Northern Bottlenose Whales has largely been conducted in the Gully and adjacent submarine canyons along the western shelf edge where the whales reside year-round, and has consisted of photo-identification and passive acoustic data collection methods. In 2016, an acoustic survey conducted from Georges Bank to the southern coast of Labrador detected Sowerby's Beaked Whale clicks within the area bounded by the AOI, and Northern Bottlenose Whale clicks in the area just east of the AOI.

#### *JASCO Applied Sciences - Acoustic Monitoring Along Canada's East Coast*

Acoustic Monitoring Along Canada's East Coast was a study funded by the Environmental Studies Research Fund, a program administered through the Canada Petroleum Resources Act to support studies that help to better understand how petroleum exploration, development, and production should be conducted in Canada. The objective of the study was to better inform future environmental assessments via two programs: 1) measurement of the existing marine soundscape, including vocalizing marine animals; and 2) understanding the effects of the acoustic footprint of seismic surveys taking place in the study area. To carry out these programs, JASCO Applied Sciences conducted passive acoustic monitoring at 20 different sites throughout the Northwest Atlantic, from Labrador to Nova Scotia, between August 2015 and July 2017. Sounds from up to 23 species of marine mammals were identified within the data, and spatial and temporal trends in species presence were discussed. A report by Delarue et al. (2020) presenting the results of the two-year monitoring program helped inform the acoustic presence of various cetacean species described here. While Delarue et al. (2018) provided information from sites throughout the Northwest Atlantic, results were only discussed when relevant to species presence near the Fundian Channel-Browns Bank AOI or to describing pertinent seasonal trends in occurrence.

#### Sightings Data and Model Predictions to identify Priority Areas for Cetacean Monitoring

Visual sightings maps presented in Gomez et al. (2020) have confirmed the presence of a variety of cetacean species near and within the AOI. Sightings summarized in the Open Data record (Gomez et al. 2020) suggest that these species may all potentially use the area and were therefore used to support discussions of cetacean occurrence in the AOI.

To predict possible suitable habitat for various cetacean species in the Northwest Atlantic, Gomez et al. (2020) followed a framework developed in Gomez et al. (2017) that used Species Distribution Models (SDM) that integrated cetacean sightings data from various sources and a series of environmental predictor variables. Sightings records were compiled from DFO’s Maritimes Region and Newfoundland and Labrador Region, the Ocean Biogeographic Information System, the North Atlantic Right Whale Consortium, the Whitehead Lab at Dalhousie University, and Environment and Climate Change Canada’s Eastern Canada Seabirds at Sea program. Data up until 2015 were gathered, although only records of free-swimming whales from after the whaling period (1975–2015) were used.

The majority of sightings from these sources are opportunistic in nature, although some are from systematic surveys. Quality control checks were conducted to discard redundant records and records that fell outside waters off Nova Scotia, Newfoundland and Labrador. The data compilation used does not reflect any updates or corrections to the databases that have occurred since the data were compiled in 2016. Additional details on the methodology can be found in Gomez et al. (2017).

It is important to note that sightings data cannot be used to assess absence over space and time, and because they are not always effort-corrected, presence shown in given areas at certain times may simply be reflective of increased effort in that area rather than increased presence. For example, data are often collected during the summer months and effort is often concentrated in specific areas (e.g., the Bay of Fundy).

In addition to sightings data, six environmental predictor variables were selected as proxies for prey availability: ocean depth, compound topographic index, sea surface temperature, areas of persistently high chlorophyll-a concentration, and regional chlorophyll-a magnitude. SDMs were then used to integrate sightings data and environmental variables in order to predict seasonal suitable habitat of cetaceans during spring (2 species), summer (10 species), and autumn (7 species) in eastern Canadian waters off Nova Scotia, Newfoundland, and Labrador (Gomez et al. 2020). The study identified areas with high suitability, referred to as “recommended priority areas for monitoring” and interpreted as areas where cetacean monitoring efforts could be prioritized according to the study’s results. These areas are discussed and the following sections included; the western shelf and shelf edge for numerous species including Fin Whales, Sei Whales, Minke Whales, Humpback Whales, Sperm Whales, Long-finned Pilot Whales, Atlantic White-sided Dolphins, and Short-beaked Common Dolphins (Gomez et al. 2020). Results were used to identify species of cetaceans for which areas of predicted highly suitable habitat overlaps with the Fundian Channel-Browns Bank AOI. Environmental variables that contributed most to the predicted highly suitable habitat for each species were also used to support discussions of species occurrence.

#### Other Sources

The U.S. National Marine Fisheries Service and United States Fish and Wildlife Service generate regular stock assessment reports for all marine mammal stocks in waters of the U.S. Exclusive Economic Zone (Hayes et al. 2020). These reports are reviewed regularly, and provide information on abundance estimates generated over recent years and the surveys upon which those estimates are based. These stock assessments were used to obtain abundance estimates for the cetacean species discussed here.

### Species Listed Under Schedule 1 of SARA

#### Blue Whale

The Blue Whale population of the Northwest Atlantic was assessed as Endangered by COSEWIC in 2002 and re-examined and confirmed as such in 2012 (Table 11). It has been listed as Endangered under Schedule 1 of SARA since 2005 (DFO 2016e). Blue Whales were severely depleted by whaling, and current population size for western Northwest Atlantic Blue Whales is estimated to be in the low hundreds, with no more than 250 mature individuals (DFO 2018b). Blue Whales in the Eastern North Atlantic are managed separately from Northwest Atlantic Blue Whales, although insufficient data exist to confirm whether these two units constitute a single population or two distinct populations (DFO 2018e). Photo-identification and satellite telemetry data suggest that Blue Whales in eastern regions of Canada, the U.S. and West Greenland/Davis Strait are part of the same population (COSEWIC 2002, Ramp and Sears 2013, Sears and Larsen 2002).

In the western North Atlantic, a portion of the population migrates south during the winter while another remains in Canadian waters yearlong (DFO 2018e). During the summer feeding season, Blue Whales are generally found between Davis Strait and the Gulf of Maine, while in winter they are thought to be distributed mainly between the St. Lawrence Estuary down to at least South Carolina, although their exact wintering areas and migration routes are still not well described. Recent satellite tracking data obtained by Lesage et al. (2016) have provided the first full record of a winter migration of a Blue Whale in the Northwest Atlantic, and hinted at the presence of a potential wintering and breeding area off the United States coast between Delaware and South Carolina.

Visual sightings of Blue Whales have been made on Georges Bank (NEFSC/SEFSC 2016), located in the vicinity of the AOI. Yet greater evidence for Blue Whale occurrence in the AOI exists in results from suitable habitat modeling, PAM efforts, prey modeling, and satellite tracking. Gomez et al. (2017) and Moors-Murphy et al. (2019) used a common approach to present habitat suitability modeling results predicting suitable habitat for Blue Whales in the Northwest Atlantic. Lesage et al. (2018) used various data sources and results from previous studies that included sightings, whaling records, acoustic detections and model results in combination with areas of krill aggregation (observed or predicted) to identify areas important for

Blue Whales in the same region (supporting information may be found in Gomez et al. 2017, Lesage et al. 2016, Moors-Murphy et al. 2019, Plourde et al. 2016). The results from these previous efforts have identified, among other areas, the continental shelf of the Scotian Shelf as an important area for Blue Whales, an area encompassing the Fundian Channel-Browns Bank AOI (Gomez et al. 2020).

Passive acoustic monitoring has also shown consistent Blue Whale presence in the Northwest Atlantic including near the vicinity of the AOI. PAM conducted by NOAA detected Blue Whale calls near the Heezen Canyon off Georges Bank, with detections showing a seasonal but consistent Blue Whale presence from summer until mid-March when presence becomes variable (NEFSC/SEFSC 2018). Davis et al. (2020) show acoustic detections of Blue Whales throughout the year off eastern Canada and the United States, including fall detections along the shelf edge off Georges Bank and in the Fundian Channel.

Bathymetric features can play a role in predicting possible Blue Whale habitat. Blue Whales tend to be associated with upwelling regions and bottom topography (Croll et al. 2005, Schoenherr 1991) because these areas are believed to contribute to krill aggregation (Genin 2004, Lavoie et al. 2000). Slope areas have previously been identified as important for Blue Whale foraging (Doniol-Valcroze et al. 2012), and Blue Whales have been shown to associate with krill patches, with the greatest density of whales occurring over slope areas (McQuinn et al. 2016). It is possible that krill concentrate in basins and along the edge of the Scotian Shelf (Wimmer 2004). Models developed by Plourde et al. (2016) predicting “Significant Aggregations of Krill” (SAK), defined as areas where environmental conditions are more likely to encourage krill aggregation, included the edges of the Fundian Channel and Browns Bank as areas where these SAKs may occur. In addition to areas where SAKs occur, internal waves have been shown to result in upward movement and concentration of euphausiids in the Gulf of Maine (Stevick et al. 2008); the Fundian Channel-Browns Bank AOI encompasses areas of the continental shelf edge and slope, with canyons incising the channel mouth, and is an area where internal waves are known to occur. Blue Whales spend much of their time in Canadian waters feeding (Lesage et al. 2016) and telemetry data from the Gulf of St. Lawrence and St. Lawrence Estuary suggest Blue Whales may be engaged in foraging behaviour 70% of the time (Lesage et al. 2016).

Finally, satellite tracking data have shown a single Blue Whale having traveled north-east along the continental shelf break to the southern edge of Georges Bank, passing through the Fundian Channel on its way to the waters off central Nova Scotia (Lesage et al. 2016). This indicates that Blue Whales may make use of the waters in and around AOI when on migratory journeys and therefore may be regularly passing through.

The AOI occupies an area of the continental shelf edge already identified as important foraging habitat by Lesage et al. (2018). It encompasses slope and edge areas predicted to be suitable habitat that may act to aggregate Blue Whale prey and PAM efforts point to Blue Whale occurrence in the vicinity of the AOI throughout the seasons. Taken together, these results suggest the area within and around the AOI represents an important foraging habitat for this endangered species throughout much of the year. Based on satellite tracking data, Blue Whales may also use the area to travel to other parts of their range.

### Fin whale

The Atlantic population of Fin Whales was reduced by whaling in the 20th century, although sightings off Atlantic Canada are still relatively common (DFO 2016b). The population was assessed as Special Concern by COSEWIC in 2005 and re-examined and confirmed in 2019 (COSEWIC 2019a) and has been listed as Special Concern under Schedule 1 of SARA since 2006. There are currently no reliable estimates of population size for the North Atlantic population and population size pre-whaling remains unknown. Lawson and Gosselin (2009) estimated 890 individuals off Newfoundland and Labrador and 462 individuals in the Gulf of St. Lawrence and on the Scotian Shelf, although these represent minimum estimates. Hayes et al. (2020) report 7,418 (CV = 0.25) as the most recent and best population estimate for the western North Atlantic stock based on 2016 NOAA shipboard and aerial surveys and the 2016 Canadian Northwest Atlantic International Sightings Survey (NAISS). The latter estimate is larger as it covered an area extending from Newfoundland to Florida while the former was concentrated in certain areas of eastern Canada.

Fin Whales are found in all oceans of the world except the Arctic Ocean (DFO 2017d). In the western North Atlantic, their range extends from Davis Strait and Baffin Bay down as far as the Canary Islands (Cooke 2018c). While stock boundaries in the North Atlantic remain uncertain, the International Whaling Commission (IWC) has proposed that whales off the eastern United States, Nova Scotia and southeastern Newfoundland constitute a single stock (Hayes et al. 2020). However, because of continued uncertainties around stock structure, whales of the North Atlantic are considered one population under DFO's management plan (DFO 2017d) and referred to as the Atlantic population.

Most information on Fin Whale presence in Canadian waters relates to their summer feeding habitat. Between May and October, they are known to aggregate in the coastal and offshore waters of Newfoundland and Labrador, the Gulf of St. Lawrence, the Atlantic coast of Nova Scotia, and the Bay of Fundy to feed (DFO 2017d). During the winter months some individuals migrate from Newfoundland and Labrador to the waters of Nova Scotia, while Nova Scotian whales migrate further south (DFO 2017d). It is believed that at least male Fin Whales in the North Atlantic may be present throughout their range throughout the year (Cooke 2018c). Delarue et al. (2018) have detected Fin Whales throughout the year on the Scotian Shelf, and more recent PAM detections have shown the presence of Fin Whales off the mid-eastern United States, Bay of Fundy, and Scotian Shelf from November to February. Summer Fin Whale habitat is characterized by low surface temperatures and the presence of oceanic fronts (DFO 2017d). In the Bay of Fundy, Fin Whales were associated with shallow but steep areas where upwelling occurs, features likely linked to the accumulation of their prey, primarily Atlantic Herring and euphausiids (Woodley and Gaskin 1996). Similarly, Fin Whale abundance in coastal Newfoundland was found to be correlated to the presence of Capelin, another major food source (Whitehead and Carscadden 1985), while Johnston et al. (2005) found that Fin Whale movements and selected foraging sites were linked to accumulations of Atlantic Herring and large zooplankton.

Copepods are the dominant zooplankton within and adjacent to the AOI boundaries including Browns Bank, the Fundian Channel, and Georges Bank. *Calanus finmarchicus, Pseudocalanus spp., Paracalanus parvus, Centropages typicus, C. hamatus,* and *Oithona similis* are the six dominant species that make up 80% of the mesozooplankton biomass on Georges Bank (Davis 1987, Kennedy et al. 2011). The presence of Fin Whale prey species as well as the steep topography that has been linked to prey accumulation suggest that the area encompassed by the AOI could be important for foraging Fin Whales. Gomez et al. (2020) identified the waters of the Scotian Shelf, including shelf edge habitat encompassed by the AOI, as predicted highly suitable habitat and recommended priority monitoring area for Fin Whales in summer and fall. Chlorophyll-a concentration was a significant contributor to these results for Fin Whales (Gomez et al. 2020) and high levels of chlorophyll-a and primary productivity are known to be present at the mouth of the Fundian Channel. Finally, sightings of Fin Whales compiled in Gomez et al. (2020) show numerous Fin Whale records in and around the AOI throughout the year. Previous sighting records along with habitat modeling results and bathymetric and oceanographic environmental features that may encourage prey accumulation indicate that the AOI may provide habitat attractive to Fin Whales throughout the year.

### North Atlantic Right Whale

North Atlantic Right Whales were designated as Endangered in 2005 under Schedule 1 of SARA after being assessed by COSEWIC in 2003. In 2013, COSEWIC re-assessed their status as Endangered (COSEWIC 2013a). Intense whaling in the 19th and 20th centuries had reduced the population of North Atlantic Right Whales to near extinction. Since that time, the species was considered to have been recovering slowly, but recent population numbers have been declining and population levels remain critically low. As of the end of 2018, the best estimate of the total number of North Atlantic Right Whales alive is 409 (Pettis 2020).

A highly migratory species that tends to be found in coastal and shelf waters, the North Atlantic Right Whale makes seasonal movements between calving grounds off Florida and Georgia to feeding grounds off New England and the east coast of Canada (Winn et al. 1986). In the past, North Atlantic Right Whales were known to migrate regularly to the lower Bay of Fundy and the WSS in the spring and summer, where high aggregations of whales were observed in August and September (Winn et al. 1986). Grand Manan Basin and Roseway Basin on the WSS are the two currently designated Critical Habitats for the species in Canadian waters (Brown et al. 2009). However, since 2015, a northward shift in summer distribution to the Gulf of St. Lawrence has emerged, following a decline in abundance in the Bay of Fundy and low numbers of whales observed in Critical Habitat areas (DFO 2019a).

Recent shifts in North Atlantic Right Whale distribution correspond to observed changes in the zooplankton community, as North Atlantic Right Whale movement is driven primarily by the distribution of their primary prey, calanoid copepods (Davies et al. 2015, Record et al. 2019). In addition to new trends in seasonal distribution, acoustic evidence suggests that a certain number of North Atlantic Right Whales remain in Canadian waters year-round, demonstrated by results from fixed acoustic and glider deployments in the Gulf of St. Lawrence and the Scotian Shelf (DFO 2019a) and combined PAM efforts from throughout the North Atlantic (Davis et al. 2017). North Atlantic Right Whales also appear to be present in the Gulf of St. Lawrence until as late as January, but with the greatest number of detections in summer and fall (Simard et al. 2019).

While not an area of increasing abundance relative to other areas, North Atlantic Right Whales are known to occur in the vicinity of the AOI as evidenced by PAM data from the area. Results from Davis et al. (2017) show acoustic presence of North Atlantic Right Whales near the Fundian Channel in summer (May–July), based on data collected between 2004 and 2014. Additional data from off the eastern United States show North Atlantic Right Whale acoustic presence along the continental shelf including a small number of detections on the edge of Georges Bank (NEFSC/SEFSC 2018). Presence of North Atlantic Right Whales in the area may be driven by migratory behaviour or food sources. As stated, copepods are the dominant zooplankton within and adjacent to the AOI boundaries including Browns Bank, the Fundian Channel, and Georges Bank. As North Atlantic Right Whales feed primarily on *Calanus* copepods (Baumgartner et al. 2003), and prey availability is an important driver of North Atlantic Right Whale distribution in Canadian waters (DFO 2019a), those individuals present on the WSS may be attracted by the area's local zooplankton community. It is also possible that the whales use the Fundian Channel as a migratory corridor to enter and exit the Bay of Fundy, although to an unknown degree given recent shifts in distribution towards the Gulf of St. Lawrence. Based on previous sightings from within the AOI, known historical habitat use, PAM results and local zooplankton composition, the waters of the Fundian Channel-Browns Bank AOI may be used by North Atlantic Right Whales, potentially to forage or travel to and from other habitats.

### Northern Bottlenose Whale

In Canadian waters, there are two separately managed and genetically distinct populations of Northern Bottlenose Whale: the Scotian Shelf population and the Baffin Bay-Davis Strait-Labrador Sea population (COSEWIC 2011c, DFO 2016d). Whaling between the 1960s and 1970s reduced both populations (COSEWIC 2011c), and the effects of whaling remain difficult to assess (O'Brien and Whitehead 2013). Nevertheless, the populations remain small and at-risk to impacts from human activity (COSEWIC 2011c). The Scotian Shelf population of Northern Bottlenose Whales is believed to number fewer than 150 individuals and was designated as Endangered under Schedule 1 of SARA in 2006, following an Endangered assessment by COSEWIC in 2002 (COSEWIC 2011c). There is no population estimate for the Davis Strait-Baffin Bay population although it was assessed as Special Concern by COSEWIC in May 2011 (COSEWIC 2011c).

Northern Bottlenose Whales are found exclusively in the North Atlantic. The species generally frequents deeper waters (> 500 m) and is strongly associated with continental slope areas of 800–1800 m depth (COSEWIC 2011c, Moors-Murphy 2018). The full range of the Scotian Shelf population is not known, but the ESS is considered the most southerly centre of abundance (Wimmer and Whitehead 2004). While sightings of Northern Bottlenose Whales have occurred as far east as the Flemish Cap off Newfoundland (DFO 2016d), it is not yet clear to which population these Newfoundland whales belong, and a recent study suggests they may represent a mixed group (Feyrer et al. 2019).

The Scotian Shelf population is primarily found in three underwater canyons along the ESS: the Gully, Shortland, and Haldimand canyons. The whales exhibit high site fidelity to the canyons, as they are present there year-round and forage throughout the year (Moors 2012). The persistence of the population within these canyons is likely due to an abundant and consistent food source, namely *Gonatus* spp. squid, the primary prey of this population (Hooker et al. 2001). The deep waters of the three canyons are designated Critical Habitat for this population (DFO 2016d), although visual and acoustic data indicate that the inter-canyon areas are also important foraging habitat and movement corridors between canyons (DFO 2020a). Different oceanographic processes that occur in the Gully canyon, including internal waves, may contribute to concentrating processes that support benthic and demersal species of cetacean prey which could attract cetaceans to the canyon (Moors-Murphy 2014).

A portion of the Fundian Channel-Browns Bank AOI includes a section of key habitat for deep-diving Northern Bottlenose Whales identified by Gomez-Salazar and Moors-Murphy (2014). Beaked whales have been associated with shelf edges (Waring et al. 2001), and it is likely that areas within the AOI with depths greater than 1,000 m represent beaked whale habitat (J. Stanistreet, DFO, pers. comm., NEFSC/SEFSC 2016). Steep topography and bathymetric features of the AOI are similar to other areas where beaked whale prey are thought to aggregate and the area may therefore provide suitable habitat for Northern Bottlenose Whales. Furthermore, recent passive acoustic monitoring by the Ocean and Ecosystem Sciences Division, Fisheries and Oceans Canada from 2018–2019 has shown acoustic detections of Sowerby's Beaked Whales, Cuvier's Beaked Whales, and clicks likely produced by True's Beaked Whales (*Mesoplodon mirus*) in the deep waters of the AOI just north of the Fundian Channel (J. Stanistreet, unpublished data). Acoustic detections of Northern Bottlenose Whales collected by the Whitehead Lab, Dalhousie University have also been confirmed near the AOI (Feyrer, L. unpublished data). Finally, sighting records of Northern Bottlenose Whales at the edge of the AOI are documented in (Gomez et al. 2017). Taken together, acoustic data, previous sightings in the area and the bathymetry and habitat type that characterize the AOI, suggest that the Fundian Channel-Browns Bank area is used by various beaked whale species including Northern Bottlenose Whales. While the data do not suggest distinct seasonal patterns of occurrence for any beaked whale species in the western North Atlantic, acoustic detections are consistent throughout the year in many other areas (e.g., the Gully Marine Protected Area) (DFO 2020a, Rafter et al. 2018, Stanistreet et al. 2017).

### Sowerby's Beaked Whale

Few population estimates exist for Sowerby's Beaked Whale and those available rely on limited data (COSEWIC 2019c). COSEWIC (2019c) has estimated the number of mature individuals to be in the hundreds to low thousands, while (Hayes et al. 2020) report 10,107 (CV = 0.27) as the best available abundance estimate based on shipboard and aerial surveys of the Western North Atlantic. Intense anthropogenic underwater sounds such as seismic surveying and mid-frequency sonar as well as with ship strike and fishing interactions threaten this poorly-understood species (COSEWIC 2019c). The species has been assessed as Special Concern by COSEWIC (COSEWIC 2006c) and was listed as such under Schedule 1 of SARA in 2011.

Sowerby's Beaked Whales are found exclusively in the cold waters of the North Atlantic Ocean. Their distribution in the western North Atlantic ranges from Massachusetts to Labrador (IUCN 2017, IUCN SSC Cetacean Specialist Group 2007) although the majority of sightings have been in the waters off Newfoundland, Nova Scotia, and the northeastern United States. In Canada, they are thought to mainly occur along the continental slope off Nova Scotia and Newfoundland and Labrador in waters of depths of 200 m or more (DFO 2017e, f). Detailed information on spatial and temporal patterns and habitat use in Canadian waters is not available (O'Brien and Whitehead 2013).

On the Scotian Shelf, Sowerby's Beaked Whales are distributed along the shelf edge and are present year-round (Stanistreet et al. 2017). They are regularly sighted in the Gully, Haldimand, and Shortland submarine canyons of the eastern shelf (Whitehead 2013, Wimmer 2004), and an aggregation of sightings have been made further south along the shelf edge near the Fundian Channel (DFO 2017e). In general, it is believed that Mesoplodont whales tend to prefer the deep-water habitats (> 200 m) found near canyons, continental slopes, and in the open ocean (DFO 2017e). The Scotian Shelf edge was identified as key habitat for Sowerby's Beaked Whales (Gomez-Salazar and Moors-Murphy 2014).

Sowerby's Beaked Whale presence both near and within the waters of the Fundian Channel-Browns Bank AOI has been confirmed in recent years based on visual and acoustic detections made in the area. Results from shipboard and aerial NOAA surveys of the eastern seaboard show sightings of Sowerby's Beaked Whales at locations near and possibly within the boundaries of the AOI over multiple survey years (NEFSC/SEFSC 2013, 2016, 2017, 2018) and a dedicated 2018 vessel survey included both acoustic and visual detections of the species in the southern portion of the AOI near the mouth of the Fundian Channel (NEFSC/SEFSC 2018). Clicks attributed to the species have been detected along the eastern United States and Canada, primarily in waters extending from the coast of Maryland up to the edge Georges Bank (Rafter et al. 2018) and further north still to the Gully MPA (Stanistreet et al. 2017). In 2016, acoustic recordings from a survey conducted by the Whitehead Lab, Dalhousie University included Sowerby's Beaked Whale clicks detected within the AOI (Feyrer L. unpublished data). In 2018–2019, a stationary passive acoustic monitoring system deployed in the AOI just north of the Fundian Channel by the Ocean and Ecosystem Sciences Division, Fisheries and Oceans Canada recorded vocalizations of Sowerby's Beaked Whales throughout the year, suggesting regular foraging activity in the deep waters of the AOI (J. Stanistreet, unpublished data). This most recent information suggests that Sowerby's Beaked Whales may occupy the AOI year-round and that the portions of the AOI greater than 1,000 m offer suitable Sowerby's Beaked Whale habitat. Previous acoustic and visual detections in the area, the depths at which previous nearby sightings have been made (NEFSC/SEFSC 2016) and the knowledge that beaked whales are known to be associated with shelf edges and slopes (Waring et al. 2001) further support that the Fundian Channel-Browns Bank AOI offers suitable habitat for regularly-occurring Sowerby's Beaked Whales.

## Small Odontocetes

### Atlantic White-sided Dolphin

Atlantic White-sided Dolphins were assessed as Not at Risk by COSEWIC in 1991 with no identified direct threats to species in Canada at present and are not listed under SARA.

Atlantic White-sided Dolphins are an abundant species found in cold temperate to sub-polar waters of the North Atlantic. In the western North Atlantic, their range extends from the waters off North Carolina to West Greenland, and potentially as far east as the mid-Atlantic ridge (Hayes et al. 2017). The best available population estimate for the western North Atlantic stock of Atlantic White-sided Dolphins is 48,819 (CV = 0.61) individuals from a 2011 survey (Hayes et al. 2017). Lawson and Gosselin (2009) provided an estimate of 4,289 individuals, combined from the Gulf of St. Lawrence and Scotian Shelf survey blocks of the 2007 TNASS.

Based on sighting, stranding and incidental take data, there are three possible stock units: Gulf of Maine, Gulf of St. Lawrence, and Labrador Sea (Hayes et al. 2017). The Gulf of Maine population most commonly occurs in continental shelf waters from Hudson Canyon to Georges Bank and in the Gulf of Maine and lower Bay of Fundy. The species displays seasonal shifts in distribution. From January to May they are found around Georges Bank down to the waters off New Hampshire, moving in greater numbers onto Georges Bank and into the lower Bay of Fundy between June and September; from October to December they return southward towards southern Georges Bank and the southern Gulf of Maine (Hayes et al. 2017). While widely distributed, Atlantic White-sided Dolphins are found primarily around continental shelf and slope waters and seem to be associated with high seabed relief along the shelf (Braulik 2019), as these areas may provide increased feeding opportunities (Selzer and Payne 1988). The species has also been associated with steep gradients in the Gully MPA (Gowans and Whitehead 1995).

Sightings of Atlantic White-sided dolphins in the Fundian Channel area were detected throughout all seasons of the year and habitat modeling results identified the area encompassed by the AOI as part of the recommended priority area for monitoring Atlantic White-sided Dolphins (Gomez et al. 2020). Furthermore, chlorophyll-a concentration was a significant contributor to these results for Atlantic White-sided Dolphins (Gomez et al. 2020) and high levels of chlorophyll-a and primary productivity are known to be present at the mouth of the Fundian Channel. Taken together, habitat modeling results, previous sightings, and local bathymetry previously associated with Atlantic White-sided dolphins suggest demonstrate the species' presence in the AOI.

### Harbour Porpoise

The Northwest Atlantic population of Harbour Porpoises historically suffered from major mortality as a result of incidental fisheries bycatch, especially in gillnets (COSEWIC 2006b). Bycatch has declined in areas where gillnet use is reduced, but was still deemed to be a source of mortality in certain areas at the time of the last COSEWIC status report in 2006 (COSEWIC 2006b). Although the population is abundant, the ongoing threat of bycatch and acoustic harassment devices contributed to a Special Concern designation in 2006 (COSEWIC 2006b). The population is not on Schedule 1 of SARA and instead was listed as Threatened on Schedule 2 in 2006 (COSEWIC 2006b). Based on data from surveys conducted by the NEFSC and DFO in 2016, the population residing in the Gulf of Maine/Bay of Fundy is estimated to be 95,543 individuals (CV = 0.31) (Hayes et al. 2020). Lawson and Gosselin (2009) estimated an abundance of 3,667 individuals, combined from the Gulf of St. Lawrence and Scotian Shelf survey blocks surveyed during the 2007 TNASS. The global population size of Harbour Porpoises is estimated at 700,000 individuals (Hammond et al. 2008b).

Harbour Porpoises occur in temperate to sub-polar continental shelf waters throughout the Northern Hemisphere (Hammond et al. 2008b). In the Northwest Atlantic, they range from Baffin Island down to the southeastern United States. The summer distribution of Harbour Porpoises in the Bay of Fundy and northern Gulf of Maine seems to be concentrated in waters less than 150 m depth and extends along the coasts of Maine, New Brunswick, and southwest Nova Scotia (Hayes et al. 2017). In the winter, porpoises in the Bay of Fundy disperse into the Gulf of Maine and along the eastern United States down to North Carolina, although some individuals may remain in the Bay of Fundy throughout the winter months (COSEWIC 2006b).

Sightings compiled in (Gomez et al. 2020) show many sightings of Harbour Porpoise near the Fundian Chanel in winter, summer and spring while habitat modeling identified the Bay of Fundy and eastern portion of Georges Bank, near the Fundian Channel, as part of the recommended priority areas for monitoring Harbour Porpoise (Gomez et al. 2020). Chlorophyll-a concentration was a significant contributor to the predicted habitat results for Harbour Porpoise (Gomez et al. 2020) and high levels of chlorophyll-a are known to be present at the mouth of the Fundian Channel. The AOI may therefore include some attractive environmental characteristics for this species.

### Short-beaked Common Dolphin

The Short-beaked Common Dolphin has been assessed as Not at Risk by COSEWIC and is not listed under SARA. The total number of Short-beaked Common Dolphins off the United States and Canadian east coasts is not known. The best estimate for the Western North Atlantic stock abundance is 172,825 animals (CV = 0.21) (Hayes et al. 2020). Lawson and Gosselin (2009) estimated 53,049 individuals, the highest abundance of any species sighted during the TNASS survey, combined from Gulf of St. Lawrence and Scotian Shelf survey blocks.

Short-beaked Common Dolphins are a seasonal visitor to the shelf off Nova Scotia and Newfoundland and an occasional visitor to other Canadian waters, with no significant threats identified by COSEWIC. This is a widely distributed oceanic species found in temperate, tropical and subtropical marine regions (Waring et al. 2007). In the western North Atlantic, they range from Newfoundland down to eastern Florida, although sightings are fewer south of Cape Hatteras. Short-beaked Common dolphins are known to move onto Georges Bank and the Scotian Shelf in mid-summer until fall, with large aggregations seen on Georges Bank; they also migrate further north to the continental shelf off Newfoundland when waters reach above 11˚C (Waring et al. 2007). In the North Atlantic, they tend to occur over the continental shelf along the 200–2,000 m isobaths (Waring et al. 2007). The species seems to have a preference for habitats that include upwelling-modified waters, areas with steep seafloor relief, and extensive shelf areas (Hammond et al. 2008a).

Sightings compiled in Gomez et al. (2020) show many sightings of Short-beaked Common Dolphins in the area of Fundian Channel in spring, summer and autumn and recommended priority areas for monitoring based on habitat modeling include much of the Scotian Shelf, encompassing the area occupied by the AOI (Gomez et al. 2020). Furthermore, these predicted areas for Short-beaked Common Dolphins were most influenced by chlorophyll-a concentration (Gomez et al. 2020) and high levels of chlorophyll-a are known to be present at the mouth of the Fundian Channel. It is possible that the AOI may therefore include some attractive environmental characteristics for this species.

## Large Odontocetes

### Cuvier's Beaked Whale

A pelagic species rarely found in Canadian waters with no identified significant threats, Cuvier's Beaked Whale was assessed as Not at Risk by COSEWIC in 1990. The species is not listed under SARA. The best abundance estimate for the Western North Atlantic is derived from previous shipboard and aerial surveys (Hayes et al. 2020), informed most recently by two 2016 surveys that covered areas between Central Florida and the mid-United States and between Massachusetts and Browns Bank (NEFSC/SEFSC 2018). The surveys together generated a total estimate of 5,744 (CV = 0.47) Cuvier's Beaked Whales, although this is number is believed to biased low (Hayes et al. 2019).

Cuvier's Beaked Whales are the most widely distributed species of beaked whale, found throughout the oceans of the world (MacLeod et al. 2005). Little is known about the species' stock structure, but genetic analyses have revealed distinctions between populations in the Mediterranean and the Eastern North Atlantic, suggesting that populations in the greater North Atlantic and the Mediterranean be considered separate, evolutionarily distinct units (Dalebout et al. 2005). Much of the early information on Cuvier's Beaked Whale distribution came from stranding events which have occurred throughout the species' known range (MacLeod et al. 2005). In the western North Atlantic, strandings have occurred mostly along the continental shelf edge off the eastern United States (Waring et al. 2014), and have occurred in waters ranging from the Eastern Caribbean (Bachara et al. 2019), the United States (Fertl et al. 1997), and Nova Scotia (CBC News 2016). Visual sightings have mainly occurred off the mid-Atlantic region of the eastern United States around the continental shelf edge and slope in late spring and summer (Waring et al. 2014). Passive acoustic monitoring has also revealed the presence of Cuvier’s beaked whale clicks along the continental shelf slope off the eastern United States and Canada, from waters off Florida up to the edge Georges Bank (Rafter et al. 2018) and further north to the Gully Marine Protected Area (Stanistreet et al. 2017).

Cuvier’s Beaked Whales appear to prefer deeper waters of more than 1000 m with medium to high bottom variability (Cañadas et al. 2018). High encounter rates have been recorded in waters between 1,400 to over 2,000 m depth (Moulins et al. 2007). The species shows clear associations with variable bottom habitats such as steep slopes, escarpments and submarine canyons (D'Amico et al. 2003, MacLeod 2005, Podestà et al. 2016). Habitat preferences are consistent with the notion that beaked whales exploit areas of upwelling and aggregation where prey species are likely highest (Cañadas et al. 2018). Cuvier’s Beaked Whales feed primarily on various species of squid (Santos et al. 2001), although fish may also be part of their diet (MacLeod 2005).

Based on known habitat preferences, the steep slope topography that characterizes deep regions of the AOI likely represents suitable habitat for Cuvier’s Beaked Whale. Previous shipboard and aerial surveys have reported sightings of Cuvier’s Beaked Whales at locations very close to and possibly within the boundaries of the AOI over multiple survey years (NEFSC/SEFSC 2013, 2016). Furthermore, passive acoustic monitoring conducted in 2018–2019 using a stationary recorder deployed in the AOI just north of the Fundian Channel revealed the year-round presence of Cuvier’s beaked whales in this area, indicating regular foraging activity in the deep waters of the AOI (J. Stanistreet, unpublished data). Taken together, previous sightings, results from PAM efforts and local bathymetry suggest the AOI is frequented regularly by Cuvier’s Beaked Whale and offers suitable habitat for the species.

### Long-finned Pilot Whale

Long-finned Pilot Whales were assessed as Not at Risk by COSEWIC in 1994 and are not listed under SARA. While there is no information on global abundance, a total of 16,058 Long-finned Pilot Whales was estimated for Canadian Atlantic waters based on the 2007 TNASS survey results, although this number is believed to be negatively biased (Minton et al. 2018). A more recent best available estimate of 39,215 (CV = 0.30). Long-finned Pilot Whales was made based on 2016 surveys that covered an area extending from Florida to Newfoundland, although there are some uncertainties associated with this estimate separation of Short-finned and Long-finned Pilot Whale identification (Hayes et al. 2020).

Pilot Whales (including both Long- and Short-finned) are wide ranging and occur in all the world’s oceans except for polar waters (Leatherwood and Dalheim 1978). The Long-finned Pilot whale occurs throughout the North Atlantic and the waters of the Southern Hemisphere (Minton et al. 2018). Two populations have been proposed for the North Atlantic based on sea surface temperature: 1) a cold-water population west of the Labrador/North Atlantic current, and a warmer-water population extending across the Atlantic following the Gulf Stream (Fullard et al. 2000). Morphological differences have also been suggested as evidence for distinguishing Long-finned Pilot Whales of the eastern and western parts of the North Atlantic (Bloch and

Lastein 1993). However, challenges in differentiating Long-finned Pilot Whales from Short-finned Pilot Whales make it difficult to distinguish the exact geographic ranges of the two species, as both occur in the waters of the western Atlantic (Hayes et al. 2019). Based on sightings reported by Leatherwood and Dalheim (1978), the Davis Strait seems to represent the northern limit of Long-finned Pilot Whale range, with the waters off North Carolina a potential southern boundary for their distribution.

Long-finned Pilot Whales occur primarily on shelf waters and along the continental shelf edge (Hamazaki 2002, Waring et al. 1992). In Canadian Maritime waters, Pilot Whale distribution coincides with aggregations of shortfin squid, their primary prey, which tend to occur over the continental shelf from the southeastern United States to Newfoundland through the summer and fall (Abend and Smith 1999). In mid-July, the species moves further inshore following the movement of squid. Frequent sightings have also been recorded off Cape Breton during the summer (Augusto et al. 2017, Ottensmeyer and Whitehead 2003).

Sightings compiled in Hayes et al. (2019) show a concentration of Long-finned Pilot Whales off southwestern Nova Scotia that overlaps with the AOI. Sightings compiled in Gomez et al. (2020) show numerous sightings in the AOI in spring and summer and near the AOI in winter and fall. Habitat modeling results identify most of the Scotian Shelf, including several submarine canyons, basins, and the area encompassed by the AOI as recommended priority areas for monitoring Long-finned Pilot Whales (Gomez et al. 2020). Furthermore, the oceanographic characteristics of the Fundian Channel-Browns Bank AOI may also act to provide attractive habitat to Long-finned Pilot Whales. Internal waves and high concentrations of chlorophyll-a have both been associated with the presence of Pilot Whales, the former by enabling the entrenchment of small fish and squid (Moore and Lien 2007) and the latter being a significant contributor to predicted areas for enhanced Long-finned Pilot Whale monitoring (Gomez et al. 2020). The occurrence of both of these features in the area of AOI, coupled with numerous sightings throughout the year, suggest that the AOI may provide habitat attractive to Long-finned Pilot Whales throughout the year.

### Sperm Whale

Despite being targets of the whaling era, Sperm Whale population worldwide remains reasonably large. Estimates suggest a global population size of 360,000 individuals, down from a pre-whaling size of 1,100,000 (Whitehead 2002). In Canada, Sperm Whales are found in both Pacific and Atlantic waters. While the species was hunted in Canada up until 1972, Sperm Whales were assessed as Not at Risk by COSEWIC in 1996 and are not listed under SARA. There is no population estimate available for the entire North Atlantic, however 2016 aerial and shipboard surveys of the 100-m depth contour and deeper, covering an area extending from Virginia to the lower Bay of Fundy, led to a best abundance estimate of 4,349 (CV = 0.28) for that area (Hayes et al. 2020).

Sperm Whales have vast geographic ranges and are found in nearly all ocean regions from the equator to high latitudes (Taylor et al. 2019). Worldwide, they display low genetic diversity, and previous studies suggest that the species has no genetically distinct stocks (Whitehead 2009). However, vocal clans and other common charactersitics among and between groups may create culturally distinct populations that may describe these populations better than genetics (Rendell and Whitehead 2003). Females and young males tend to inhabit waters deeper than

1,000 m at latitudes less than 40˚, particularly the productive waters along continental shelf edges (Whitehead 2009). Adult males additionally range to higher latitudes (Whitehead 2009).

In the Northwest Atlantic, males have been observed on the continental shelf along the entire east coast south of Hudson Strait, with a particular concentration in the northern part of the Gully on the Scotian Shelf that may be related to the high level of effort in this area (Reeves and Whitehead 1997). While they typically inhabit deep ocean regions along and beyond the continental shelf, in some areas, including off Nova Scotia, male Sperm Whales have been regularly sighted in waters less than 300 m depth (Whitehead 2009). Over relatively large spatial scales, Sperm Whale presence tends to coincide with areas of high underwater relief (Jaquet and Gendron 2002), steep topography (Jaquet and Whitehead 1996) and higher than normal levels of primary productivity as a result of upwelling (Jaquet and Gendron 2002, Whitehead 2009). As large squid are the main prey of Sperm Whales (Whitehead 2002), these associations may be related to peaks in squid abundance (Jaquet and Gendron 2002).

Sightings of Sperm Whales in the AOI compiled by Gomez et al. (2020) show sightings in the AOI in spring and summer and sightings near the AOI in fall and winter. Furthermore, much of the Scotian Shelf, including portions of the area encompassed by the AOI, were identified as recommended priority areas for monitoring Sperm Whales, with the greatest environmental predictor for these areas being ocean depth (Gomez et al. 2020). The known preference of Sperm Whales for deeper waters and shelf edges, coupled with previous sightings and habitat modeling results suggest that Sperm Whales may use the waters of the AOI.

## Baleen Whales

### Humpback Whale

Western North Atlantic Humpback Whales were assessed as Not at Risk by COSEWIC in 2003 and are not listed under SARA (COSEWIC 2003). While the species was reduced by whaling, COSEWIC lists a population estimate for the Northwest Atlantic population of about 4,000 whales and asserts that the population has regrown to at least a substantial proportion of its pre-whaling size (COSEWIC 2003). Multiple stocks in the western North Atlantic are recognized by the IWC, including the Gulf of Maine, Gulf of St. Lawrence, Newfoundland/Labrador, and western Greenland (Hayes et al. 2020). Based on models using previous sighting histories, the best abundance estimate for the Gulf of Maine Stock is 1,396 individuals (Hayes et al. 2020). The Canadian NAISS conducted between August-September 2016 generated an estimate of 1,854 (CV = 0.40) for an area encompassing the Bay of Fundy/Scotian Shelf/Gulf of St. Lawrence area (Hayes et al. 2020). As certain stocks of Humpback Whales elsewhere in the world have not yet been assessed, it is not possible to estimate global population relative to 1940 levels when the species was seriously depleted by whaling (Baird 2003).

Humpback Whales are found in all major ocean basins. They are known to be a highly migratory species, spending summers feeding in productive temperate and high-latitude waters and winters in low-latitude tropical waters used for calving and mating (Baird 2003). In Canada, Humpback Whales are found off both the Pacific and Atlantic coasts. In the western North Atlantic, their summer range extends from the Davis Strait to the Gulf of Maine. Main feeding grounds have been identified as the Gulf of Maine, Gulf of St. Lawrence and Newfoundland (Cooke 2018d). In winter the majority of whales migrate to calving and breeding areas in the West Indies (Cooke 2018d). However, some individuals may remain in high latitude feeding grounds well into the breeding season (Baird 2003). A peak in Humpback Whale song and nonsong calls has been described in the Gully canyon in December and January, with calls continuing sporadically in March followed by a decline in the summer and fall (Kowarski et al. 2018). These findings indicate that some individuals may not migrate south until very late in the season, may return from southern habitats early, or remain in northern latitudes throughout the winter before heading to summer feeding grounds (Kowarski et al. 2018). Acoustic presence of Humpback Whales over the winter has also been documented in Massachusetts Bay (Murray et al. 2014) and throughout the year on parts of the Scotian Shelf (Davis et al. 2020).

Humpback Whales have generally been classified as a largely coastal species. However, acoustic evidence indicates that some individuals use offshore areas when not known to be migrating (Baird 2003), and shows presence of Humpback Whales in offshore areas of the Grand Banks in winter (Delarue et al. 2018). Acoustic presence in the offshore Gully Marine Protected Area in winter as revealed by Kowarski et al. (2018) suggests that some individuals may make use of offshore areas in the winter months when inshore feeding grounds decline in productivity. Sightings compiled in Gomez et al. (2020) also show a great number of sightings in the offshore area throughout the year. Migratory movements of tagged whales show that some Humpback Whales migrate to eastern United States and Canadian waters from the West Indies by way of the Georges Bank shelf break (Kennedy et al. 2014).

In the Fundian Channel area, acoustic Humpback Whale presence appears to overlap with the AOI in spring, summer and fall with presence persisting nearby in winter (Davis et al. 2020). Humpback Whale presence in the AOI in spring and summer is also evidenced by sightings compiled in Gomez et al. (2020). Recommended priority areas for monitoring Humpback Whales include the Scotian Shelf, and the area encompassed by the AOI (Gomez et al. 2020). These predicted areas were most influenced by ocean depth and sea surface temperature, environmental variables that may be important for Humpback Whales for various reasons including prey distribution (Gomez et al. 2020). It is also worth noting that internal waves, important food coupling mechanisms in the Fundian Channel-Browns Bank AOI, can influence predator-prey interactions, and this has been shown to increase concentrations of plankton available for Humpback Whales in deep-channel habitat (Pineda et al. 2015). Humpback Whale occurrence in the AOI may therefore be driven by certain oceanographic features that create an attractive environment to the species. Humpback Whales may also use the area as part of their migratory corridor, as mentioned above.

### Minke Whale

Minke Whales in Canada were assessed as Not at Risk by COSEWIC in 2006 and are not listed under SARA. There are four recognized populations of Minke Whales in the North Atlantic including the Canadian East Coast Stock. While little information exists specifically on this population, it is considered to include whales inhabiting the western Davis Strait down to the Gulf of Mexico (Hayes et al. 2020). The best available estimate for the Canadian East Coast stock is from the 2016 NEFSC and DFO surveys which together produced an estimate of 24,202 (CV = 0.30) whales. Lawson and Gosselin produced a 2011 estimate of 20,741 (CV = 0.30) Minke Whales (Cooke 2018a). There is no current global population size estimate, although estimates for the majority of both the North Atlantic and North Pacific summer range is around 200,000 whales (Cooke 2018a).

Minke Whales are a cosmopolitan species, occurring in all oceans from tropical to temperate and high latitudes and occupying both coastal and offshore waters. The species makes strong seasonal movements both in coastal habitats and in deeper offshore waters (Waring et al. 2007), moving from low latitude breeding grounds in the winter to higher latitude feeding grounds in the summer (Risch et al. 2014). In spring and fall, Minke Whales are common on the shelf and off New England (Hayes et al. 2019) and are present in the Bay of Fundy between July and September, likely exploiting aggregations of prey (Ingram et al. 2007, Johnston et al. 2005). As Minke Whales head south in cooler months, acoustic data collected off Nova Scotia suggest their presence is related to prey availability, as the whales may take advantage of the peak in Herring spawning activity on their way back down to southern latitudes (Risch et al. 2014). During the winter, they are widespread in waters off the eastern United States and the Caribbean from the continental shelf edge to the Mid-Atlantic ridge (Risch et al. 2014). It is also likely that at least part of the North Atlantic population spends the winter in their summer range (Cooke 2018a).

Minke Whales appear to move close to the shelf break while migrating north in spring, possibly following the Gulf Stream. In contrast, they use deeper offshore waters when moving south in the fall (Risch et al. 2014). In the Bay of Fundy, encounters were reported to happen predominantly in waters greater than 60 m depth and sightings increased with increasing benthic slope, suggesting that Minke Whales favour deeper areas with steeper benthic topography (Ingram et al. 2007).

Sightings compiled in Gomez et al. (2020) show Minke Whale presence in the Fundian Channel in the summer and fall. Gomez et al. (2020) also identified much of the Scotian Shelf, including the area encompassed by the AOI as recommended priority areas for monitoring Minke Whales (Gomez et al. 2020). Similar to Humpback Whales, these predicted areas were most influenced by ocean depth and sea surface temperature, environmental variables that may be important for Minke Whales for various reasons including prey distribution (Gomez et al. 2020). Based on sightings, known preference for deeper waters and slope areas, and the influence of ocean depth on predicted areas for future monitoring, Minke Whale presence in the AOI may be driven by bathymetric and environmental features that are favoured by the species.

### Sei Whale

The Atlantic population of Sei Whales was assessed as Endangered by COSEWIC in 2019 and are currently not listed though are under consideration for addition to Schedule 1 of SARA as Endangered. The population was reduced by commercial whaling, and no recent abundance estimates are available for Sei Whales in the northwest Atlantic. The 2007 TNASS and 2011 NAISS surveys conducted off the Canadian east coast counted merely seven Sei Whales, suggesting that the population is composed of only a few hundred animals or fewer (COSEWIC 2019b). A “Nova Scotia stock” is recognized by the IWC and used as management unit for assessments performed by NOAA to include whales from the east coast of the U.S. to Cape Breton (Hayes et al. 2020). The best available population estimate for this stock is 6,292 (CV = 1.015). This larger estimate is based on multiple surveys conducted between 2010 and 2013 in a portion of the species’ range extending from Halifax to Florida (Hayes et al. 2020). This estimate is considered uncertain, however, because the full known range of the species was not surveyed. No reliable global population estimates exist (Cooke 2018b).

Sei Whales are a cosmopolitan species with a wide distribution, occurring mainly in deeper offshore waters (Cooke 2018b). They are thought to occur largely in pelagic habitats and in the Northwest Atlantic appear to be associated with the continental shelf edge (COSEWIC 2019b).

Sei Whales are migratory, moving between tropical and subtropical wintering areas to temperate and subpolar summer feeding grounds (Cooke 2018b, COSEWIC 2019b). Based on results from passive acoustic monitoring, Sei Whales are present in eastern Canadian waters throughout most of the year, with the majority of detections occurring between May and November (Delarue et al. 2018). Some seasonality in Sei Whale presence across the Scotian Shelf may occur, as peak call presence occurs in the summer months on the eastern shelf edge (Emery and Moors-Murphy 2017), while a fall peak in call presence has been documented on the western shelf (Sweeney 2017). Spring appears to be when the highest numbers of Sei Whales occur in U.S. waters (Hayes et al. 2019). Calls occur most frequently around Cape Cod in winter and spring (NEFSC/SEFSC 2018). Wintering grounds are not well known, but it has been hypothesized that Sei Whales migrate south to waters of the Gulf of Mexico (Prieto et al. 2012).

Habitat preference is likely driven by the presence of concentrations of prey, largely copepods (Baumann et al. 2016, COSEWIC 2019b, Skov et al. 2008). A previous study examining habitat drivers found that Sei Whale presence is influenced by seafloor aspect and surface and subsurface fronts, and that steep topography and strong flow gradients are important (Skov et al. 2008). The species may also have an affinity for submarine canyons (Prieto et al. 2012). Sei Whales are known to occur in the Gully and adjacent canyons of the ESS (Emery and Moors-Murphy 2017, Krieg 2016). Passive acoustic monitoring also suggests a preference for deep waters of the continental slope (Delarue et al. 2018).

Previous surveys have visually detected Sei Whales along the southern and eastern edge of Georges Bank, and the Fundian Channel (Hayes et al. 2017). Sightings presented in Gomez et al. (2020) show Sei Whale presence in the Fundian Channel in spring and nearby sightings in summer. Recommended priority areas for monitoring Sei Whales include the Scotian Shelf and the area encompassed by the AOI (Gomez et al. 2020). These predicted areas were most influenced by chlorophyll-a concentration (Gomez et al. 2020) and high levels of chlorophyll-a are known to be present at the mouth of the Fundian Channel Taken together, previous sightings, known habitat preferences, and predicted areas for future monitoring suggest Sei Whales may use the AOI and that local oceanographic characteristics may play a role in attracting Sei Whales to the area.

## Conclusion

The AOI encompasses habitats suitable to both feeding and migration for different cetacean species (Gomez et al. 2020). The continental shelf edge has been identified as an important foraging area for Blue Whale (Endangered – SARA), including a portion of the AOI (Lesage et al. 2018). The same oceanographic processes that support Blue Whale foraging are likely relevant for other large baleen whales including Fin Whales, Sei Whales, and North Atlantic Right Whales. It is possible that North Atlantic Right Whales use the area as a migratory route between habitats on the Scotian Shelf and the Bay of Fundy.

Sowerby’s Beaked Whale (Special Concern – COSEWIC) and Northern Bottlenose Whale (Endangered – SARA) are distributed along the Scotian Shelf slope near the Fundian Channel, and in submarine canyons on the ESS. These species are present within the AOI and their presence is supported by recent acoustic and visual detections from NOAA, DFO, and the Whitehead lab at Dalhousie University. The steep slope topography and deep depths of the AOI are characteristic of known preferred habitat types for deep-diving beaked whales that forage for deep-water prey. This same deep-water edge and slope habitat may also be suitable for deep-diving Sperm Whales. Long-finned Pilot Whales and Humpback Whales may also be attracted to the area due to prey-aggregating oceanographic processes such as internal waves, while migratory species such as Humpback Whales and Minke Whales may rely on the area as part of their seasonal migratory route.

Of particular conservation concern are SARA-listed species with small population sizes and for which threats from anthropogenic activities threaten recovery. Among the species for which information exists to support their regular use of the Fundian Channel-Brown's Bank AOI habitat, these include Blue Whales, Northern Bottlenose Whales, and Sowerby's Beaked Whales. Sounds (noise) generated by human activities such as hydrocarbon exploration, shipping, and military-exercises, are causing large-scale changes in the marine acoustic environment. Noise can have a broad variety of effects on marine mammals, sea turtles, fish, and zooplankton. Effects of noise on marine mammals can include loss of hearing sensitivity, deafness, behavioural changes, displacement, and induce stress responses. Further, noise from human activities can interfere with an individuals' ability to detect, recognize and discriminate sounds used for foraging, conspecific communications, navigation, and predator/hazard avoidance. While all cetaceans are sensitive to anthropogenic underwater noise, Sowerby's and Northern Bottlenose whales are vulnerable species that are particularly sensitive to noise resulting from human activities (McCarthy et al. 2011, Miller et al. 2015, Pirotta et al. 2012). Anthropogenic noise and food availability have been identified as the threats of most concern for Northwest Atlantic Blue Whales (DFO 2018b). Contaminants, vessel collisions, entanglement in fishing gear, toxic spills, and others are also known threats to this population (DFO 2018b). The at-risk status and known vulnerability of Northern Bottlenose Whales, Sowerby's Beaked Whales and Blue Whales necessitates enhanced protection; given the presence of suitable habitat for these three species in the AOI, they represent cetacean species of particular conservation priority in the AOI.

As additional data are collected and analyzed, the occurrence of other species near and within the AOI may become apparent. This is particularly true for PAM efforts which are ongoing in the AOI through the use of long-term moored PAM systems. Thus far, PAM efforts have indicated the regular occurrence of either True's (*Mesoplodon mirus*) Beaked Whale or Gervais' Beaked Whale (*Mesoplodon europaeus*) within the AOI (J. Stanistreet, DFO, pers. comm.). Little other information currently exists on the presence of these species off eastern Canada, and future results will help to inform understanding of beaked whales and other cetacean species that inhabit or visit the AOI.

Finally, there are some sources of data that were not considered in depth as part of this assessment. These include data from prey sampling and tagging. While the value of these data in predicting and describing cetacean occurrence is acknowledged, these types of data are not available for all species. In addition, information from other primary and secondary sources (namely, sighting records, habitat modeling results, PAM efforts, and dedicated survey results) was deemed sufficient for the scope and purpose of this assessment. In the future, as information from other data sources becomes available, it too will help to provide a more comprehensive understanding of cetacean use and occurrence in and around the AOI.

## SEA TURTLES

### Sources of Information

Since 2001, at-sea observer programs conducted by DFO have included the collection of information on the bycatch of sea turtles from commercial fishing trips in the Newfoundland, Quebec, Gulf, and Maritimes regions. Since 2005, DFO has implemented monitoring requirements so that encounters with species listed under SARA are recorded in specifically designed SARA logbooks. The Canadian Sea Turtle Network[3] (CSTN) maintains a sightings database that includes records of free-swimming, entangled, and stranded turtles in Atlantic Canada, and live-captured and released turtles from CSTN field research off the coast of Nova Scotia (1998–present). The DFO Cetaceans Sightings Database maintained by the Maritimes Region includes opportunistic sightings of sea turtles from aerial and at-sea cetacean surveys; dedicated research surveys by DFO and other institutions; whale-watching activities; at-sea fisheries observers, fisheries officers, consultants; and marine mammal observers on military and oil and gas platforms. Regional sea turtle sightings databases are also maintained by regional DFO Science staff in Newfoundland and Quebec regions.

### Leatherback Turtle

The Leatherback Turtle (*Dermochelys coracea*; Endangered – SARA) is the largest, marine turtle with measurements recorded up to 175 cm in length (curved carapace) and 640 kg, in the Canadian Atlantic (James et al. 2007). Leatherbacks feed on gelatinous prey such as salps, siphonophores, and medusae (sea jellies) that are seasonally abundant in the temperate shelf and slope waters off eastern Canada.

#### Geographic Range and Habitat Preferences

The Leatherback SeaTurtle is the most widely distributed reptile in the world. Genetics and tag-recapture data confirmed that Leatherbacks in Atlantic Canadian waters originate from the Northwestern Atlantic subpopulation (Goff et al. 1994, James et al. 2007, Stewart et al. 2013), which nest on tropical and subtropical beaches in the Caribbean, South and Central America, and Florida. Leatherback turtles can be found in relatively high densities in waters off Atlantic Canada, from June to October, and it is an important seasonal foraging habitat (Heaslip et al. 2012, Wallace et al. 2018).

Three primary areas of important habitat for Leatherback SeaTurtles in Atlantic Canada, which have been identified from the movements of 70 satellite-tagged Leatherback Sea Turtles, suggest a higher probability of residency in and near Georges Bank (including the Northeast Channel near the southwestern boundary of the Canadian EEZ), the southeastern area of the Gulf of St. Lawrence by eastern Cape Breton Island, and in waters south and east of the Burin Peninsula, Newfoundland (DFO 2012b). These areas were identified as important habitat for Leatherbacks because they support seasonal residency associated with foraging areas (DFO 2012b). A revised habitat use analysis, based on an enhanced sample size and longer term dataset was recently completed (DFO 2020b). This update revealed patterns of Leatherback Turtle spatial use similar to those identified previously, and will be reflected in the

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[3] Canadian Sea Turtle Network

upcoming amended Atlantic Leatherback Turtle Recovery Strategy, and in the proposal of Leatherback Turtle critical habitat for designation by the Minister of Fisheries and Oceans.

### Populations or Stock Definitions

The global population of Leatherback Turtles is comprised of seven subpopulations that vary in population size, geographic range, and population trends. These subpopulations define management units that are currently used for global conservation status assessments (Wallace et al. 2011, Wallace et al. 2010). The East Pacific Ocean and the Northwest Atlantic Ocean subpopulations have foraging ranges that overlap with waters on Canada's Pacific and Atlantic coasts, respectively. The Northwest Atlantic Ocean subpopulation nests from Florida, USA, throughout the Wider Caribbean region and the Guiana Shield of South America, and forages broadly at high latitudes in the northeastern and northwestern Atlantic, including the temperate waters of Atlantic Canada.

### Fisheries

Leatherback Turtles are incidentally entangled in a variety of fishing gears as bycatch, including gear used by fisheries in the AOI. The threat of highest concern in Atlantic Canadian waters is entanglement in lines associated with fixed fishing gear (Hamelin et al. 2017, James et al. 2005). Leatherbacks seem to be vulnerable to injury and mortality from entanglement in pelagic longlines, lines for pots and gillnets, buoy anchor lines, and other ropes and cables.

### Other Vulnerabilities

Other vulnerabilities that are currently undocumented but may affect Leatherbacks in Canadian waters include vessel collisions; marine debris (through the ingestion of plastics); and acoustic disturbances from anthropogenic sources (e.g., from fishing vessels, shipping, oil and gas exploration and production, and military detonations), which may cause increased surfacing (O'hara and Wilcox 1990) and displace sea turtles from foraging areas (Moein et al. 1994, O'hara and Wilcox 1990). Climate change may impact prey distribution in Canadian waters and impact reproductive success at nesting beaches. Poaching, coastal development, and artificial light are not known to be threats in Canadian waters.

### Status and Trends

#### *Stock Status*

An estimate of the number of Leatherbacks in specific foraging areas in the North Atlantic and their area of origin has not been proposed.

#### *Species at Risk Considerations*

The Leatherback Turtle is assessed as Endangered by COSEWIC and listed as such under SARA in Canada and the *Endangered Species Act* in the USA, as a result of global population declines. The Leatherback Turtle is also categorized as Vulnerable globally and Endangered for the Northwest Atlantic Ocean subpopulation by the International Union for Conservation of Nature (IUCN). It is globally protected under the Convention on International Trade in Endangered Species.

### Sources of Uncertainty

We are still gaining an understanding of seasonal habitat use and preference of Leatherback Turtles in Canadian waters. For animals that have been tagged, it seems that there is a relatively higher probability of residency in and near the Northeast Channel (DFO 2012b).

Varying the threshold used for relative probability of residency behaviour highlights similar important habitats, such as the Northeast Channel, although the extent of areas can change. Besides nesting animals, turtles have not been tagged prior to entry into Canadian waters in the late spring or early summer. Seasonality of tagging data may, therefore, result in the underestimation of habitat use for some areas. Site fidelity of individuals to broad foraging areas has been confirmed (James et al. 2005), suggesting predictability in location of prey concentrations between years.

## Loggerhead Turtle

### Geographic Range and Habitat Preferences

Loggerhead Sea Turtles (*Caretta caretta*; Endangered – SARA) in Atlantic Canada occur in offshore waters from Georges Bank to the Flemish Cap. The estimated range of Loggerheads in Atlantic Canadian waters extends from Georges Bank, along the edge of the Scotian Shelf and Grand Banks, to the limits of the EEZ, with occasional forays into waters on the shelf.

Loggerhead Sea Turtle habitat seems to be partially defined geographically and temporally by sea surface temperature. The species favors a distribution in thermally dynamic waters along the shelf break and offshore; they are encountered in waters greater than 15°C, especially between 20 and 25°C. The primary use of habitat in Atlantic Canadian waters is thought to be for foraging.

Most of their life is spent at sea; however, mature females return to land to nest. No nesting occurs within Canada. Although available data are limited, most Loggerheads in Atlantic Canadian waters are thought to be oceanic/neritic juveniles whose genetic origins are the nesting beaches in the Northwest Atlantic (Mike James, DFO, pers. comm.).

### Fisheries

The only documented source of human-induced harm or mortality of Loggerhead Sea Turtles in Canadian waters is the Canadian tuna and swordfish longline fishery. Potential mitigation measures and alternatives to minimize the threat posed by the tuna and swordfish longline fishery have been identified (e.g., hook type and size, set time, bait type). Further study is required to evaluate their effectiveness. In addition to minimizing threats to Loggerhead Sea Turtles in Canadian waters, international cooperation to reduce threats to the population as a whole is needed to achieve recovery of this species.

### Other Vulnerabilities

Other vulnerabilities that may affect Loggerheads in Canadian waters include vessel collisions, dredging activities, entanglement, and oil pollution.

### Status and Trends

#### *Stock Status*

There are currently no estimates of Loggerhead Sea Turtle abundance in Atlantic Canadian waters. A paucity of data precludes estimation of the overall Northwest Atlantic population abundance in oceanic habitat. However, because females exhibit nesting site fidelity, trends in nests can be used as a proxy for trends in mature female abundance. The total estimated number of nests on Northwest Atlantic nesting beaches has fluctuated between 47,000 and 90,000 nests per year over the last decade. There appears to have been a decline in the number of nests since 1998, notably in the largest breeding unit in the Atlantic (Peninsular Florida).

*Species at Risk Considerations*

The Loggerhead Sea Turtle is assessed as Endangered by COSEWIC and listed as such under SARA in Canada and the *Endangered Species Act* in the USA, as a result of global population declines. The IUCN lists Loggerheads as Vulnerable globally, with a decreasing population trend.

### Kemp's Ridley and Green Sea Turtles

Kemp's Ridley and Green Sea Turtles have been recorded by at-sea observers as incidental catch in Canadian Atlantic Swordfish and tuna pelagic longline fisheries. Such instances are very rare. Canadian Atlantic Pelagic longline fisheries interactions with Kemp's Ridley Turtles are believed to be rare, with fisheries observers recording four captures between 2000 and 2008. While Kemp's Ridley turtles are relatively distinct among hard shelled sea turtles, it's possible that turtles recorded as Green Sea Turtles by at-sea observers may be misidentified juvenile Loggerheads. Incidental capture records of Kemp's Ridley and Green Sea Turtles have not been confirmed with photographs, however, both species have been confirmed in Atlantic Canada (e.g., James et al. 2004), including waters in the vicinity of the AOI, from surveys, directed sampling, and/or stranding observations (Mike James, DFO, pers. comm.).

## MARINE BIRDS

The AOI components and surrounding waters (heretofore referred to as “the AOI area”) present strong evidence of important concentrations of several marine bird functional groups, occurring throughout the year and across decades. These include: shallow-diving pursuit generalists (shearwaters), surface-seizing plank-piscivores (phalaropes, storm-petrels), surface shallow-diving piscivores (large gulls, small gulls, and terns), pursuit-diving piscivores (alcids), pursuit-diving planktivores (Dovekie), and plunge-diving piscivores (Northern Gannet) (Table 9). Such concentrations are indicative of a diverse and productive prey base.

The boundary of the AOI overlaps with two of 32 EBSAs in the Maritimes Region (DFO 2014). These EBSAs were identified in part based on evidence of importance for marine birds and the prey base on which they depend.

### At-sea Surveys

Data derived from at-sea surveys were collected by expert observers hosted aboard ships-of-opportunity travelling over large geographic areas. These data are the result of the historic PIROP (Programme intégré de recherche sur les oiseaux pélagiques) active from 1965 to 1992, and the recent ECSAS (Eastern Canada Seabirds at-Sea) initiated in 2006 and ongoing. While some at-sea surveys targeted priority areas (e.g., DFO Atlantic Zonal Monitoring Program lines, RV Survey program, Sustainability Surveys for Fisheries), others were opportunistic in nature and addressed knowledge gaps (e.g., data collected during coral and sponge surveys). Additional data were collected during surveys focused on offshore oil and gas infrastructure monitoring and support, ecotourism, or simply transit of passengers and transportation of goods. These data provide critical information on the distribution of marine birds that, for example, have been instrumental for environmental assessments related to offshore development, emergency response related to oil spills, risk assessments, marine conservation planning, and other marine management and conservation initiatives. Collectively these data provide year-round and geographically comprehensive information on bird densities at sea within the Scotian Shelf bioregion, most notably in the offshore, using standardized protocols (Gjerdrum et al. 2012).

Though not treated in this contribution to the working paper, in addition to ongoing ship-based surveys, aerial surveys in the Bay of Fundy and Gulf of St. Lawrence have also been undertaken to overcome gaps and enhance coverage. Aerial survey data were not treated here as they are not presently available for the entire AOI area, or the AOI components within. In future, design of aerial survey geographical scope could be enhanced to cover the AOI area more comprehensively.

For the purpose of this review, an “important area” is defined where measures of species’ linear densities derived from at-sea surveys fall within the top decile class of counts (top 10%), as calculated for the entire Scotian Shelf bioregion, including the area outside the bioregion that is encompassed within the AOI buffer. This is consistent with the approach used to inform the design of the Network for the Scotian Shelf bioregion (DFO 2018c). An initial list of species and species groupings were derived from all available data (PIROP and ECSAS). To assess the persistence of an important area, the PIROP (1965–92) and ECSAS (2006–current) were assessed separately. A Kernel Density Estimation with a 10 km search radius and a 1 km cell resolution was used to highlight clusters of high counts, excluding values of “0”. Associated maps present decile classes (each class by definition containing an equal number of 1 km$^2$ cells for the bioregion), with the top decile class highlighted. Additionally all observations (data points) used to generate the Kernel Density layer were overlaid to convey survey effort. It should be noted that in addition to interannual and geographical differences, some seasonal differences in effort exist between the datasets. As such, there would be value in assessing monthly subsets of data to confirm certain inferences.

Although most species known to occur in significant numbers within the AOI area do so outside of their breeding season, some species shown to be relatively abundant are not known to breed in the Northern Hemisphere (e.g., Great Shearwater, Sooty Shearwater, and Wilson’s Storm-petrel). Neither historic PIROP nor recent ECSAS survey datasets distinguish between breeding and non-breeding birds observed at sea (although such information, where it can be obtained, is noted and stored in the database). However, timing of observations in relation to known species’ life histories, knowledge of colony locations, colony composition, and knowledge of foraging ranges, contribute to distinguish those species and individuals breeding in adjacent coastal areas from those occurring during non-breeding.

The Canadian Wildlife Service Colonial Waterbird database shows locations and size estimates of colonies of multiple breeding marine bird species. Knowledge of mean maximum foraging range for these species can help evaluate the relative value of the AOI for local breeding populations of certain species. Given an approximate distance of 75 km from the Northeastern Channel – Browns Bank AOI component of the AOI to the nearest breeding habitat, in addition to best available information on mean maximum foraging range (Table 10), only Leach’s Storm-petrel (*Oceanodroma leucorhoa*) has a foraging range (400-830 km) that would enable it to reach the AOI during the breeding season (Pollet et al. 2014), by individuals from large colonies on Kent and Bon Portage Islands (Hedd et al. 2018). Historically, Northern Gannet also could have accessed the AOI during breeding, as colonies of this species existed on nearby coastal islands. However, this species remains locally extirpated as a breeder.

## Species at Risk Considerations

### Roseate Tern (*Sterna dougallii*; SARA Endangered)

This species has occupied and continues to occupy colony locations along the coast of Nova Scotia (COSEWIC 2009c). Despite recent shifts in tern colony locations, emphasizing potential significance of previously unused sites for breeding, the AOI boundary remains well out of range for this species. Not only do adults of this species generally forage within a 20 km radius of breeding colonies or less (Thaxter et al. 2012), they also typically prefer to forage in shallow waters over sandy substrate adjacent to sandy shorelines (Rock et al. 2007). Nonetheless, migratory behaviour during non-breeding remains less well-known, a knowledge gap that could be addressed through deployment of tracking devices once appropriate technology for this species becomes available. Birds of this species nesting in Atlantic Canada could be expected to pass through the AOI area in order to reach known migratory staging areas at Cape Cod (Trull et al. 1999).

## International Union for the Conservation of Nature (IUCN) Red List species:

### Bermuda Petrel (*Pterodroma cahow*; IUCN Endangered; not assessed by COSEWIC)

The global population of Bermuda Petrel is assessed at slightly more than 200 mature individuals. Two recent confirmed sightings exist for this species within the vicinity of the AOI (eBird 2018), and additional sightings lacking photographic evidence also exist. Available tracking data also suggest the AOI was visited by multiple individuals during the course of multiple long-distance, multi-day breeding season foraging trips from Bermuda (exceeding 5,000 km, round-trip), as well as during the non-breeding period (Madeiros 2009). This illustrates the relative value of foraging resources in this portion of the Northwest Atlantic. This species feeds by seizing prey including squid and crustaceans, at or just beneath the surface.

### Black-capped Petrel (*Pterodroma hasitata*; IUCN Endangered; not assessed by COSEWIC)

The global population of this species is estimated at between 1,000 and 2,000 mature individuals. Two recent confirmed sightings have been reported for this species, one within the area surrounding the AOI (O'Connell et al. 2009), and the other specifically within the Northeastern Channel – Browns Bank AOI component (eBird 2018). This species is known to feed by seizing prey including squid, fish, and crustaceans at or just beneath the surface.

## Evidence of top decile concentrations within the AOI polygons and AOI buffer:

### Shearwaters (Shallow-pursuit generalists; Figure 93, Figure 94)

Though largely dominated by Great Shearwater and Sooty Shearwater, the shearwaters group also includes Cory’s Shearwater, Manx Shearwater (*Puffinus puffinus*), Audubon’s Shearwater (*Puffinus lherminieri*), and all individuals identified as shearwaters, but not identified to species. Shearwaters, as a group, present PIROP and ECSAS top-decile counts in the AOI area, and in the eastern, but not western, AOI component. These patterns suggest persistence within the AOI area, and Northeastern Channel – Browns Bank AOI component. Patterns are associated with bank and channel habitats, but PIROP top-decile counts appear more strongly associated with bank habitat than those during ECSAS, most notably along the northeastern portion of Georges Bank, perhaps resulting from lower historic effort within the AOI boundaries.

*Great Shearwater (Figure 95, Figure 96)*

Given that this is the most commonly observed shearwater species in the Scotian Shelf bioregion and within the AOI area, it accounts for much of the pattern observed for the shearwaters group. As a result, patterns generated using only Great Shearwater data include persistent top decile counts in the AOI area, and again within the eastern, but not western, AOI components. As per the overarching shearwaters group, patterns suggest use of waters over bank and channel habitats, with historic top decile counts appearing more strongly associated with bank habitat than with channel habitat, most notably along the northeastern portion of Georges Bank.

*Sooty Shearwater (Figure 97, Figure 98)*

Top decile counts for this species have occurred at many sites over the Scotian Shelf, although historic patterns appear relatively more concentrated within the AOI area than recent patterns, perhaps partly as a result of differences in effort. Although historic top decile counts were obtained for the AOI, recent top-decile patterns are associated only with the Georges Basin AOI component. These findings suggest persistence of use within the AOI area, and within Georges Basin, though evidence of persistence is not apparent within the Northeastern Channel – Browns Bank AOI component.

*Cory's Shearwater (Figure 99, Figure 100)*

Top decile counts of Cory's Shearwater within the AOI area were recorded during both PIROP and ECSAS. However, during PIROP, top-decile patterns were almost entirely limited to Georges Bank, with no occurrence of top-decile counts within the AOI. In contrast, recent ECSAS top-decile patterns are far more broadly spread out within the Scotian Shelf bioregion. More recent top-decile counts for Cory's Shearwater do occur within the AOI, perhaps more prominently in shallower waters over Browns Bank. Interestingly, top-decile patterns over Georges Bank during ECSAS are nowhere near as prominent as they were during PIROP. These findings are consistent with other broad scale assessment of changes to at-sea distribution of this species over time (Gjerdrum et al. 2018).

**Large gulls (Surface shallow-diving piscivores; Figure 101, Figure 102):**

Though largely dominated by Herring Gull and Great Black-backed Gull, the large gulls group also represents several other species, including Glaucous Gull (*Larus hyperboreus*), Iceland Gull (*Larus glaucoides*), Lesser Black-backed Gull (*Larus fuscus*), Thayer's Gull (*Larus thayeri*), as well as all individuals identified as large gulls, but not to species. As a group, both PIROP and ECSAS time spans present top-decile counts within the AOI, suggesting persistence in use over time at both scales. Top-decile patterns are associated with both shallow bank and deeper channel habitat areas, essentially as far out as the shelf break. More recent top-decile patterns are more clustered and appear more closely associated with Georges Bank than historic patterns. Note that gulls are known to be attracted by fishing activities. As such, patterns of distribution and relative abundance are expected to at least partly be the result of association with fishing activities.

*Herring Gull (Figure 103, Figure 104)*

Top-decile counts were obtained within the AOI during PIROP and ECSAS time spans, with important concentrations over Georges Bank during both. Though not the case during PIROP, most patches representing top-decile concentrations within the AOI area during ECSAS are well beyond the mean maximum foraging range for this species. As such, recent concentrations detected in the buffer area cannot be attributable to local breeding populations.

*Great Black-backed Gull (Figure 105, Figure 106)*

Top-decile counts of Great Black-backed Gull were obtained within the AOI during both PIROP and ECSAS. Patterns overlap in both shallow bank and deeper channel waters, though top-decile counts generally were limited to areas within the shelf break. More extensive top-decile count areas within the AOI area, especially during ECSAS, are largely beyond the mean maximum foraging range of the species and therefore cannot be attributed to local breeding populations.

**Storm-petrels (surface-seizing plank-piscivores; Figure 107, Figure 108):**

The storm-petrels group includes Leach's Storm-petrel and Wilson's Storm-petrel, also including individuals identified as storm-petrels, but not identified to species. Patterns associated with top-decile counts of storm-petrels as a group during PIROP, though appearing elsewhere on the Scotian Shelf, are concentrated within the AOI area, and within both eastern and western AOI polygons. Evidence of persistence exists through ECSAS at the scale of the AOI area, and at the scale of the eastern, but not western, AOI polygon. During ECSAS, but not PIROP, patterns in waters beyond the shelf break are apparent, likely as a result of increased effort.

*Leach's Storm-petrel (Figure 109, Figure 110)*

Top-decile patterns during PIROP are evident across the Scotian Shelf, including within the AOI area and within the AOI. These patterns persist through ECSAS, but only within the Northeastern Channel – Browns Bank AOI component.

*Wilson's Storm-petrel (Figure 111, Figure 112)*

During PIROP, top-decile patterns are concentrated within the western portion of the Scotian Shelf, and are encompassed within the AOI area as well as within both AOI polygons. During ECSAS, persistence within the AOI area remains evident, including within the Northeastern Channel – Browns Bank AOI component.

**Phalaropes (Surface-seizing plank-piscivores; Figure 113, Figure 114):**

The phalaropes group includes Red-necked Phalarope (*Phalaropus lobatus*) and Red Phalarope (*Phalaropus fulicarius*), also including individuals identified as phalaropes, but not identified to species. During PIROP, patterns associated with top-decile counts are almost entirely absent from the ESS and top-decile counts are evident at the scale of the AOI. During ECSAS, top-decile patterns persist within the AOI area, but only the channel and bank components of the AOI. Top-decile counts are somewhat more apparent over the ESS during ECSAS than during PIROP.

**Large alcids (Pursuit-diving piscivores; Figure 115, Figure 116):**

The large alcids group is exclusively composed of Thick-billed Murre, Common Murre (*Uria aalge*), Razorbill (*Alca torda*), and Atlantic Puffin (*Fratercula arctica*), also including all individuals identified as large alcids, but not identified to species.

During PIROP, top-decile patterns are largely limited to the AOI area, including portions within the Northeast Channel and Browns Bank components of the AOI. Persistence within the AOI area and eastern polygon is evident during ECSAS, with top-decile patterns during the latter extending far more broadly across the Scotian Shelf, possibly in part to differences in effort.

*Large alcids (on-water detections only; Figure 117, Figure 118):*

During PIROP, top-decile patterns are not evident within either the AOI and surrounding waters. In contrast, during ECSAS, top-decile patterns are evident within the AOI area and within the Northeastern Channel – Browns Bank AOI component.

*Thick-billed Murre (Figure 119, Figure 120)*

During PIROP, top-decile patterns are largely limited to the AOI area, including portions within the Northeastern Channel – Browns Bank AOI component. Persistence within the AOI area and eastern AOI polygon is evident through ECSAS, with top-decile patterns during the latter extending far more broadly across the Scotian Shelf.

**Black-legged Kittiwake (Surface shallow-diving piscivores; Figure 121, Figure 122):**

During PIROP, top-decile patterns are much more concentrated within the western portion of the Scotian Shelf, notably off western Nova Scotia and over Georges Bank and parts of the Gulf of Maine, including within the larger Northeastern Channel – Browns Bank AOI component. In contrast, during ECSAS, patterns are more concentrated within the eastern portion of the Scotian Shelf, though isolated patterns associated with top-decile counts remain apparent on NE Georges Bank, and suggest some persistence within the eastern AOI polygon. Patterns for this species during both PIROP and ECSAS are generally limited to shelf waters.

**Dovekie (Pursuit-diving planktivores; Figure 123, Figure 124):**

During PIROP, no top-decile patterns for Dovekie are associated with either of the AOI boundaries, though some important areas are apparent for limited portions of Georges and Browns Banks. During ECSAS, top-decile patterns occur within the AOI area, and within the Northeastern Channel – Browns Bank AOI component. Although top-decile patterns associated with this species during ECSAS are apparent in many parts of the shelf area, they are remarkably absent from Georges Bank. In general, though patterns within the AOI polygons appear more pronounced during ECSAS than PIROP, there appears to be evidence of a large scale shift in the distribution of this species from the western to the eastern portion of the Scotian Shelf (also see Black-legged Kittiwake).

**Northern Gannet (Plunge-diving piscivores; Figure 125, Figure 126):**

During PIROP, top-decile patterns for this species are included within the AOI and are relatively concentrated within the AOI area, over shallower bank and deeper channel waters. In contrast, during ECSAS, top-decile patterns occur only within the larger Northeastern Channel – Browns Bank AOI component. More generally, broader patterns appear concentrated mostly along coastlines, highlighting migratory corridors associated with behaviours associated with skirting headlands and terrestrial coastal features during migration. Persistence of use by this species is relatively less clear than it is for some other species.

**Skuas and jaegers (Surface shallow-diving piscivores; Figure 127, Figure 128):**

This group of species includes both South Polar Skua (*Stercorarius maccormicki*) and Great Skua (*Stercorarius skua*), as well as Parasitic Jaeger (*Stercorarius parasiticus*), Pomarine Jaeger (*Stercorarius pomarinus*), and Long-tailed Jaeger (*Stercorarius longicaudus*). It also includes all individuals attributed to this group, but not identified to species. During PIROP top-decile patterns appear more concentrated within the AOI area than elsewhere, and portions are included within the AOI boundaries. Though not as concentrated, patterns persist through ECSAS within the AOI area, including within the Northeastern Channel – Browns Bank AOI component.

**Terns (Surface shallow-diving piscivores; Figure 129, Figure 130):**

This group of species includes Common Tern (*Sterna hirundo*), Arctic Tern (*Sterna paradisaea*), and Roseate Tern (*Sterna dougallii*) (SARA – endangered). It also includes all individuals attributed to this group, but not identified to species. Top decile patterns for terns as a group are evident for the AOI area during both PIROP and ECSAS. However, no top decile patterns occur within the AOI boundaries during either time period. As such, there is some evidence of persistence, but only at the scale of the AOI area.

### Discussion

The AOI area is characterized by a variety of well-known enduring habitat features known to host significant seabird diversity. Specifically, offshore habitats of the AOI area and include offshore bank, as well as deep water channel and basin habitats. Although abundance and diversity of seabirds in the vicinity of the Northeastern Channel – Browns Bank AOI component is of inherent interest to conservation, their presence is reflective of an abundant and varied prey base. For example, the avifaunal community includes species that access prey on the surface, such as storm-petrels and phalaropes; those that can access waters to about 1 m, including gulls, terns, skuas and jaegers; plunge divers, such as Northern Gannet; shallow divers, such as shearwaters; and deep divers such as auks that can reach nearly 200 m in depth. As a group, their prey varies from phytoplankton and zooplankton, to larger crustaceans, squid, and fish. Seabirds have been shown to be useful indicators of biodiversity, ecosystem productivity, and ecosystem health.

## SPECIES AT RISK CONSIDERATIONS

A variety of marine fish, mammals, turtles, and birds that have been observed in the AOI are considered At Risk by COSEWIC and/or the Species At Risk Act (SARA) and the International Union for the Conservation of Nature (IUCN). Some of these species may be considered as conservation priorities depending on their prevalence, representative habitat, and relative occurrence within the AOI.

Atlantic Bluefin Tuna, Atlantic Cod, Cusk, Porbeagle Shark, Shortfin Mako, and Roundnose Grenadier are assessed as Endangered by COSEWIC, while Blue Whale, Leatherback Turtle, Loggerhead Turtle, North Atlantic Right Whale, Northern Bottlenose Whale, Roseate Tern, and White Shark are listed as Endangered under SARA.

American Plaice, Northern Wolffish, Acadian Redfish, Spotted Wolffish, and White Hake have been assessed as Threatened under COSEWIC.

Basking Shark, Harbour Porpoise, Killer Whale, Smooth Skate, Spiny Dogfish, and Thorny Skate have been assessed as Special Concern by COSEWIC. Atlantic Wolffish, Fin Whale, and Sowerby’s Beaked Whale have been assessed as Special Concern by COSEWIC as well as designated a species of Special Concern under SARA.

The Black-capped Petrel and the Bermuda Petrel have been assessed as Endangered by the IUCN, but have not been assessed by COSEWIC.

# TROPHIC LEVELS AND ECOSYSTEMS

## MIGRATION IN THE FUNDIAN CHANNEL – BROWNS BANK

### Overview

Many of the species discussed in this overview undergo seasonal or annual migration. Several species of groundfish and invertebrates undergo seasonal migrations to spawn or feed, whereas larger, primarily pelagic, fishes (e.g., billfish, tuna, and sharks), marine mammals, and sea turtles undergo annual migrations from breeding grounds to summer feeding areas. Bluefin Tuna, for example, spawn in the Gulf of Mexico or the Mediterranean Sea before migrating to the Northwest Atlantic to feed in the summer.

### Groundfish

American Plaice in NAFO divisions 4VWX5YZ, known as the Scotian Shelf and Georges Bank populations, represent the southern limit of this species' range, and biomass is relatively low in this area. In a review of different stocks of Plaice by Busby et al. (2007), it was shown that only the southern Gulf of St. Lawrence population undergoes seasonal spawning migrations, while those on the Scotian Shelf do not.

Several tagging studies on Yellowtail Flounder on Georges Bank have revealed that this species undergoes limited movements, though some individuals were recovered to the south in the winter (Lux 1963, Royce et al. 1959, Stone and Nelson 2003). This suggests Yellowtail Flounder in this region have limited dispersal, but a possible seasonal migration component (Stone and Nelson 2003).

In the Gulf of Maine Winter Flounder undergo seasonal migrations that are relatively localized. In a study conducted between 1960 and 1965, 12,151 Winter Flounder were tagged at 21 locations off Massachusetts. Movements north of Cape Cod were localized and confined to inshore waters, while individuals tagged south of Cape Cod underwent seasonal migrations to the southeast, likely pursuing warmer waters (Howe and Coates 1975). There was little mixing observed between inshore areas and Georges Bank adjacent the AOI (Howe and Coates 1975). In a more recent study, DeCelles and Cadrin (2010) tagged 72 adult Winter Flounder in the southern Gulf of Maine and tracked them between 2007 and 2009. Two groups of Winter Flounder were detected; those that remained in the coastal zone during spawning season (March to May) and those that were observed migrating to estuarine habitats to spawn. As noted by previous studies, the seasonal movements observed by these individuals were highly related to temperature (DeCelles and Cadrin 2010). Nye et al. (2009) used data collected from the NEFSC spring trawl survey over the past 40 years and observed a shift in the mean depth occupied by Winter Flounder into deeper waters, potentially reflecting a general shift from estuarine spawning to coastal spawning. Their study also revealed a significant poleward shift in the distribution of Winter Flounder, among other groundfish species analyzed (Nye et al. 2009).

Atlantic Cod undergo seasonal movements in Divisions 4X5Y, including those found within the AOI. Cod tagged in the Bay of Fundy were primarily recaptured within the bay in Fall, but were recaptured in the Gulf of Maine, or on Browns or Georges banks in the spring (Clark and Emberley 2009). Cod tagged within the AOI on Browns Bank have been recovered broadly across the Scotian Shelf and in the Bay of Fundy, indicating this bank is a mixing area for the two stock components of 4X5Y (Clark and Emberley 2009). Cod tagged on Browns Bank have moved south to Georges Bank, while Cod tagged on the eastern portion of Georges Bank have been recorded moving into the Bay of Fundy and Georges Basin (Clark and Emberley 2009, O'Brien and Worcester 2009). However, total mixing rates among these regions has not been quantified, as the results are influenced by fishing effort distribution and the timing of release and recapture (O'Brien and Worcester 2009). While Cod in different regions of Atlantic Canada undergo different migrations, ranging from tens to hundreds of kilometres, genetic evidence suggests that Cod across NAFO divisions represent separate populations on a scale of < 500 km (Bradbury et al. 2014, Ruzzante et al. 1998, Ruzzante et al. 2000) or even finer scales (Barney et al. 2017).

Haddock undergo seasonal movements, typically being found in shallower, colder water during the spring and moving to deeper water along the edge of the bank or in the Gulf of Maine during the summer and fall when the bank waters are warmer (Begg 1998, Begg and Weidman 2001). Tagging studies have shown that little mixing occurs between Haddock on Georges Bank and those in surrounding areas (e.g., 4X) and limited east to west movements on the bank (Van Eeckhaute et al. 1999). Georges Bank Haddock is considered a resident population, distinct from Haddock within the AOI on Browns Bank because of physical separation by the Fundian Channel (Begg 1998, Fowler 2011).

Juvenile Atlantic Halibut are known to migrate large distances. Individuals have been reported to migrate from Labrador to West Greenland (Godø and Haug 1988), and from the Gulf of St. Lawrence to Iceland (McCracken and Martin 1955). On the Scotian Shelf, juvenile Halibut tend to move east or northeast towards the offshore or Grand Banks (Stobo et al. 1988, Trzcinski et al. 2009). Tagging studies in the Gulf of Maine show no movements of Halibut into U.S. waters from Canada, though low fishing effort in the U.S. limits the likelihood of recapturing tagged individuals (Col and Legault 2009). Adults are more sedentary than juveniles, but may undergo seasonal migrations between feeding grounds and spawning grounds (Armsworthy et al. 2014, Godø and Haug 1988, Stobo et al. 1988). Some tagged adult females have been found within 20 km of their tagging location after multiple years. Overall connectivity of juvenile Halibut in Atlantic Canada is estimated to be less than 250 km, though an investigation of genetic population structure could provide more accurate estimates of gene flow among suspected populations (Boudreau et al. 2017). While Canadian Halibut are assessed as Not At Risk, American stocks are depleted. As such, it was deemed unlikely that any appreciable recruitment from outside Canadian waters is occurring, though this requires further investigation (COSEWIC 2011b). A study by Kersula and Seitz (2019) revealed that of more than 2,500 Halibut tagged in the Gulf of Maine between 2000 and 2017, 43% were recaptured by the Canadian Halibut fishery. At least one individual was captured directly within the current AOI boundaries, while others were captured in the vicinity on Browns Bank. Tagged Halibut moved from a few meters to a maximum of 1,564 km, with a median travel distance of 38 km (Kersula and Seitz 2019). This study highlights the range of migratory behaviours in Atlantic Halibut.

Migrations in skates varies significantly among species, with little movement in Smooth and Thorny skates, to long distance migrations in Winter Skate (Frisk 2010). Templeman (1984a) analyzed tagging data from 722 Thorny Skate off Newfoundland, with returns of 19% and 5% from those tagged in the inshore and offshore, respectively. Migrations were generally less than 111 km from the tagging locality up to 20 years after tagging, and of 97 returns with known recapture locations, 13% were recorded 185–445 km from the tagging sites after 0.2 to 11 years (Templeman 1984a). Both Smooth Skate and Thorny Skate do not undergo seasonal migrations in the Gulf of Maine and Georges Bank regions (Frisk 2010), west of the AOI. In contrast, some Winter Skate individuals that aggregate on Georges Bank in the fall undergo extensive southern migrations to North Carolina in the winter and spring, while other individuals do not undergo any annual migrations (Frisk 2010). Winter Skate also undergo inshore-offshore seasonal movements, and long distance migrations between Cape Hatteras and the Hudson Canyon and Georges Bank (430 and 940 km, respectively) have been observed (Frisk 2010).

## Pelagics

Most of the species of sharks occurring in Atlantic Canada, including Porbeagle, Shortfin Mako, White, and Basking shark are highly migratory species that visit Atlantic Canada in warm months. The White Shark Hilton[4] was recorded transiting over the Fundian Channel in July 2017 and the White Shark Savannah[5] was detected along the continental slope immediately adjacent to the AOI in November 2017 on her way south.

Bluefin Tuna are a highly migratory species that are present in Atlantic Canada from June through November. Bluefin Tuna forage in New England and Canadian waters from June to November before migrating south to spawn in the warm waters of the Gulf of Mexico (Lutcavage et al. 1999). However, they are also known to make trans-Atlantic migrations and spawn in the Mediterranean Sea (Block et al. 2001). As Bluefin Tuna are seasonal visitors to the Northwest Atlantic, protection of both of these spawning regions could help protect this migratory species. However, because Bluefin Tuna can move across the Atlantic from the west to east and back again within a single year, they are vulnerable to fishing mortality from a number of Atlantic tuna fisheries (Block et al. 2001).

### Basking Shark

Basking Sharks (*Cetorhinus maximus*) frequent the Bay of Fundy between May and October (Figure 131). Preliminary tagging work conducted by the Grand Manan Whale and Seabird Research Station (Andrew Westgate unpublished data) revealed migration patterns of the species in the vicinity of the AOI. In this survey 12 individual Basking Sharks were tagged using Pop-up Satellite Tags during a 3 year period (August-September 2011, 2012, and 2015). Migration analyses were conducted using position estimates based on paired light, temperature, and depth data from the PSATs over the course of each deployment. Results from these analyses suggest that 9 of the 12 tagged individuals swam through the Fundian Channel as they headed for the shelf break (Figure 132). Three sharks that had longer deployments were also tracked through this region as they returned to the Bay of Fundy the following May (Figure 133). Although this is a small sample size, these data revealed the Fundian Channel to be a migration pathway for individuals of this species that enter and exit the Bay of Fundy. Since all twelve tagged Basking Sharks moved off the continental shelf after exiting the Bay of Fundy and Gulf of Maine it is not surprising that the majority swan through the AOI as it lies directly in their path.

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[4] White Shark Hilton

[5] White Shark Savannah

### Commercially Harvested Invertebrates

Historically off southern Nova Scotia, Lobster have shown seasonal migrations, moving offshore in the winter and towards the coast in the spring and summer (Campbell and Robinson 1983, Cooper and Uzmann 1971, Pezzack and Duggan 1986). Stasko and Graham (1976) tagged 4,260 lobsters in the summer of 1975 off Southwestern Nova Scotia, with a return rate of approximately 1% (49 lobsters) over a 3-year period. Of the lobsters returned, a majority showed a migration from inshore to offshore waters including Browns Bank within the AOI. This ontogenetic migration of large, mostly ovigerous female lobsters to shallower and warmer bank habitat from the inshore (e.g., Browns and Georges banks) to spawn was thought to potentially be a behavioural mechanism to place hatched larvae into more suitable developmental conditions (Campbell 1986). Indeed, recent trap studies have documented sex ratios and size distributions that suggest a bias towards large bodied female lobsters (Cook et al. 2017). With a lack of recent tagging studies, it remains unknown whether this migratory behaviour persists off southwestern Nova Scotia (Cook et al. 2017).

Northern Shrimp in the Gulf of Maine and WSS undergo seasonal spawning migrations to avoid warming deep warm. In the fall, deep waters become too warm so the shrimp move inshore to spawn and release their larvae; they then move back to cold, deep waters in the spring (Hardie et al. 2018).

Squid are also migratory invertebrates off southern Nova Scotia. Shortfin Squid are a migratory species (Dawe et al. 1981) that spawn in winter offshore of Cape Hatteras; their eggs are neutrally buoyant below the surface, and newly hatched larvae swim to the surface and are transported by the Gulf Stream (Dawe et al. 2007). An individual Shortfin Squid tagged at Twillingate, Newfoundland, was recovered off the coast of Maryland, representing a migration of at least 2,000 km in 107 days (Dawe et al. 1981). It is likely that both species of squid migrate through the AOI, but specific data for this were not available.

Seasonal or annual migrations of other mobile invertebrates, such as crabs, remain unknown in this region. In general, there is a lack of information on invertebrate dispersal and migration patterns in the vicinity of the AOI. Future work could examine movements of mobile invertebrates such as decapods and cephalopods within and around the AOI, quantifying seasonal or annual migration patterns and variations in biomass.

## LONG-TERM CHANGES AND CLIMATE CHANGE CONSIDERATIONS

Bottom and surface temperatures have been warming on the Scotian Shelf and Gulf of Maine, with a record warm year in 2012. The AZMP report for 2016 notes above normal winter sea surface and bottom temperatures on the Scotian Shelf and Bay of Fundy (DFO 2017g), and in April 2018 water column temperatures in the Northeast Channel reached a record-breaking 14°C (D. Hebert, DFO, pers. comm.). In August 2018, the average sea surface temperature for the Gulf of Maine was 20.52°C, a record temperature second only to the 2012 warm year. These anomalies originate from the interaction between the Gulf Stream and Labrador Current, which then penetrate onto the Scotian Shelf and into the Gulf of Maine through deep channels along the shelf-break (Brickman et al. 2018). This climate warming in the Northwest Atlantic has been attributed to the simultaneous collapse of Lobster stocks in southern New England and record-breaking landings in the Gulf of Maine (Le Bris et al. 2018). Warming waters have been associated with decreased juvenile habitat (Wahle et al. 2015) and increased prevalence of shell disease (Glenn and Pugh 2006) in Lobster in the southern extreme of their range, but increased habitat availability in the north (Stanley et al. 2018, Steneck and Wahle 2013). This ocean warming may also lead to an overall regime shift in the Gulf of Maine and WSS, including the AOI, with more southern species moving into the area (as described in section 3.5.2) and the possible extirpation of colder-water preferring species.

Associated with this warming temperature is an observed shift in the zooplankton community. The large copepod *C. finmarchicus* and other dominant *Pseudocalanus* species are in lower abundance on the Scotian Shelf, including Browns Bank, starting in 2010 following warming temperatures, and are being replaced by smaller, warm-water associated copepods and larvae of benthic invertebrates (DFO 2017g). This shift in the zooplankton community has direct consequences for animals that depend on large-bodied copepods, such as larval fishes and Right Whales, and as such requires continued monitoring. While the zooplankton community has shifted, chlorophyll concentration in the Gulf of Maine has been declining in association with warming temperatures since 2011, and phytoplankton blooms are becoming shorter but more frequent, as opposed to the more regular spring and fall blooms (NOAA 2018).

Deep-water corals in the North Atlantic are susceptible to destruction by bottom-contact fishing, and the effects of climate change. The cumulative impacts of human stressors and climate change on these systems will likely lead to their loss, which may alter the state of deep-water ecosystems altogether (Levin and Le Bris 2015). Both warming temperatures and increased acidification as a result of climate change will negatively impact deep-water corals. Their three-dimensional structure requires aragonite or calcite to grow, and as the pH of the ocean declines, concentrations of aragonite subsequently decline (Gledhill et al. 2015, Levin and Le Bris 2015). The resilience of these systems to change remains unknown. Deep-water corals are long-lived with relatively low fecundity, and individuals may not be replaced if they are lost. Connectivity with other deep-water corals could potentially allow immigration rescue in the AOI, but this will require further study of deep-water coral larval dispersal and genetic analysis.

Pershing et al. (2015) note that sea surface temperatures in the Gulf of Maine have warmed faster than 99% of the global ocean. This warming is related to a northward shift in the Gulf Stream and shifts in the Atlantic Multidecadal Oscillation that have led to reduced recruitment and increased mortality in Atlantic Cod in this region. Despite a 73% cut in quota in 2013 for Cod in the Gulf of Maine, spawning stock biomass has continued to decline. Increasing temperatures have likely contributed to this trend, though the exact mechanism is unknown. Declines in the abundance of zooplankton that are important prey for larval Cod have also been noted in this region (Friedland et al. 2013). Additionally, the increased prevalence of juvenile Cod in deeper waters, potentially to escape warming in shallower water, may increase the risk of predation (Linehan et al. 2001). Brander (2018) suggests that climate change is not a primary cause of the continued decline of Cod in the Gulf of Maine, instead attributing fishing pressure(s) as the primary determinant, noting that Cod stocks have increased in the North Sea, which has undergone a similar climate shift to the Gulf of Maine. Pershing et al. (2015) model that rebuilding the Cod stock in the Gulf of Maine under different temperature scenarios could be achievable by 2025 in the absence of any fishing mortality; however, including even small amounts of fishing mortality delays rebuilding the stock by at least three to eight years.

Zwanenburg (2000) shows that since the 1970s, the average individual weight of commercial demersal fish has decreased by 41% on the WSS and 51% on the ESS. There have been long-term declines in the proportion of large individual fish following a doubling in fishing effort and increases in bottom temperature in the WSS. Zwanenburg (2000) concludes that both fishing and changes in bottom temperature have led to these decreases in demersal fish size, but the relative effects of each cannot be determined. Zwanenburg et al. (2002) examine the decadal changes across the Scotian Shelf and report declines in trawlable demersal fish biomass of up to 80% on the ESS, but lower declines in the WSS owing to increased biomass of Spiny Dogfish since the 1980s. The average size of demersal fish on the WSS declined by 70% between 1983 and 1995 following a period of stability in the 1970s. Zwanenburg et al. (2002) conclude that increased fishing effort from 1977 to the 1990s took place at a time of changing environmental conditions, especially bottom temperatures. These changes have significantly altered fish and invertebrate communities, with changes in biomass and size structure, community composition, and distributions. The relative roles of changing environmental conditions and increased fishing pressure on these ecosystem changes cannot be disentangled based on the available data, and further investigations are required (Zwanenburg et al. 2002).

Frank et al. (2005) suggested a trophic cascade was responsible for the lack of recovery in Atlantic Cod on the Scotian Shelf. A loss of large predatory groundfish, including Cod, Haddock, hake, skates, and others, may have led to an increase in smaller, planktivorous forage fish and macroinvertebrates which were the preferred prey of these groundfish. These forage fish and invertebrates then competed with or preyed upon the larval and juvenile stages of large groundfish. The impacts of Grey Seal on remaining Cod during this trophic cascade were thought to be minimal (Frank et al. 2005). Using updated data, Frank et al. (2011) suggest the Scotian Shelf ecosystem is slowly returning towards a groundfish-dominated system due to the collapse of pelagic forage fish, with increases in the biomass of Cod, Redfish, and Haddock to levels similar to those of the early 1990s. Similarly, Pedersen et al. (2017) found that the Newfoundland Shelves demonstrated a similar, albeit slower than expected, shift to taxonomic and functional composition of groundfish communities similar to those observed before declines in the 1990s. With the decline in forage fish biomass, large-bodied zooplankton have increased, providing prey for the early life stages of benthic and demersal fishes (Frank et al. 2011). However, it remains to be seen if these trophic cascades are the primary causes driving the slower than expected recovery in groundfish in the northwest Atlantic, and whether this reversal to a groundfish-dominated ecosystem is truly occurring.

Stortini et al. (2015) assessed the vulnerability of 33 fish and invertebrate species to projected warming on the Scotian Shelf under mild (+0.7°C) and severe (+3.0°C) scenarios. Stortini et al. (2015) follow the IPCC’s definition of vulnerability as the degree to which a system is susceptible to adverse effects of climate change, or is unable to cope with these adverse effects. Populations of fish in the southwest portion of the Scotian Shelf were found to be more vulnerable than those in the northeast, and that 45% of populations examined in the study may be vulnerable under the severe warming scenario. One species, the Moustache Sculpin (*Triglops murrayi*), was the only species with a relatively high vulnerability score under the mild warming scenario. Under the severe warming scenario, 18 species or populations, including WSS Cusk, Smooth Skate, Winter Skate, Little Skate, WSS Pollock, WSS Cod, and Atlantic Wolffish, are considered vulnerable.

Stanley et al. (2018) report on the genetic structure of five species of commercially or ecologically important species in the northwest Atlantic, including Atlantic Cod, American Lobster, Atlantic Sea Scallop, Northern Shrimp, and the invasive European green crab. The authors modeled genetic population coefficients with latitude and noted a genetic cline (break) occurring near Halifax, Nova Scotia. Populations south of this break were part of the southern ecotype, while populations north of Halifax were considered the northern ecotype. This population structure was strongly correlated with ocean bottom and surface temperatures (Stanley et al. 2018). Using habitat suitability models tuned this synoptic genetic structure, the authors they predict a 225 km northward shift in the delineation of this genetic break by 2075 under a climate change model based on Restriction Concentration Pathway 8.5 (Brickman et al. 2016). Changes in the southern part of the range, which encompasses the AOI, appear to be most pronounced for Atlantic Cod agreeing with observations and predictions for the Gulf of Maine (Pershing et al. 2015). Overall, Stanley et al. (2018) demonstrate that warming associated with climate change can influence not only the distribution of species but the spatial distribution of their respective genetic structure, which in turn could influence connectivity-recruitment in the southern portion of the bioregion.

Overall, climate change will likely have myriad impacts on the Gulf of Maine and Scotian Shelf, including changes in community structure, shifting distribution of a variety of taxa, the introduction of non-indigenous species, and impacts on animal physiology as a result of warming temperatures and ocean acidification. The direct impacts of climate change on the proposed conservation priorities cannot be directly demonstrated, though the threat of climate change should be included in monitoring plans should the AOI become an MPA.

## KNOWLEDGE GAPS

The information summarized in the ecological overview of the AOI was based on data from the DFO Multispecies Summer RV Survey, Atlantic Zone Monitoring Program (AZMP), DFO-Industry Halibut Longline Survey, Continuous Plankton Recorder, NOAA seasonal surveys, DFO’s Whale Sightings Database, fisheries-dependent landings and CPUE data for tunas and Swordfish, tagging data (unpublished), and academic research, providing a comprehensive understanding of the communities within the AOI.

Data documenting the full distribution of corals and sponges within the AOI, knowledge of the infaunal community composition, and population genetic information for most fish and invertebrate populations are not currently available. While this information could assist boundary delimitation and zoning within a potential MPA, its absence does not preclude the development of conservation priorities.

The Summer RV Survey provided the majority of the groundfish and invertebrate diversity information used in this ecological overview. Therefore, seasonal migrations, variations in abundance, and changes in groundfish and invertebrate community composition within the AOI remain largely unknown.

Observations of faunal composition in deep water slope habitat are limited to adjacent strata in the Summer RV Survey. There have been no Summer RV Survey sets conducted deeper than 400 m within the AOI. The community composition of these deep water sets adjacent to the AOI are summarized in Clark and Emberley (2011).

Finally, the movements and seasonal distributions of large pelagic fishes, sharks, cetaceans, and sea turtles in the vicinity of the AOI remain largely uncharacterized. Many species occur in the summer months and are presumed to be feeding based on the productivity and oceanographic features of the AOI; however, no direct observations of feeding in association with the features of the AOI have been recorded.

## SOURCES OF UNCERTAINITY

Key data uncertainties include species catchability for specific survey gears, use of opportunistic sightings in the absence of systematic surveys for some species, and limited seasonal or temporal coverage of surveys and sampling.

Most of the sightings of cetaceans for this area are opportunistic in nature. Therefore, we expect the data used for cetacean sightings reflect presence of species at specific time periods. Data do not reflect abundances or diversity of cetacean species in the area.

The trawl gear used in the DFO Summer RV survey has known catchability issues (Harley et al. 2001) for some pelagic and benthic fish species that burrow or hide in crevices, including Cusk, Atlantic Wolffish, and Atlantic Halibut. For these fishes, the Industry-DFO Longline Halibut Survey was used to supplement patterns of distribution, which includes other catchability issues (e.g., bait; Cox et al. 2018).

Some data collections, like tagging and passive acoustics, have a shorter time series on which to characterize the usage of the AOI as habitat. Approaches to integrating these data sources with traditional sampling methods are under development.

## CLIMATE CHANGE CONSIDERATIONS

There is some uncertainty about how key biological and physical attributes of the AOI have been responding, or will respond, to the impacts of a changing marine climate. Specifically, we acknowledge the uncertainty regarding the impacts of:

- the observed shift in zooplankton communities within and in the vicinity of the AOI on productivity and distribution of predators, and overall use of the area by pelagic species;
- ocean acidification and warming on corals and sponges, which are noted as conservation priorities;
- climate change and associated warming temperatures on the distribution, biomass, and resilience of groundfish and invertebrate communities within the AOI; and
- changing fish and invertebrate community composition associated with the increased prevalence of warm-water species and loss of habitat for some colder adapted species, especially in the WSS.

## CONSERVATION PRIORITIES

Potential conservation priorities for the AOI were identified prior to the CSAS Science Peer-Review process by the Oceans Management Program. These conservation priorities were assessed through this CSAS review and were either recommended to be retained, modified, or rejected based on the strength of available scientific evidence. Features were assessed against the Ecologically and Biologically Significant Area (EBSA) criteria of aggregation, uniqueness, and fitness consequences (DFO 2004), or the species-based vulnerability, conservation status, and Ecologically Significant Species criteria.

While consensus was reached on the majority of proposed conservation priorities, based on whether sufficient evidence existed for their inclusion, a minority view was expressed on the inclusion of persistent juvenile Atlantic Halibut as a conservation priority. This conservation priority was proposed based on analysis that indicates there has been a hotspot for juvenile

Halibut on southern Browns Bank that has persisted over the past three decades. While there was agreement that this hotspot is a feature of the AOI, that it is persistent, and that the hotspot is currently expanding, a minority view was presented that the mature Halibut stock is currently healthy and existing management measures prevent/reduce juvenile Halibut fishing mortality, and, therefore, this feature should not be considered as a conservation priority for the AOI.

Additionally, the following features were discussed but not supported as Conservation Priorities for the AOI based on the information that was available for review:

- Habitat for Smooth Skate: Did not meet decline or aggregation criteria.
- Habitat for redfish: Did not meet decline or aggregation criteria.
- Habitat for Spiny Dogfish: Did not meet aggregation criteria and stock status was uncertain (did not meet decline criteria).
- Habitat for Roundnose Grenadier: Did not meet aggregation criteria.
- Benthic invertebrate diversity hotspots: Not supported as a conservation priority on its own, but is captured under the conservation priority related to the diverse representation of habitats types.
- Fish diversity hotspots: Not supported as a conservation priority on its own, but captured under the conservation priority related to the diverse representation of habitats types.
- Migratory habitat between southern and temperate waters and on/off shelf movements: Considered a feature of the AOI but did not meet aggregation criteria.
- Significant concentrations of sea pens: Did not meet aggregation criteria, but would be expected to receive ancillary benefit.
- Feeding area for sea turtles: Did not meet aggregation criteria.

Should adjustments to the AOI boundary be made, new information becomes available, or shifts in distribution occur, these could be reassessed as conservation priorities through a review process.

The following features (Table 1) were supported as conservation priorities by the majority of participants, based on the information that was available for review:

**Habitat**

- Diverse representation of habitat types, including basin, bank, deep water slope and channel habitats, and their associated fish and invertebrate communities
- Persistent habitat for juvenile Atlantic Halibut
- Concentrations of large mature female lobster
- Suitable habitat for Sowerby’s Beaked Whale and Northern Bottlenose Whale

**Biodiversity**

- Deep-water corals

- Significant concentrations of sponges
- Representative habitat for Atlantic Cod, Atlantic Wolffish, Winter Skate, Thorny Skate, and White Hake
- Highly suitable habitat for Cusk

**Productivity**

- The collection of oceanographic features, such as internal waves, areas of upwelling, and occasional presence of Gulf current and warm-core rings, at the mouth of the Fundian Channel that make it a highly productive area that is associated with the presence of large pelagic fishes, sea turtles, and cetaceans
- Blue Whale foraging area
- Foraging ground for most functional guilds of marine birds, particularly Leach’s Storm Petrel (*Oceanodroma leucorhoa*)

# SUMMARY

The Fundian Channel-Browns Bank is an offshore AOI identified, in part, through an MPA network design analysis for the Scotian Shelf Bioregion that considered available ecological and economic information in consultation with other government agencies, First Nations and Indigenous groups, and key stakeholders. This area includes portions of the continental slope, Browns Bank, Georges Basin, the Fundian Channel, and Northeast Channel, and spans several existing fisheries closures, including LFA 40 (a lobster closure), the Northeast Channel Coral Conservation Area, and a seasonal groundfish spawning closure.

Circulation in this region is driven largely by the Labrador Current traveling south along the Scotian Shelf, delivering cold, lower salinity water into the Gulf of Maine and Bay of Fundy region. The Fundian Channel acts as the primary connection between the Gulf of Maine and the Atlantic Ocean, allowing nutrient exchange between these two water bodies. Strong currents and tidal flushing provide nutrients for benthic invertebrates that filter feed and provide biogenic habitat for fishes and other invertebrates, including corals, sponges, and sea pens. The combination of dynamic and persistent oceanographic features lead to high productivity that may provide foraging grounds for large pelagic animals (including fishes and mammals), in addition to a diversity of seabird functional groups.

Phytoplankton and zooplankton communities in the AOI are similar to those on the Scotian Shelf and within the Gulf of Maine. Phytoplankton blooms provide food for zooplankton, including larval fish, jellyfish, copepods, krill, amphipods, and chaetognaths. These zooplankton in turn provide prey for pelagic fishes, marine birds, sea turtles, cetaceans, and sea birds. Recent shifts in the zooplankton communities in the Gulf of Maine and Scotian Shelf are attributed to warming temperatures, displacing large-bodied calanoid copepods with subtropical and offshore species.

The benthic invertebrate community overall is diverse with the AOI encompassing a wide variety of depths and substrate types. These species include important Atlantic Sea Scallop habitat, dense sponge beds, sand dollars, hydroids, brachiopods, tunicates and other infauna and epifauna. In the Fundian Channel and into Georges Basin, arthropods, echinoderms and sea pens are widespread, but may be sparse. Towards the continental slope, one of the largest concentrations of large gorgonian corals in the Maritimes Region exists, as well as records of the Russian Hat sponge which coexist with these corals. Small gorgonian corals are also present in this portion of the AOI. Evidence suggests that some of these corals are hundreds of years old. Corals, sea pens, and sponges provide biogenic habitat to other invertebrates and fishes, including Redfish, Atlantic Cod, and Cusk. Invertebrate fisheries within, and in the vicinity of, the AOI primarily focus on American Lobster and Atlantic Sea Scallop.

The pelagic and benthic/demersal fish communities are diverse and some species are particularly abundant in the region of the AOI relative to the rest of the Scotian Shelf. The AOI seems to be particularly important for Atlantic Halibut, being identified as one of two persistent juvenile hotspots. The demersal fish community includes several depleted species, including Atlantic Cod, White Hake, Redfish, Cusk, American Plaice, Atlantic Wolffish, and Smooth and Thorny skate. Other important groundfish to this area include Haddock, Pollock, Yellowtail Flounder, and other skates and flatfish. The deep portions of the AOI represent highly suitable Cusk habitat, and protection of this habitat could contribute to their recovery. Atlantic Cod have continued to decline in the WSS despite declines in bycatch rates, and it is unknown if protection of habitat within the AOI would aid in the recovery of this species. Forage fish,

including Atlantic Mackerel and Atlantic Herring may feed or migrate through the AOI to reach their spawning grounds. These species provide prey for tunas, sharks, marine mammals, and marine birds. Large pelagic fishes in the area include Bluefin, Yellowfin, Bigeye, Skipjack, and Albacore tunas, Swordfish, White and Blue marlin, and Mahi-Mahi, all of which are commercially fished.

Sharks found in the AOI include Blue, Shortfin Mako, Porbeagle, White, and Basking sharks. Other species that are seasonally present include Loggerhead and Leatherback sea turtles, cetaceans, seals, and marine birds. Many of these species transit through the AOI as a migratory route into the Bay of Fundy and/or to travel north along the Scotian Shelf to the Gulf of St. Lawrence. Preliminary analysis of tagging data demonstrated that nine Basking Sharks (75% of tagged individuals) transited directly through the AOI from the Bay of Fundy on their way to the shelf break. The continental shelf edge is also a Blue Whale foraging and socializing area.

The deep channel and continental slope coupled with high primary productivity provide deep water habitat for a variety of cetacean species. The portion of the AOI along the continental slope provides foraging grounds for endangered Blue Whales, and beaked whales, including Northern Bottlenose and Sowerby's beaked whales, are found along the continental slope and in the deep channel habitat. A wide variety of baleen and toothed cetaceans have been observed within the AOI, potentially feeding or transiting through the area to summer feeding grounds and winter breeding grounds.

Overall, the Fundian Channel-Browns Bank AOI hosts diverse invertebrate, fish, marine bird, and marine mammal communities, linked to the unique physical (bathymetry and oceanography) and biological (productivity) attributes, in addition to a diverse assemblage of habitats associated with a broad depth range, varied substrate base, and significant biogenic habitat, that characterize the area.

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# TABLES

*Table 1. The area (km$^2$) and percent representation of geomorphic units found within the Fundian Channel – Browns Bank Area of Interest (AOI) relative to the entire Maritimes bioregion. Of note, 25% of all channel habitat found in the bioregion is found within the AOI. Numbers here are approximate and subject to change with changes in boundaries.*

| Biophysical Unit | Area within AOI (km$^2$) | % within AOI |
|---|---|---|
| Abyssal Plain | 0 | 0% |
| Continental Rise | 1094 | 1% |
| Inner Shelf Bank | 0 | 0% |
| Inner Shelf Flat | 0 | 0% |
| Inner Shelf Inlet | 0 | 0% |
| Shelf Bank | 2180 | 3% |
| Shelf Basin | 707 | 6% |
| Shelf Channel | 2052 | 25% |
| Shelf Flat | 601 | 2% |
| Shelf Topo Complex | 0 | 0% |
| Shelf Topo Complex Bank | 0 | 0% |
| Shelf Topo Complex Basin | 0 | 0% |
| Slope | 520 | 5% |
| Slope Channel | 0 | 0% |

*Table 2. Seasonally averaged (mean, standard deviation (SD, and range) bottom temperature (BT) and sea surface temperatures (SST) within the Area of Interest (Inside) compared to the Scotian Shelf Bioregion (Outside). Data collated from 0 m to the maximum depth within the AOI (approx. 2050 m).*

| Variable | Season | Location | Mean (°C) | SD (°C) | Range (°C) |
|---|---|---|---|---|---|
| BT | Winter | Inside | 6.53 | 1.23 | 3.82–7.82 |
| | | Outside | 4.74 | 1.89 | -1.04–8.07 |
| | Spring | Inside | 6.52 | 1.35 | 3.75–8.45 |
| | | Outside | 5.02 | 1.77 | 0.5–10.67 |
| | Summer | Inside | 6.99 | 1.55 | 3.77–9.23 |
| | | Outside | 5.88 | 2.41 | 2.54–19.28 |
| | Fall | Inside | 6.96 | 1.48 | 3.82–8.79 |
| | | Outside | 5.89 | 1.71 | 3–11.11 |
| | Annual | Inside | 6.75 | 1.44 | 3.74–9.35 |
| | | Outside | 5.38 | 2.12 | -1.45–20.76 |
| SST | Winter | Inside | 2.95 | 0.45 | 2.22–4.15 |
| | | Outside | 1.73 | 1.31 | -1.11–5.18 |
| | Spring | Inside | 7.37 | 0.56 | 6.53–8.84 |
| | | Outside | 5.86 | 1.7 | 0–10.63 |
| | Summer | Inside | 17.28 | 0.5 | 16.63–18.51 |
| | | Outside | 15.79 | 1.93 | 0–19.22 |
| | Fall | Inside | 10.92 | 0.61 | 10.28–12.55 |
| | | Outside | 9.51 | 1.58 | 0–12.98 |
| | Annual | Inside | 9.63 | 5.75 | 1.32–19.59 |
| | | Outside | 8.22 | 5.86 | -1.63–20.68 |

*Table 3. Seasonally averaged (mean, standard deviation (SD), and range) bottom temperature (BT) and sea surface temperature (SST) anomalies projected for the year 2075 based on RCP 8.5 (Brickman et al. 2016) within the Area of Interest (Inside) compared to the Scotian Shelf Bioregion (Outside).*

| Variable | Season | Location | Mean (°C) | SD (°C) | Range (°C) |
|---|---|---|---|---|---|
| BT | Winter | Inside | 1.52 | 0.74 | -0.22–2.98 |
| | | Outside | 0.74 | 0.76 | -0.15–2.86 |
| | Spring | Inside | 1.38 | 0.54 | - 0.28–2.32 |
| | | Outside | 0.73 | 0.74 | -0.24–2.51 |
| | Summer | Inside | 1.39 | 0.62 | -0.2–2.83 |
| | | Outside | 0.69 | 0.72 | -0.18–2.93 |
| | Fall | Inside | 1.59 | 0.75 | -0.22–3.05 |
| | | Outside | 0.68 | 0.72 | -0.31–3.27 |
| | Annual | Inside | 1.47 | 0.61 | -0.25–2.17 |
| | | Outside | 0.71 | 0.72 | -0.07–2.34 |
| SST | Winter | Inside | 1.78 | 0.26 | -1.27–2.57 |
| | | Outside | 1.37 | 0.9 | -3.3–4.47 |
| | Spring | Inside | 1.58 | 0.15 | -1.12–1.96 |
| | | Outside | 1.32 | 0.73 | -2.09–4.47 |
| | Summer | Inside | 1.21 | 0.11 | -0.91–1.57 |
| | | Outside | 1.06 | 0.64 | -2.3–3.22 |
| | Fall | Inside | 1.64 | 0.26 | -1.23–2.46 |
| | | Outside | 1.18 | 0.74 | -1.94–3.94 |
| | Annual | Inside | 1.55 | 0.07 | -1.49–1.77 |
| | | Outside | 1.23 | 0.51 | -1.03–1.87 |

*Table 4. Seafloor classification of the Fundian Channel-Browns Bank Area of Interest based on World Wildlife Fund Canada (2009).*

| Area | Physical Conditions | Characteristic Fauna |
|---|---|---|
| Outer Gulf of Maine — Channel | 200–300 m deep. Strong tidal currents flow through the Fundian/Northeast Channel, creating sand waves and ripples. Complex mix of clay, silt, sand, gravel, and boulders. | Densest known aggregations of large gorgonian corals live on boulders in the Channel. Juvenile Redfish and shrimp live amongst these corals. Tunas, Swordfish, and whales aggregate in the pelagic zone above the Hell Hole. |
| Outer Gulf of Maine — Basin | Deep, elliptical depression with a smooth substrate. Some bedrock, sand, and cobble. | Patches of hard substrata provide environment for corals, sponges, anemones. |
| Scotian Slope West — Fan | Extends from mouth of the Fundian Channel into deep water. Low light penetration, benthic species rely on falling detritus. | Soft corals, sponges, Redfish. Abundant food for pelagic fishes and whales. |
| Outer Scotian Shelf — Saddle | Depths < 200 m, covered by sand, silt, and gravel. | Phytoplankton, Shortfin Squid, groundfish and crustaceans. |
| Outer Scotian Shelf — Bank | Covered by sand and gravel, shell beds and patchy boulders. Cold slope waters mix with water over the banks, providing nutrients. | Phytoplankton provide food for filter-feeders and grazers, including Atlantic Sea Scallop, clams, sand dollars. Other invertebrates including Horse Mussels, brittle stars, crabs, and lobster are found in rockier spots. |

*Table 5. Benthic habitats of Browns Bank based on substrate type, depth, and benthic community. Modified from Kostylev et al. (2001).*

| **Habitat** | **Physical Characteristics** | **Benthic Species** |
|---|---|---|
| Shallow water habitat | Sand substrate, high-energy environment with mobile sediment. | Rich in meiofauna, low diversity of visible megafauna. Possibly Surf Clam (*Spisula solidissima*), Softshell Clam (*Mya truncata*) and other infauna. |
| Deep water habitat | Sand substrate, shell hash. | Low diversity of visible megafauna. Sand-dwelling fauna may be found, including Sand Dollar. Solitary hydroids (*Corymorpha* sp.). |
| Soft coral and sea cucumber habitat | Gravel substrate, western part of the bank. Shallow water, strong currents. Substrate suitable for larval settlement. | Soft corals (*Alcyonium digitatum, Duva multiflora*), sea cucumber (*Cucumaria frondosa*). |
| Scallop habitat | Gravel substrate, western part of the bank. Strong currents and shallow water make this area ideal for scallop recruitment and feeding. Low silt levels. Maximum scallop densities occur at 70 to 90 m. | Atlantic Sea Scallop, hydroids, whelks, hermit crabs. Predatory fish and crabs often attracted to the area to prey on damaged scallops from dredging. |
| *Terebratulina* community habitat | Gravel substrate with boulder-sized particles (> 256 mm). Depth approx. 90 m. Located in central and eastern parts of the bank. | Brachiopods, sponges, suspension feeding polychaetes, infaunal bivalves |
| Deposit feeder habitat | Accumulated silt on gravel. Located in the deeper, eastern portion of the bank. | Tube-dwelling deposit feeding polychaetes, occasional anemones and sponges |

*Table 6. List of species and associated coding captured during the Multispecies RV Survey from 1970–2017 (467 trawls during Spring, Winter and Summer surveys) within the Fundian Channel-Browns Bank AOI boundaries. Depth (range) and temperature (mean ± SD) were evaluated within the AOI boundaries. In cases where data were unavailable (*), mean (± SD) temperature was estimated from captures within the Scotian Shelf planning region (e.g., Figure 10).*

| **Species** | | **Code** | **Count** | **Depth(m)** | **Temp (°C)** |
|---|---|---|---|---|---|
| Haddock | *Melanogrammus aeglefinus* | 11 | 417 | 69.8–359.2 | 7.8 ± 2.3 |
| Atlantic Cod | *Gadus morhua* | 10 | 303 | 69.8–320.6 | 7.3 ± 2.2 |
| Silver Hake | *Merluccius bilinearis* | 14 | 280 | 69.8–359.2 | 8.6 ± 1.8 |
| Yellowtail Flounder | *Limanda ferruginea* | 42 | 244 | 69.8–236.9 | 7.6 ± 2.5 |
| Pollock | *Pollachius virens* | 16 | 202 | 69.8–358.9 | 7.6 ± 2 |
| Longhorn Sculpin | *Myoxocephalus octodecemspinosus* | 300 | 197 | 69.8–252.9 | 7.4 ± 2.6 |
| Atlantic Herring | *Clupea harengus* | 60 | 184 | 69.8–358.9 | 7.6 ± 2 |
| American Plaice | *Hippoglossoides platessoides* | 40 | 182 | 69.8–358.9 | 7.1 ± 2.1 |
| Atlantic Halibut | *Hippoglossus hippoglossus* | 30 | 161 | 69.8–276.4 | 7.4 ± 2.4 |
| Thorny Skate | *Amblyraja radiata* | 201 | 155 | 72.3–359.2 | 7.4 ± 1.9 |
| Atlantic Argentine | *Argentina silus* | 160 | 148 | 91.5–359.2 | 8.4 ± 1.6 |
| Little Skate | *Leucoraja erinacea* | 203 | 146 | 69.8–301.9 | 8 ± 2.5 |
| Winter Skate | *Leucoraja ocellata* | 204 | 131 | 79.8–357.3 | 7.8 ± 2.7 |
| White Hake | *Urophycis tenuis* | 12 | 124 | 84.4–359.2 | 8.3 ± 1.4 |
| Spiny Dogfish | *Squalus acanthias* | 220 | 119 | 74.8–358.9 | 7.9 ± 1.8 |
| Winter Flounder | *Pseudopleuronectes americanus* | 43 | 118 | 69.8–230.5 | 7.2 ± 2.4 |
| Monkfish | *Lophius americanus* | 400 | 116 | 69.8–351.2 | 7.8 ± 1.8 |
| Redfish | *Sebastes* sp. | 23 | 112 | 79.8–359.2 | 7.8 ± 1.7 |
| Squirrel or Red Hake | *Urophycis chuss* | 13 | 108 | 79.8–343.2 | 9.1 ± 2 |
| Witch Flounder | *Glyptocephalus cynoglossus* | 41 | 104 | 74.8–359.2 | 7.6 ± 1.7 |
| Sea Raven | *Hemitripterus americanus* | 320 | 86 | 69.8–359.2 | 6.6 ± 2.4 |
| Striped Atlantic Wolffish | *Anarhichas lupus* | 50 | 79 | 79.8–252.9 | 6.5 ± 2.4 |
| Black Belly Rosefish | *Helicolenus dactylopterus* | 123 | 69 | 95.9–359.2 | 8.4 ± 1.2 |
| Smooth Skate | *Malacoraja senta* | 202 | 66 | 79.8–358.9 | 7.7 ± 1.4 |
| Cusk | *Brosme brosme* | 15 | 65 | 74.8–358.9 | 7.7 ± 1.8 |
| Longfin Hake | *Urophycis chesteri* | 112 | 57 | 132.2–359.2 | 8 ± 0.8 |
| Alligatorfish | *Aspidophoroides monopterygius* | 340 | 55 | 69.8–254.8 | 6.9 ± 2.2 |
| Moustache Sculpin | *Triglops murrayi* | 304 | 50 | 79.8–245.5 | 6.3 ± 2.3 |
| Atlantic Mackerel | *Scomber scombrus* | 70 | 45 | 80.7–317.6 | 8.4 ± 2.2 |
| Butterfish | *Peprilus triacanthus* | 701 | 45 | 79.8–343.3 | 8.7 ± 2.2 |
| Barndoor Skate | *Dipturus laevis* | 200 | 37 | 79.8–358.9 | 8.2 ± 2.4 |
| Marlin-Spike Grenadier | *Nezumia bairdii* | 410 | 35 | 131.4–358.9 | 7.9 ± 0.9 |
| Alewife | *Alosa pseudoharengus* | 62 | 32 | 80.7–345.2 | 8.1 ± 1.1 |
| Atlantic Hagfish | *Myxine glutinosa* | 241 | 24 | 79.8–357.3 | 8.1 ± 1.5 |
| Shad American | *Alosa sapidissima* | 61 | 18 | 86.4–345.2 | 8.3 ± 1.3 |
| Atlantic Soft Pout | *Melanostigma atlanticum* | 646 | 17 | 88.9–358.9 | 8.6 ± 0.7 |
| Northern Sand Lance | *Ammodytes dubius* | 610 | 16 | 69.8–308.1 | 7.8 ± 1.8 |
| Lanternfish | *Myctophidae* | 150 | 11 | 115.3–341.3 | 8.3 ± 0.7 |

| Species | | Code | Count | Depth(m) | Temp (°C) |
|---|---|---|---|---|---|
| Short-Nose Greeneye | *Chlorophthalmus agassizi* | 156 | 11 | 87.9–285.6 | 8.6 ± 1.7 |
| Gulf Stream Flounder | *Citharichthys arctifrons* | 44 | 10 | 95.9–220.4 | 10.4 ± 2 |
| Hookear Sculpin | *Argentinidae* | 323 | 6 | 89.7–307 | 7.8 ± 1 |
| Radiated Shanny | *Ulvaria subbifurcata* | 625 | 5 | 89.6–133.2 | 5.8 ± 3.3 |
| Cunner | *Tautogolabrus adspersus* | 122 | 4 | 83.3–90.5 | 9.5 ± 2.4 |
| Arctic Hookear Sculpin | *Artediellus uncinatus* | 306 | 4 | 89.2–285.6 | 7 ± 3 |
| Fourbeard Rockling | *Enchelyopus cimbrius* | 114 | 3 | 216.2–320.6 | 8.8 ± 0.2 |
| Slender Snipe Eel | *Nemichthys scolopaceus* | 604 | 3 | 175.8–357.3 | 9.5 ± 0.5 |
| Wrymouth | *Cryptacanthodes maculatus* | 630 | 3 | 312.5–348.3 | 8.1 ± 0.5 |
| White Barracudina | *Arctozenus risso* | 712 | 3 | 308.1–351.2 | 8.3 ± 0.8 |
| Brill | *Scophthalmus aquosus* | 143 | 2 | 119.2–254.8 | 7.6 |
| Longnose Greeneye | *Parasudis truculenta* | 149 | 2 | 220.4–223.1 | 8.2 ± 0.5 |
| Lumpfish | *Cyclopterus lumpus* | 501 | 2 | 92.6–114.8 | 2.9 ± 0.6 |
| Atlantic Spiny Lumpsucker | *Eumicrotremus spinosus* | 502 | 2 | 84.4–88.1 | 7.7 ± 1.3 |
| Atlantic Saury | *Scomberesox saurus* | 720 | 2 | 80.7–91.3 | 7.3 ± 0.5 |
| Gray Triggerfish | *Balistes capriscus* | 3 | 1 | 98.2 | 7.2* |
| Off-Shore Hake | *Merluccius albidus* | 19 | 1 | 143.4 | 7.82* |
| Turbot | *Reinhardtius hippoglossoides* | 31 | 1 | 318.4 | 8.48* |
| Rainbow Smelt | *Osmerus mordax* | 63 | 1 | 144.5 | 5.2 ± 4* |
| Atlantic Moonfish | *Selene setapinnis* | 94 | 1 | 224.5 | 10.43* |
| Spotted Hake | *Urophycis regia* | 111 | 1 | 119.1 | 12.34* |
| Muller's Pearlsides | *Maurolicus muelleri* | 158 | 1 | 100.3 | 7.5 ± 2.1* |
| Boa Dragonfish | *Stomias boa* | 159 | 1 | 301.9 | 7.24* |
| Blueback Herring | *Alosa aestivalis* | 165 | 1 | 130.8 | 7.5 ± 1.9* |
| Viperfish | *Chauliodus sloani* | 169 | 1 | 317.6 | 5.8 ± 1.6* |
| Loosejaw | *Malacosteus niger* | 177 | 1 | 236.9 | 8.55* |
| Sea Lamprey | *Petromyzon marinus* | 240 | 1 | 271.8 | 7.1 ± 1.9* |
| Argentines | *Artediellus* sp. | 288 | 1 | 215.3 | 9.17* |
| Spatulate Sculpin | *Icelus spatula* | 314 | 1 | 90.5 | 5.09* |
| Armored Sea Robin | *Peristedion miniatum* | 331 | 1 | 193.2 | 12.29* |
| Atlantic Sea Poacher | *Leptagonus decagonus* | 350 | 1 | 90.6 | 4.26* |
| Rock Grenadier (Roundnose) | *Coryphaenoides rupestris* | 414 | 1 | 308 | 7.8* |
| Grenadiers | *Macrouridae* | 416 | 1 | 285.6 | 8.54* |
| Wolf Eelpout | *Lycenchelys verrillii* | 603 | 1 | 295.6 | 7.92* |
| Checker Eelpout | *Lycodes vahlii* | 647 | 1 | 312.2 | 8.52* |
| Fawn Cusk Eel | *Lepophidium profundorum* | 650 | 1 | 178.7 | 12.82* |
| Hatchetfish | *Sternoptychidae* | 741 | 1 | 175.8 | 9.82* |
| Atlantic Batfish | *Dibranchus atlanticus* | 742 | 1 | 134.9 | 13.13* |
| Northern Puffer | *Sphoeroides maculatus* | 746 | 1 | 88.4 | 8.13* |
| Beardfish | *Polymixia lowei* | 771 | 1 | 216.2 | 9.9 ± 1.8* |
| Myctophiformes | *Myctophiformes* | 811 | 1 | 358.9 | 7.29* |
| Tongue Fish | *Symphurus* sp. | 816 | 1 | 89.3 | 7.4 ± 2.5* |

*Table 7. List of species and associated coding captured during the summer Multispecies RV Survey from 1970–2017 identified as originating from lower latitudes and warmer temperatures (DFO 2018a). Mean bottom temperature at capture (± SD) are reported along with species identification codes for the RV Survey database. Species are categorized by the first year observed in the survey and partitioned to those found inside and outside the AOI based on a 25 km buffer.*

| Species | | Code | First Observed | AOI | Mean ± SD |
|---|---|---|---|---|---|
| Fawn Cusk Eel | *Lepophidium profundorum* | 650 | 2013 | Inside | 10.31 ± 2 |
| Atlantic Moonfish | *Vomer setapinnis* | 94 | 2006 | Inside | 9.22 ± 1.05 |
| Greeneyes (not identified) | Chlorophthalmidae | 593 | 1999 | Inside | 8.77 ± 1.75 |
| Spotted Hake | *Urophycis regia* | 111 | 1994 | Inside | 8.77 ± 3.12 |
| Longnose Greeneye | *Parasudis truculenta* | 149 | 1993 | Inside | 8.38 ± 1.84 |
| Atlantic Torpedo Ray | *Tetronarce nobiliana* | 216 | 1981 | Inside | 9.07 ± 2.09 |
| Beardfish | *Polymixia lowei* | 771 | 1980 | Inside | 9.29 ± 1.63 |
| Shortnose Greeneye | *Chlorophthalmus agassizi* | 156 | 1979 | Inside | 8.66 ± 1.77 |
| American John Dory | *Zenopsis ocellata* | 704 | 1978 | Inside | 9.34 ± 1.98 |
| Armored Sea Robin | *Peristedion miniatum* | 331 | 1976 | Inside | 8.88 ± 3.59 |
| Blackbelly Rosefish | *Helicolenus dactylopterus* | 123 | 1974 | Inside | 8.57 ± 1.7 |
| Stout Beardfish | *Polymixia nobilis* | 744 | 1974 | Inside | 8.05 ± 1.2 |
| Deep-bodied Boarfish | *Antigonia capros* | 384 | 2016 | Outside | 12.7 ± * |
| Silver-rag Driftfish | *Ariomma bondi* | 785 | 2015 | Outside | 11.85 ± * |
| Thorny Tinselfish | *Grammicolepis brachiusculus* | 777 | 2010 | Outside | 8.93 ± 1.57 |
| Black Scabbard Fish | *Aphanopus carbo* | 784 | 2008 | Outside | 5.12 ± * |
| Lefteye Flounder | Bothidae f. | 196 | 1996 | Outside | 9.07 ± 0.62 |
| Spotfin Dragonet | *Foetorepus agassizi* | 637 | 1996 | Outside | 7.76 ± 2.16 |
| Conger Eel | *Conger oceanicus* | 608 | 1993 | Outside | 11.11 ± 1.84 |
| Summer Flounder | *Paralichthys dentatus* | 141 | 1992 | Outside | 1.98 ± 0.49 |
| Sea basses | *Mycteroperca* spp. | 664 | 1974 | Outside | 8.79 ± 1.67 |

*Table note: *Species were only captured in one trawl set.*

*Table 8. Determination on the Health of Canadian Large Pelagic Species Stocks from their individual International Commission for the Conservation of Atlantic Tunas Stock Assessment Processes.*

| Species | Stock Assessment | Overfished | Overfishing |
|---|---|---|---|
| Albacore Tuna | 2016 | No | No |
| Bigeye Tuna | 2014 | Yes | Yes |
| Bluefin Tuna | 2017 | N/A | No |
| Skipjack Tuna | 2014 | No | No |
| Yellowfin Tuna | 2014 | Yes | No |
| Swordfish | 2015 | No | No |
| Blue Marlin | 2009 | Yes | Yes |
| White Marlin | 2010 | Yes | Not likely |
| Blue Shark | 2013 | Not likely | Not likely |
| Shortfin Mako Shark | 2015 | Yes | Yes |
| Porbeagle Shark | 2008 | Yes | No |

*Table 9. Species groupings and/or species shown to reach concentrations within either AOI polygon that reach top-decile values (important areas, determined at the scale of the Scotian Shelf bioregion), regardless of variation within the annual cycle. Their status under the International Union for the Conservation of Nature (IUCN) is also listed.*

| Species Grouping | Species* | IUCN Status |
|---|---|---|
| Shearwaters | (all shearwaters; see text) | |
| | Great Shearwater (*Puffinus gravis)* | Least Concern |
| | Sooty Shearwater (*Puffinus griseus)* | Near Threatened |
| | Cory's Shearwater (*Calonectris diomedea*) | Least Concern |
| Large gulls | (all large gulls; see text) | |
| | Herring Gull (*Larus argentatus*) | Least Concern |
| | Great Black-backed Gull (*Larus marinus)* | Least Concern |
| Storm-petrels | (all storm-petrels; see text) | |
| | Leach's Storm-Petrel (*Oceanodroma leucorhoa*) | Vulnerable |
| | Wilson's Storm-Petrel (*Oceanites oceanicus*) | Least Concern |
| Phalaropes | (all phalaropes; see text) | |
| Large alcids | (all large alcids; all detections, see text) | |
| | (all large alcids; on-water detections only, see text) | |
| | Thick-billed Murre (*Uria lomvia*) | Least Concern |
| Single species | Black-legged Kittiwake (*Rissa tridactyla*) | Vulnerable |
| Single species | Dovekie (*Alle alle*) | Least Concern |
| Single species | Northern Gannet (*Morus bassanus*) | Least Concern |
| Skuas and jaegers | (all skuas and jaegers; see text) | n/a |
| Terns | (all terns; see text) | n/a |

*Table notes: *Maps generated from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) and ECSAS presented separately for species/species groups listed. Only individuals that can be detected and identified to species/species grouping during the course of at-sea surveys are included in this list and treated within this document. During migration, several landbird and shorebird species would be expected to fly over the Area of Interest and surrounding area, though they would not use the marine resources within them.*

*Table 10. Approximate mean maximum foraging range (km) of marine bird species known to breed in the vicinity of the Fundian Channel – Browns Bank Area of Interest.*

| **Species** | | **Approximate Mean Maximum Foraging Range (km)** |
|---|---|---|
| Leach’s Storm-petrel | *Hydrobates leucorhous* | 800 |
| Northern Gannet* | *Morus bassanus* | 300 |
| Herring Gull | *Larus argentatus* | 60 |
| Great Black-backed Gull | *Larus marinus* | 60 |
| Atlantic Puffin | *Fratercula arctica* | 60 |
| Razorbill | *Alca torda* | 40 |
| Terns | *Sterna* spp. | 20 |

*Table note: * Presently extirpated from Scotian Shelf bioregion as a breeding species.*

*Table 11. Species occurring within or near the Area of Interest (AOI), arranged in alphabetical order, with the population or designatable unit (DU), conservation status including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designation and year of last assessment, reason for designation in Canada, and risk status for the Species at Risk Act (SARA) and year listed if on schedule 1; the International Union for Conservation of Nature (IUCN) Red List Category and year published); and notes on species presence within or near the AOI.*

| **Species** | **Conservation Status in Canada** | | | | **IUCN Red List Category (year published)** | **Confirmed presence within or near AOI** |
|---|---|---|---|---|---|---|
| | **Population/DU** | **COSEWIC (year assessed)** | **Reason for Designation** | **SARA (year listed on schedule 1)** | | |
| Acadian Redfish (*Sebastes fasciatus*) | Atlantic | Threatened (2010) | Abundance of mature individuals has declined by up to 99%. Directed fishing and incidental harvest are the main known threats. | No status | Global status: Endangered A1bd* (1996, needs updating) | Yes |
| American Plaice (*Hippoglossoides platessoides*) | Maritime population | Threatened (2009) | Mature individuals have declined by 67% on the Scotian Shelf | No status | Has not yet been assessed | Yes |
| Atlantic Bluefin Tuna (*Thunnus thynnus*) | NA | Endangered (2011) | Decline in spawning individuals by 69% | No status | Western Atlantic stock: Endangered A2bd† (2011) | Migratory |
| Atlantic Bottlenose Dolphin (*Tursiops truncatus*) | NA | Not at Risk (1993) | NA | No status | Global status: Least Concern† (2012) | Potential visitor |
| Atlantic Cod (*Gadus morhua*) | Southern DU | Endangered (2010) | Populations have declined by 90% and have not improved | No status | Global status: Vulnerable A1bd* (1996, needs updating) | Yes |
| Atlantic White-Sided Dolphin (*Lagenorhynchus acutus*) | NA | Not at Risk (1991) | NA | No status | Global status: Least Concern† (2008) | Non-migratory individuals are likely |
| Atlantic Wolffish (*Anarhichas lupus*) | NA | Special Concern (2000, confirmed 2012) | Steep declines until the mid-1990s, continued | Schedule 1, Special | Has not yet been assessed | Species of Wolffish most likely |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| | | | declines on Scotian Shelf | Concern (2003) | | to be present |
| Basking Shark (*Cetorhinus maximus*) | Atlantic population | Special Concern (2009) | Extremely low productivity, bycatch in various trawl, gillnet, and longline fisheries. Ship collisions are also a threat. | No status | Global status: Vulnerable A2ad+3d† (2009, needs updating) | Migratory |
| Blue Whale (*Balaenoptera musculus*) | Atlantic population | Endangered (2002, confirmed 2012) | Less than 250 mature individuals, low calving rate, and threats including ship strikes, pollution, and entanglement in fishing gear. | Schedule 1, Endangered (2005) | North Atlantic population: Endangered A1abd† (2008) | Migratory individuals are likely |
| Cusk (*Brosme brosme*) | Atlantic population | Endangered (2012) | Mature portion of the population has declined by 85% over three generations. Its area of occupancy has also declined significantly. | No status | Has not yet been assessed | Yes |
| Cuvier's Beaked Whale (*Ziphius cavirostris*) | NA | Not at Risk (1990) | NA | No status | Global status: Least Concern† (2008) | Possible visitor |
| Fin Whale (*Balaenoptera physalus*) | Atlantic population | Special Concern (2005) | Whaling during the 20th century reduced the population. Current threats include ship strikes and entanglements. | Schedule 1, Special Concern (2006) | North Atlantic populations: Endangered A1d† (2013) | Migratory (likely) |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| Harbour Porpoise (*Phocoena phocoena*) | Northwest Atlantic population | Special Concern (2006) | Bycatch in fishing gear is a major source of mortality. Acoustic harassment devices may also be excluding individuals from their habitat. | No status | Global status: Least Concern† (2008) | Non-migratory (Likely) |
| Humpback Whale (*Megaptera novaeangliae*) | Western North Atlantic population | Not at Risk (2003) | Population appears to have regrown to a substantial proportion of pre-whaling size. Population is deemed not at risk from current activity levels. | No status | Global status: Least Concern† (2008) | Migratory (Likely) |
| Killer Whale (*Orcinus orca*) | Northwest Atlantic / Eastern Arctic population | Special Concern (2008) | Small population size, life history and social attributes, threats from acoustic and physical disturbance and contaminants, contribute to its status of Special Concern. | No status | Global status: Data Deficient† (2017) | Unlikely |
| Leatherback Sea Turtle (*Dermochelys coriacea*) | Atlantic population | Endangered (2012) | Global populations have declined by 70% due to bycatch, marine pollution, entanglement in longline and fixed fishing gear. | Schedule 1, Endangered (re-listed as separate population 2017) | Northwest Atlantic subpopulation: Endangered† (2019) and Global status: Vulnerable A2bd† (2013) | Migratory |
| Loggerhead Sea Turtle (*Caretta caretta*) | NA | Endangered (2010) | Declines in adults and juveniles in the Northwest Atlantic associated with bycatch or entanglement in pelagic longline | Schedule 1, Endangered (2017) | Northwest Atlantic subpopulation (2017): Least Concern† and Global status: Vulnerable A2b† (2017) | Migratory |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| | | | fisheries. Destruction of nesting habitat in the southern United States and the Caribbean. | | | |
| Long-Finned Pilot Whale (*Globicephala melas)* | North Atlantic subspecies | Not at Risk (1994) | NA | No status | Global status: Data Deficient† (2008) | Non-migratory (Likely) |
| Minke Whale (*Balaenoptera acutorostrata acutorostrata*) | North Atlantic subspecies | Not at Risk (2006) | Population size is estimated to be in the order of 15,000. Recent and current removals are likely sustainable. | No status | Global status: Least Concern† (2008) | Migratory (Likely) |
| North Atlantic Right Whale (*Eubalaena glacialis)* | NA | Endangered (2013) | Historical whaling reduced the population. Current threats include ship strikes and entanglements. | Schedule 1, Endangered (2005) | Northwest Atlantic population: Endangered D† (2017; if the recent decline continues, the species should be reclassified as Critically Endangered C2a(ii)†) | Migratory (likely) |
| Northern Bottlenose Whale (*Hyperoodon ampullatus*) | Scotian Shelf population | Endangered (2011) | Well-studied population estimated at 164 individuals (93 mature) – at time of designation. Population seems to be stable but is small and at risk from entanglement in fishing gear and possibly also anthropogenic noise from seismic surveys for oil and gas and from exposure to contaminants. | Schedule 1, Endangered (2006) | Global status: Data Deficient† (2008) | Possible visitor |

| **Species** | **Conservation Status in Canada** | | | | **IUCN Red List Category (year published)** | **Confirmed presence within or near AOI** |
|---|---|---|---|---|---|---|
| | **Population/DU** | **COSEWIC (year assessed)** | **Reason for Designation** | **SARA (year listed on schedule 1)** | | |
| Northern Wolffish (*Anarhichas denticulatus*) | NA | Threatened (2012) | Strong declines in both abundance and range size in the 1980s. Despite slight increases, the species is still at low levels compared to the early 1970s. | Schedule 1, Threatened (2003) | Has not yet been assessed | Unlikely |
| Porbeagle Shark (*Lamna nasus*) | NA | Endangered (2014) | Declined starting in the 1960s and again in the 1990s. Numbers have remained low but stable, though bycatch is still an issue. | No status | Northwest Atlantic population: Vulnerable A2bd+3d+4bd† (2008, needs updating) | Migratory |
| Risso's Dolphin (*Grampus griseus*) | NA | Not at Risk (1990) | NA | No status | Global status: Least Concern† (2012) | Non-migratory (Possible) |
| Roseate Tern (*Sterna dougallii*) | Northeastern (Canadian) population | Threatened (1986), Endangered (1999, confirmed 2009) | Only 200 mature individuals occupying 7 locations in Canada. Adult survival rates are low. | Schedule 1, Endangered (2003) | Global status: Least Concern† (2017) | Migratory |
| Roundnose Grenadier (*Coryphaenoides rupestris*) | Atlantic population | Endangered (2008) | Declines of 98% from 1978 to 1994, and further decline between 1995 and 2003. | No status | Global status: Critically Endangered A4bd† (2015) | NA |
| Sei Whale (*Balaenoptera borealis*) | Western North Atlantic population | Data Deficient (2003) | Data are lacking to properly assess degree of depletion by whaling, current population size, or population recovery. Effects of current threats are unknown. | No status | Global status: Endangered A1ad† (2008) | Migratory (Likely) |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| Short-Beaked Common Dolphin (*Delphinus delphis*) | NA | Not at Risk (1991) | NA | No status | Global status: Least Concern† (2008) | Non-migratory (Likely) |
| Shortfin Mako Shark (*Isurus oxyrinchus*) | NA | Threatened (2006), Special Concern (2017) | Long lifespan and low productivity makes this species vulnerable. The species has a single migratory population, but abundances are stable. | No status | Atlantic subpopulation: Vulnerable A2bd+3bd+4bd† (2009, needs updating) and Global status: Vulnerable A2abd+3bd+4abd† (2009, needs updating) | Migratory |
| Smooth Skate (*Malacoraja senta*) | Laurentian-Scotian population | Special Concern (2012) | Abundance and area of occupancy has declined since the 1970s and numbers remain low. | No status | Global status: Endangered A2bcd* (2009, needs updating) | Yes |
| Sowerby's Beaked Whale (*Mesoplodon bidens*) | NA | Special Concern (2006) | Acute exposure to intense sounds from sonar and seismic surveys occurring in their habitat. High sensitivity to sound, unknown population-level effects and little information on abundance are causes for concern. | Schedule 1, Special Concern (2011) | Global status: Data Deficient† (2008) | Likely to be present |
| Sperm Whale (*Physeter macrocephalus*) | NA | Not at Risk (1996) | NA | No status | Global status: Vulnerable† (2008) | Migratory (Likely) |
| Spiny Dogfish (*Squalus acanthias*) | Atlantic population | Special Concern (2010) | Low fecundity, long generation time (23 years), uncertainty of abundance of mature females, and vulnerability to overfishing in U.S. waters are causes for concern. | No status | Northwest Atlantic subpopulation: Endangered A2+4bd† (2006, needs updating; would be Vulnerable A1† if science-based management measures were introduced and adhered to over the long term across the whole stock) and Global status: | Yes |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| | | | | | Vulnerable A2bd+3bd (2016) | |
| Spotted Wolffish (*Anarhichas minor*) | NA | Threatened (2012) | Numbers of this large, slow-growing, long-lived, solitary, nest-building fish have declined over 90% over three generations. The number of locations where the fish is found has decreased. Threats include mortality as bycatch and habitat alteration from bottom trawling. Dispersal is limited. | Schedule 1, Threatened (2003) | Has not yet been assessed | Unlikely |
| Striped Dolphin (*Stenella coeruleoalba*) | NA | Not at Risk (1993) | NA | No status | Global status: Least Concern† (2008) | Possible visitor |
| Thorny Skate (*Amblyraja radiata*) | NA | Special Concern (2012) | Slow-growing, late-maturing fish that have undergone severe population declines over the southern part of their distribution, including range contractions. Declines in the southern part of their range have continued despite a reduction in fishing mortality. In contrast, the abundance of mature individuals in the northern part of their range has been increasing, approaching abundance levels observed at the beginning of surveys (mid-1970s). Thus, while the species as a whole does not meet the criteria for a Threatened status, declines and range | No status | Canadian waters: Vulnerable, USA waters: Critically Endangered, and Global status: Vulnerable A2b† (2009, needs updating) | Yes |

| Species | Conservation Status in Canada | | | | IUCN Red List Category (year published) | Confirmed presence within or near AOI |
|---|---|---|---|---|---|---|
| | Population/DU | COSEWIC (year assessed) | Reason for Designation | SARA (year listed on schedule 1) | | |
| | | | contractions in the south are causes for concern. | | | |
| White-Beaked Dolphin (*Lagenorhynchus albirostris*) | NA | Not at Risk (1998) | NA | No status | Global Status: Least Concern† (2012) | Possible visitor |
| White Hake (*Urophycis tenuis*) | Atlantic and Northern Gulf of St. Lawrence population | Threatened (2013) | Adults in this population are estimated to have declined by approximately 70% over the past three generations with most of this decline occurring before the mid-1990s. The population has remained fairly stable since this decline with little overall trend in area of occupancy. Restrictions on fisheries since the mid- to late 1990s over most of their range may have resulted in the stabilization of their numbers. | No status | Has not yet been assessed | Yes |
| White Shark (*Carcharodon carcharias*) | Atlantic population | Endangered (2006) | NA | Schedule 1, Endangered (2011) | Global status: Vulnerable A2cd+3cd† (2009, needs updating) | Migratory |

*Table Notes:*
**version 2.3*
*†version 3.1*
*NA = not applicable*

# FIGURES

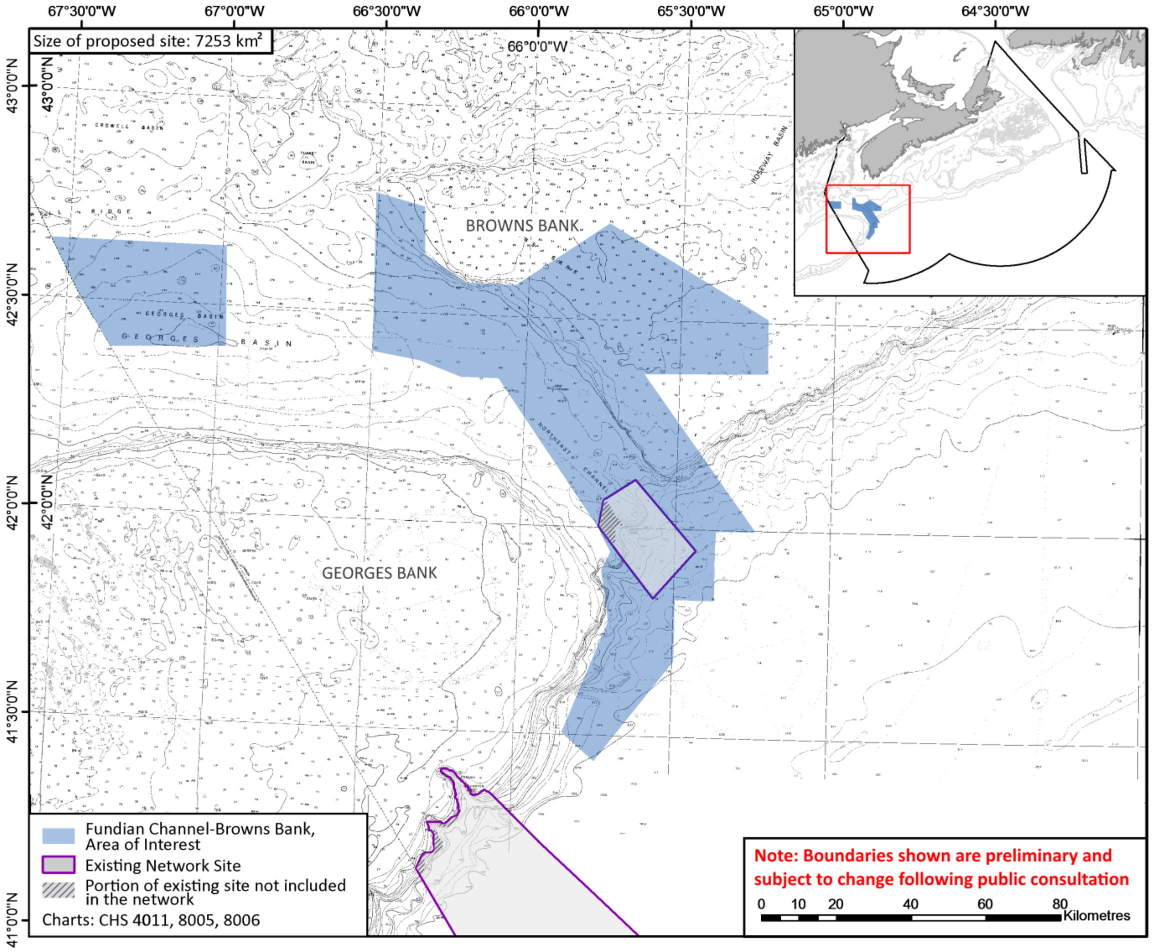

*Figure 1. Location of Fundian Channel-Browns Bank Area of Interest (AOI; shaded blue area) in Nova Scotia. AOI boundary is not final, is for evaluation purposes only, is subject to change, and does not necessarily reflect a proposed MPA boundary. Basemap: Canadian Hydrographic Service (CHS) nautical charts 4011, 8005, and 8006.*

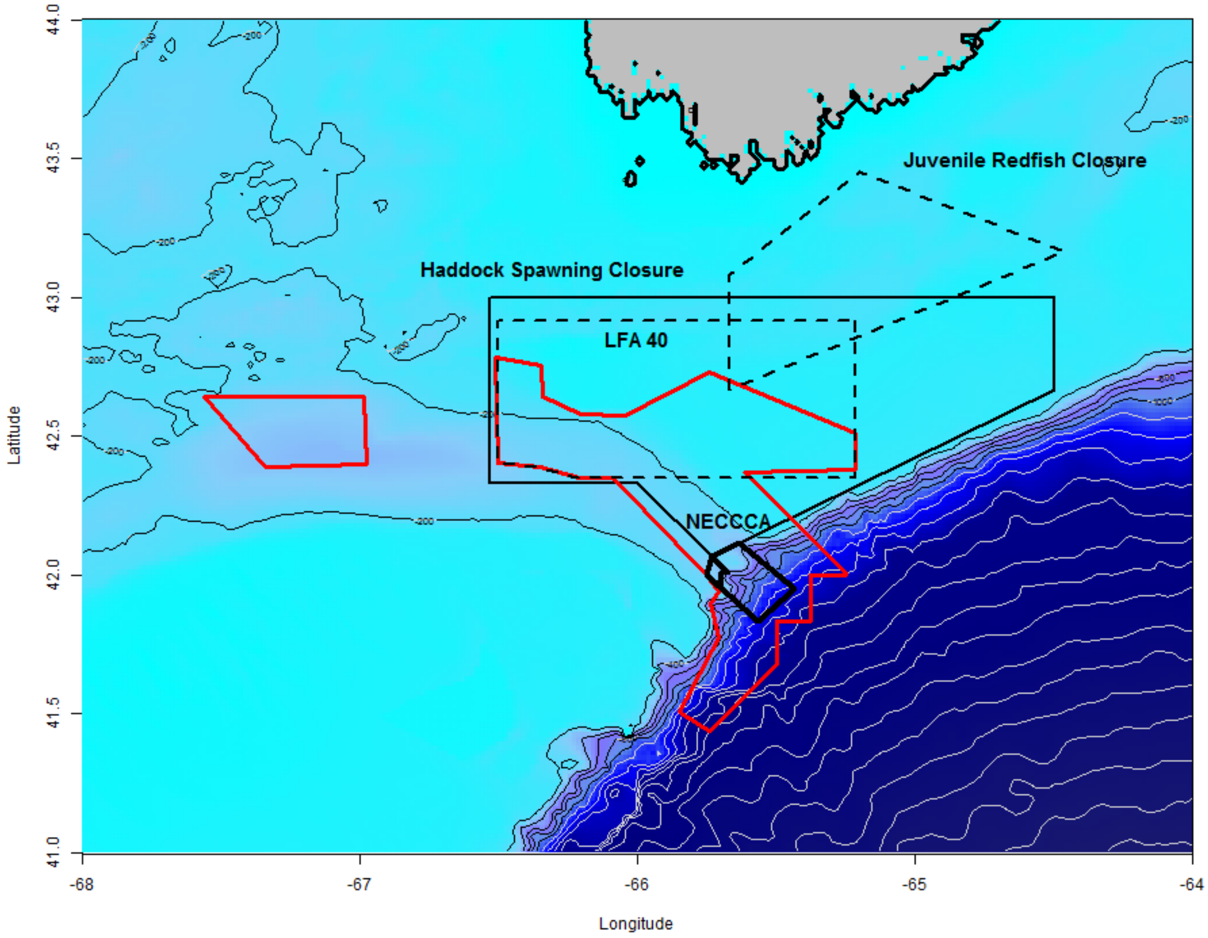

*Figure 2. Closed areas in the vicinity of the AOI (shown in red) include a seasonal Haddock spawning closure, a juvenile redfish closure, and Lobster Fishing Area 40, which is closed to Lobster fishing but not to other fisheries, such as Atlantic Sea Scallop.*

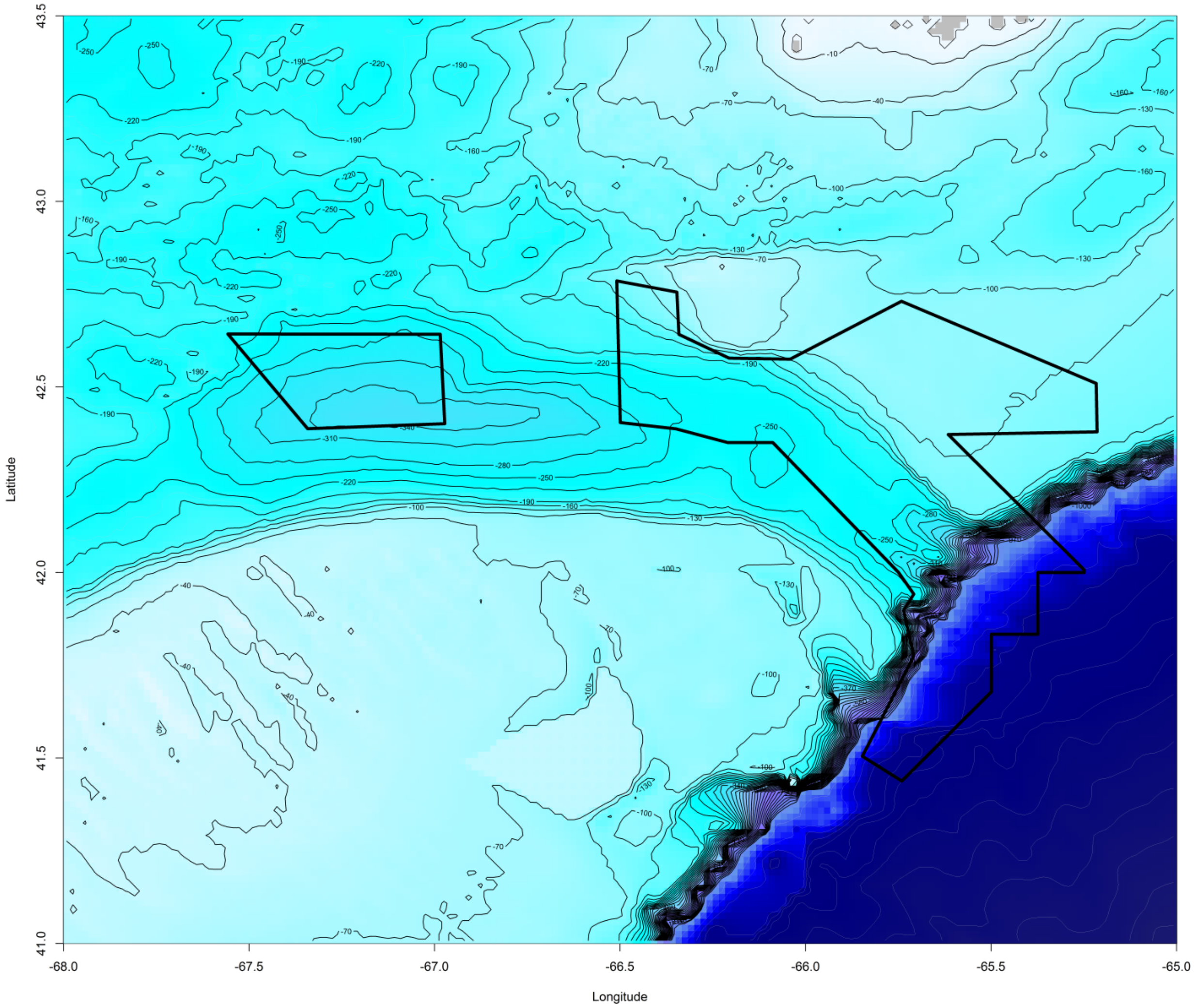

*Figure 3. Bathymetry of the Fundian Channel-Browns Bank Area of Interest. Data source: NOAA bathymetry accessed through the Marmap R package (Pante and Simon-Bouhet 2013).*

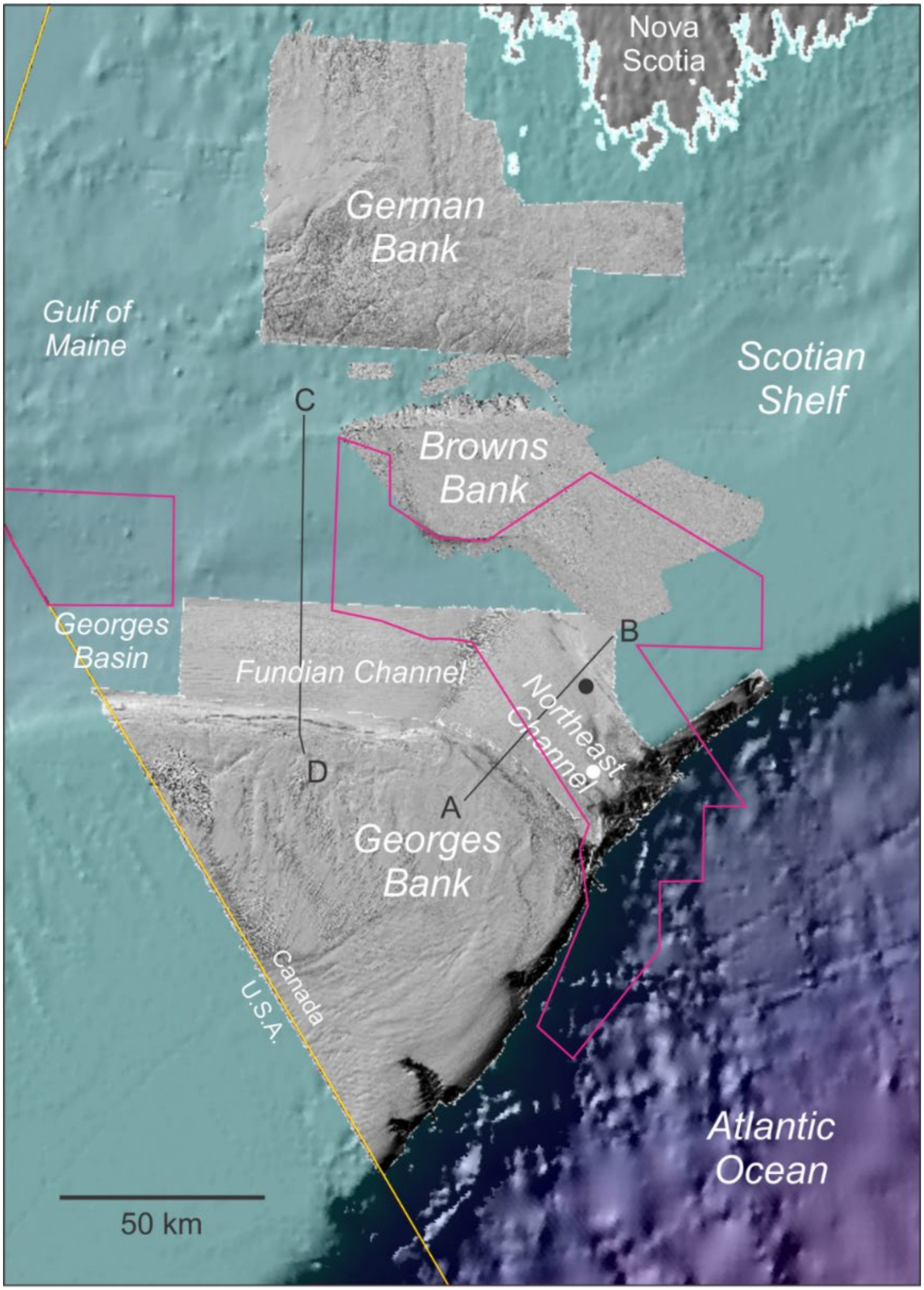

*Figure 4. Southern Scotian Shelf multibeam sonar coverage (grey shading). The Area of Interest is outlined in red. Seismic profiles AB and CD in Figure 6 indicated by solid black lines. Black and white dots indicates locations of Figure 7.*

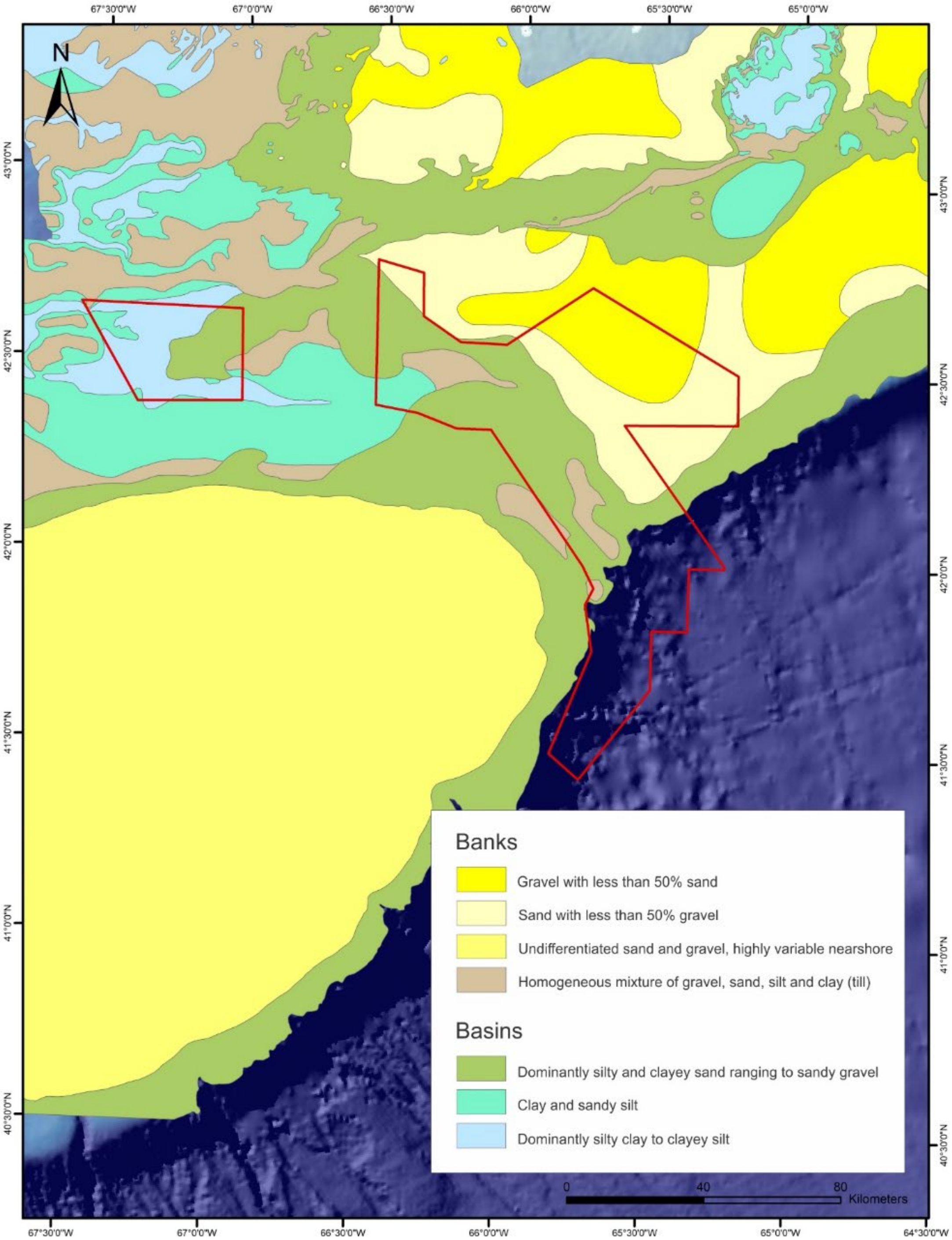

*Figure 5. Generalized overview of Southern Scotian Shelf surficial sediments. Mud unit (greens and blue) distribution is better represented in basins than the more complex till, sand and gravel distribution on the banks.*

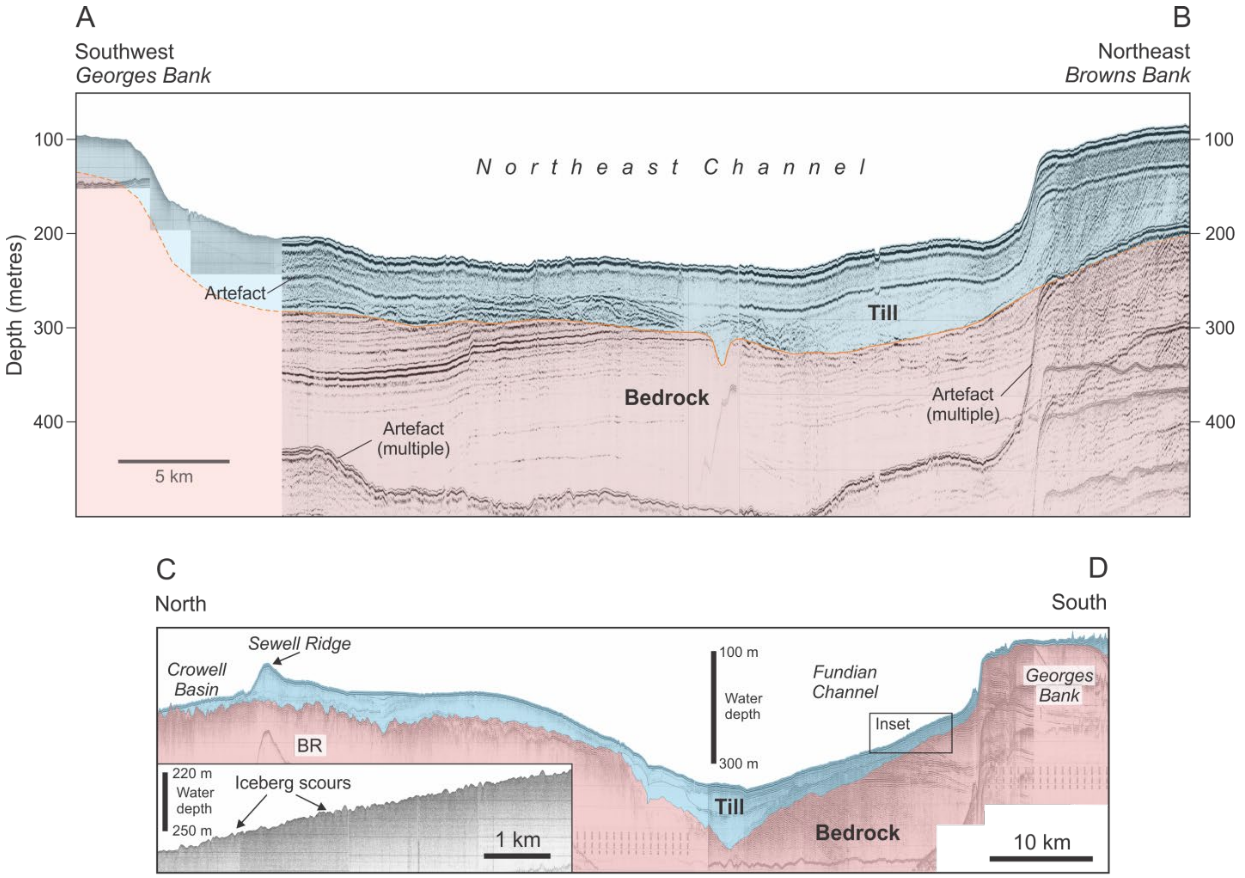

*Figure 6. Upper: seismic reflection profile AB across the Northeast Channel. Lower: seismic reflection profile CD across the Fundian Channel. See Figure 4 for location of profiles.*

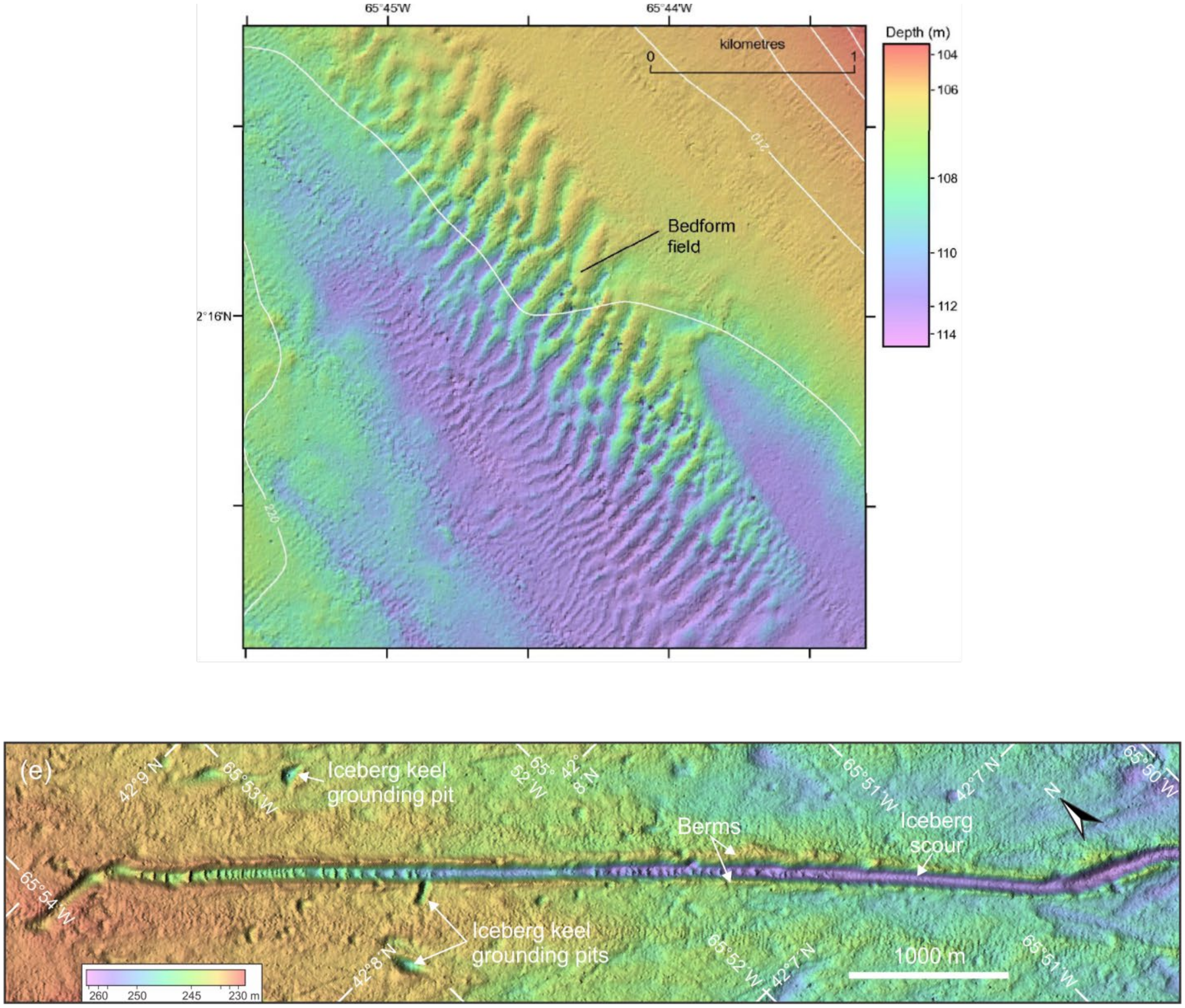

*Figure 7. Upper: Bathymetric detail of flow-transverse sediment bedforms on the north flank of Northeast Channel. Bedform crests are symmetrical and aligned normal to the northwest–southeast current direction. Studies on bedform fields demonstrate complex migration of the larger bedforms and very active mobility of smaller bedforms, not resolved at this scale. See black dot on Figure 4 for location. Lower: Bathymetric detail of a portion of a 14 km long iceberg scour in Northeast Channel showing well defined berms. See white dot on Figure 4 for location.*

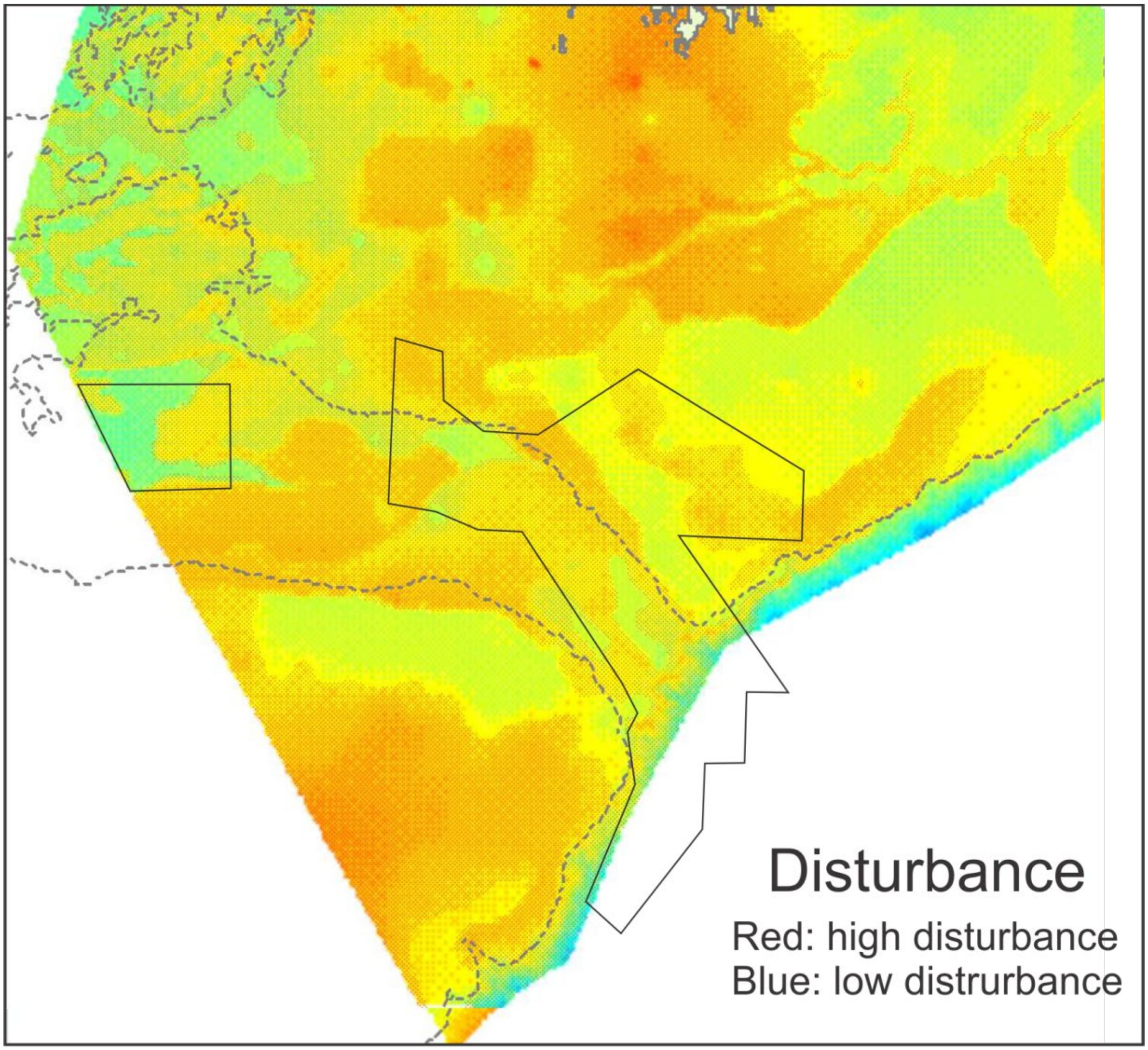

*Figure 8. Disturbance derived from high-resolution bathymetry, sediment grain size, tidal currents, and wave height and period.*

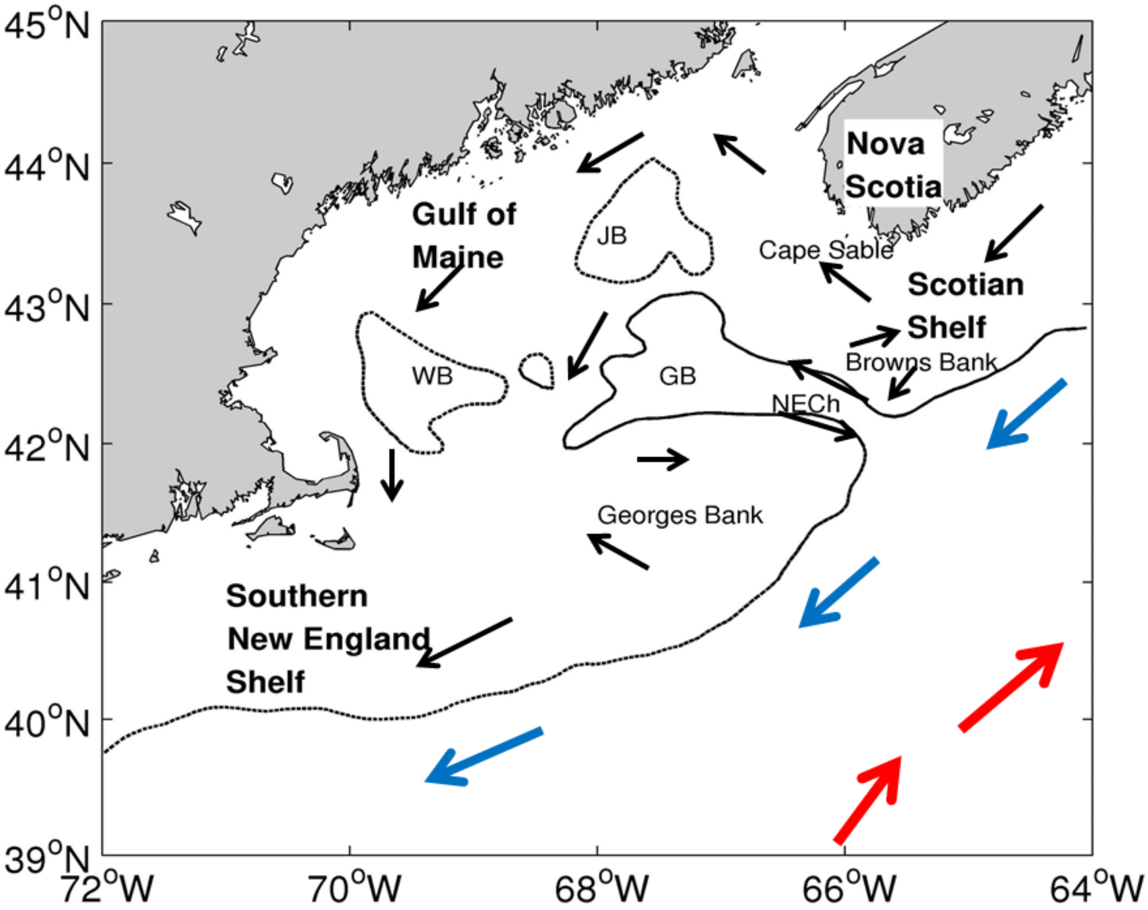

*Figure 9. General circulation patterns for the Northeast Channel (NECh), Jordan Basin (JB), Georges Bank (GB) and Wilkinson Basin (WB). Labrador Current and Gulf Stream denoted by blue and red arrows, respectively.*

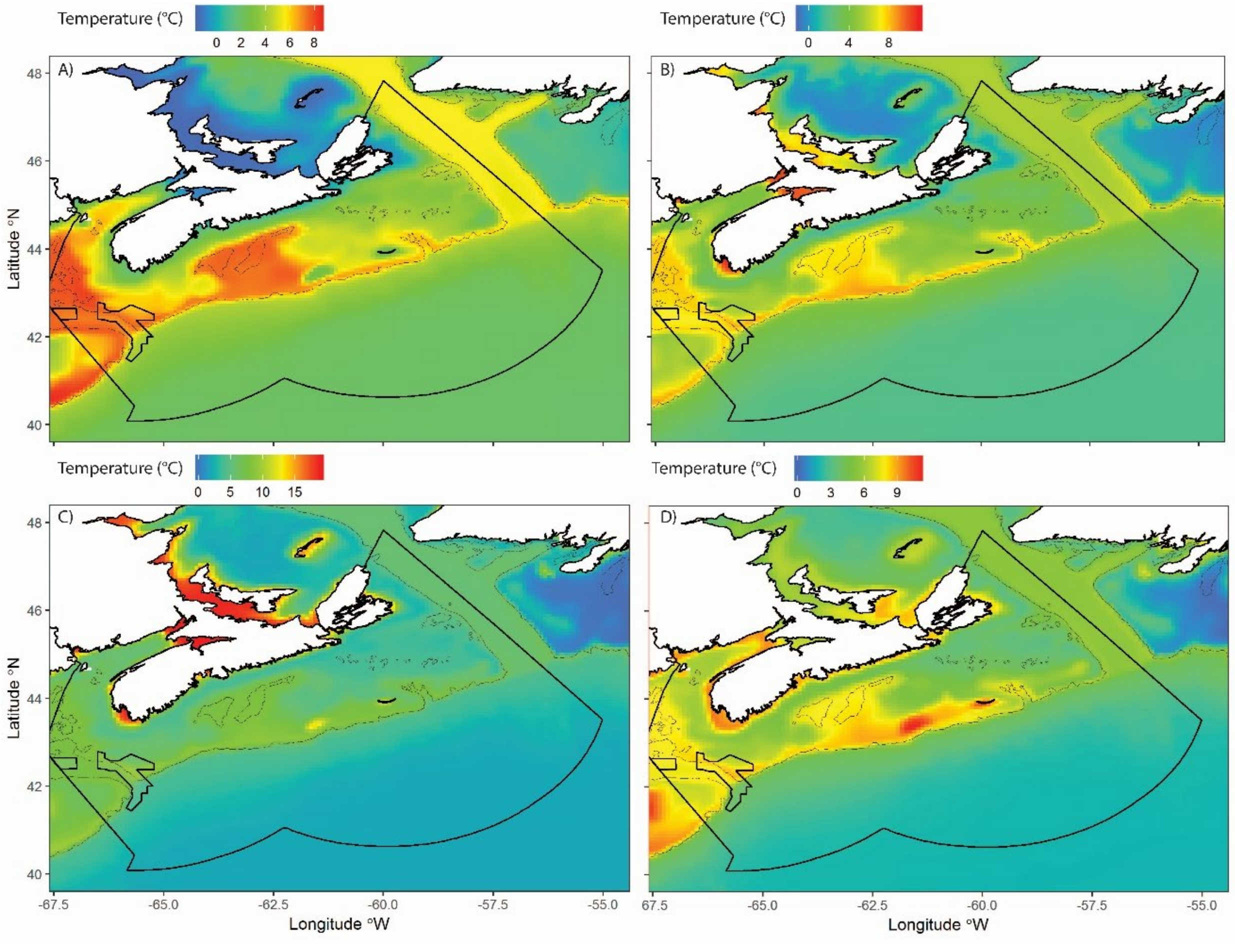

*Figure 10. Seasonally averaged bottom temperature (2008–17) based on ocean models described in Wang et al. 2016. Panels A-D correspond to winter (January–March), spring (April–June), summer (July–September) and fall (October–December), respectively. Data gridded at a resolution of 7.5 km$^2$. Solid lines demark the boundaries of the Scotian Shelf Bioregional planning area and of the Fundian Channel-Browns Bank AOI.*

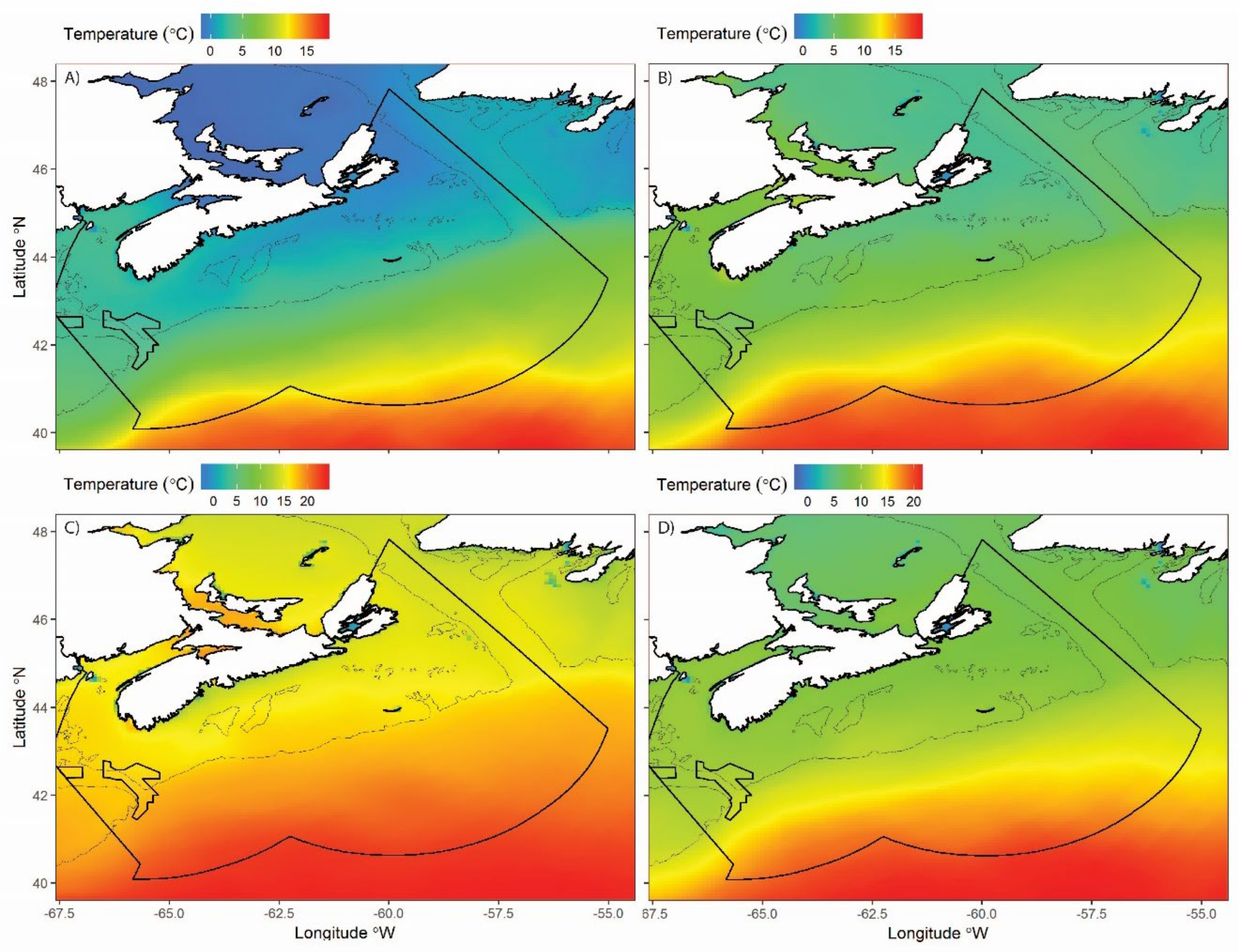

*Figure 11. Seasonally averaged surface temperature (2008–17) based on ocean models described in Wang et al. 2016. Panels A–D correspond to winter (January–March), spring (April–June), summer (July–September) and fall (October–December), respectively. Data gridded at a resolution of 7.5 km$^2$. Solid lines demark the boundaries of the Scotian Shelf Bioregional planning area and of the Fundian Channel-Browns Bank AOI.*

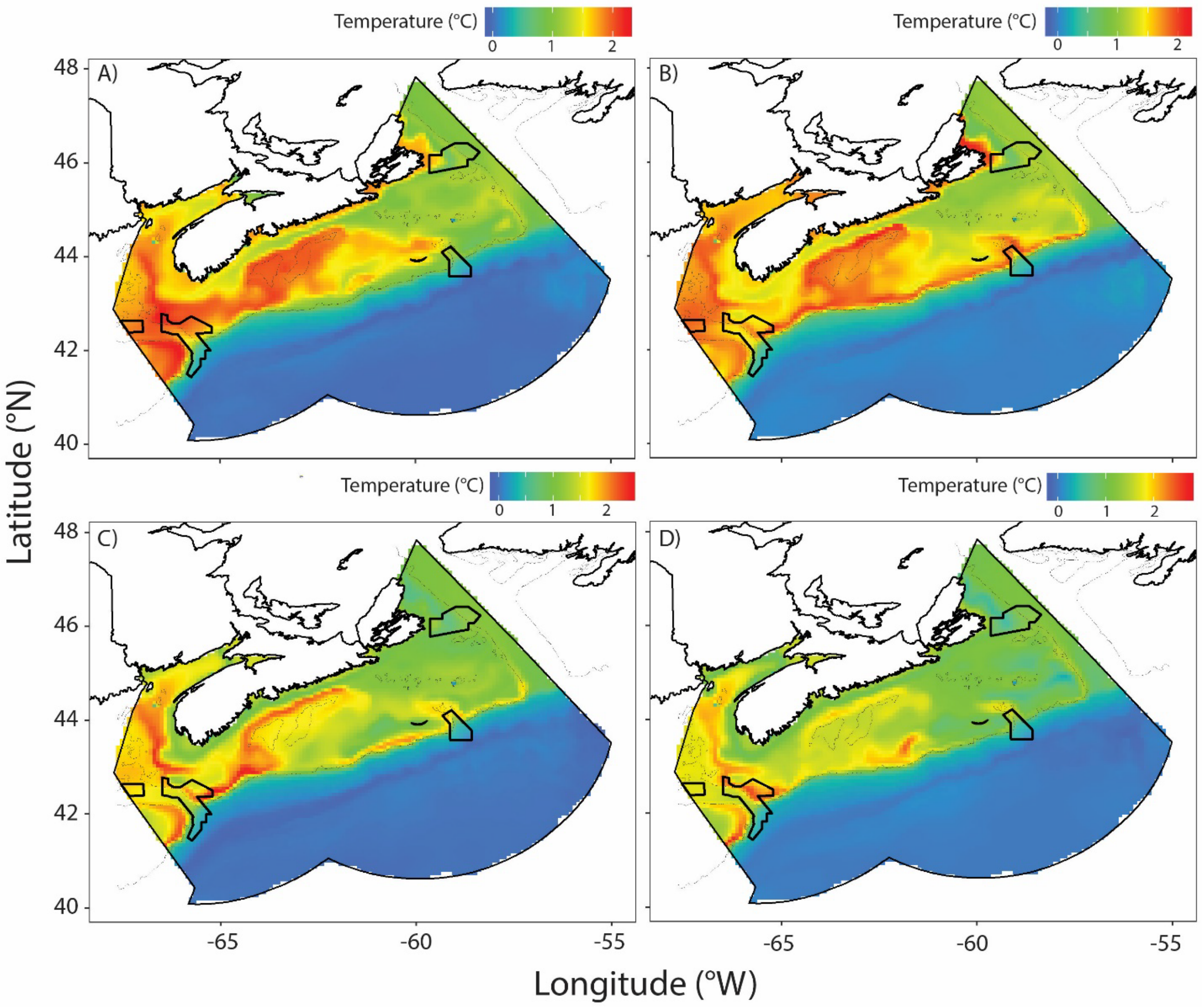

*Figure 12. Seasonally averaged bottom temperature anomalies for the year 2075 based on RCP 8.5 simulations (Brickman et al. 2016). Panels A-D correspond to winter (January–March), spring (April–June), summer (July–September) and fall (October–December), respectively. Anomaly data are gridded at a resolution of 7.5 km$^2$. Climate projections are cropped to the boundaries of the Scotian Shelf Bioregion. Solid lines correspond to the boundaries of the Fundian Channel-Browns Bank AOI, Gully MPA, and St. Anns Bank MPA, oriented from West to East.*

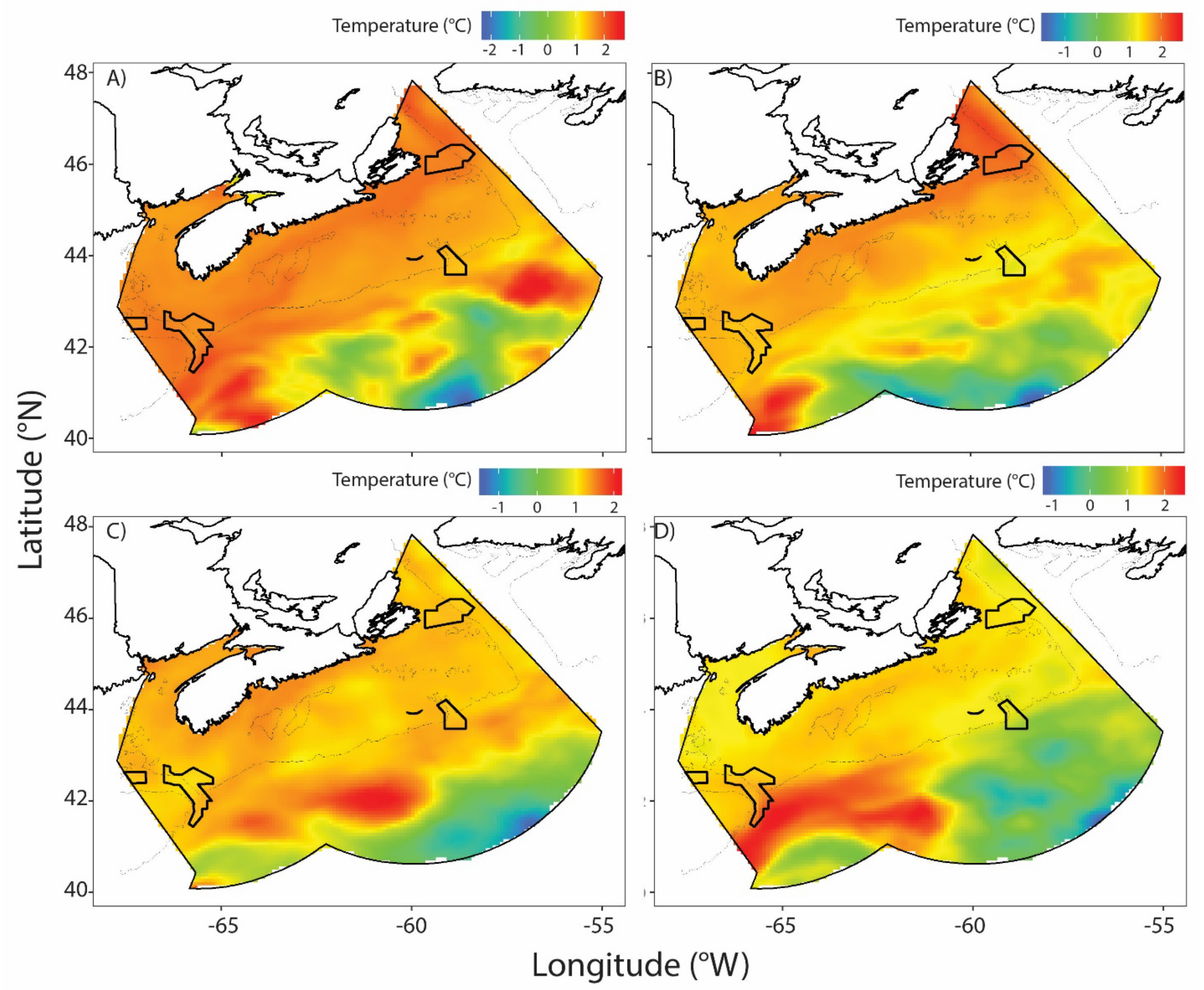

*Figure 13. Seasonally averaged surface temperature anomalies for the year 2075 based on RCP 8.5 simulations (Brickman et al. 2016). Panels A-D correspond to winter (January–March), spring (April–June), summer (July–September) and fall (October–December), respectively. Anomaly data are gridded at a resolution of 7.5 km$^2$. Climate projections are cropped to the boundaries of the Scotian Shelf Bioregion. Solid lines correspond to the boundaries of the Fundian Channel-Browns Bank AOI, Gully MPA, and St. Anns Bank MPA, oriented from West to East.*

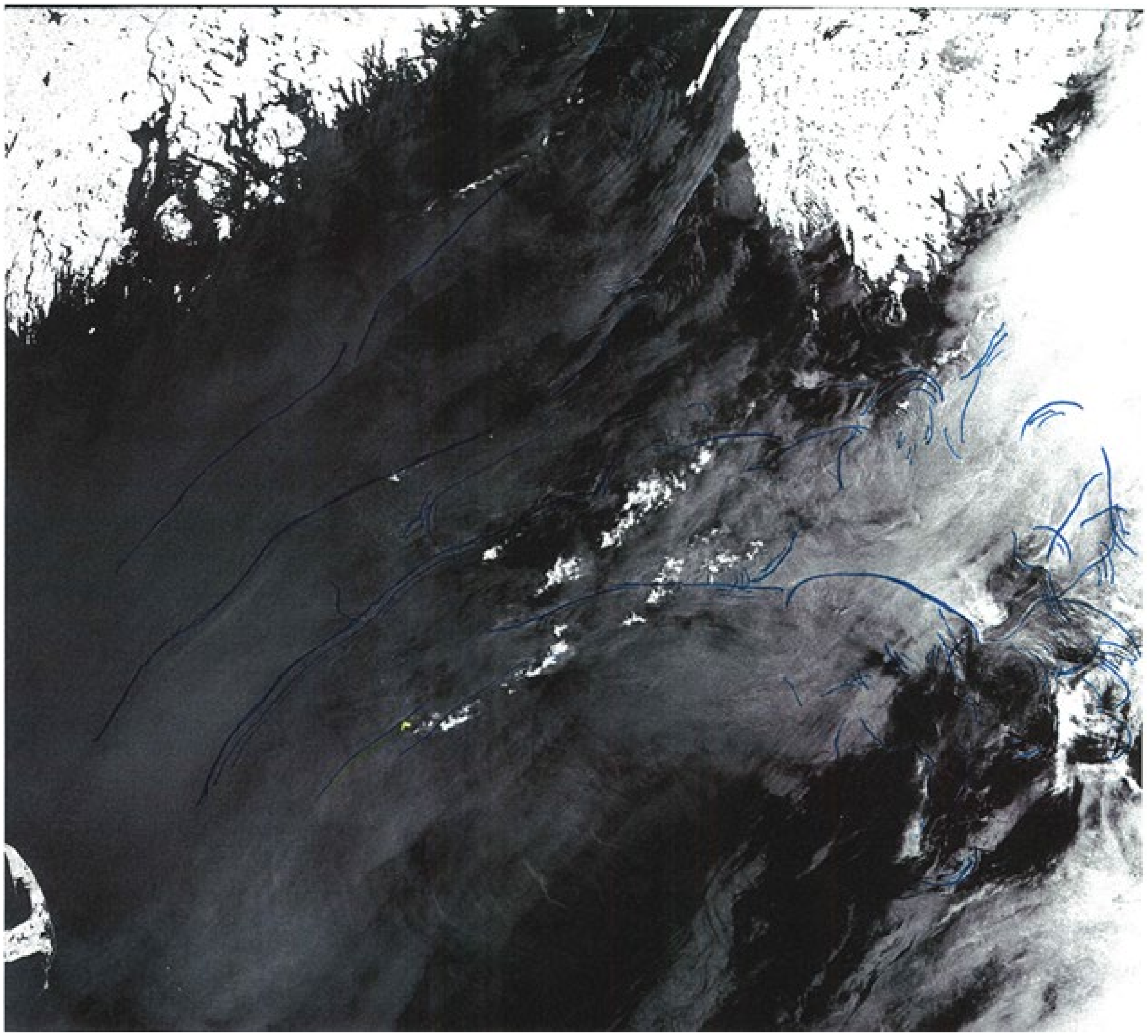

*Figure 14. Internal wave observed by Synthetic Aperture Radar (SAR) images of Gulf of Maine. RADARSAT®-2 SAR Data for August 28, 2014 (Image copyright: MacDonald, Dettwiler, and Associates. Blue lines highlight position of internal waves identified in SAR image.*

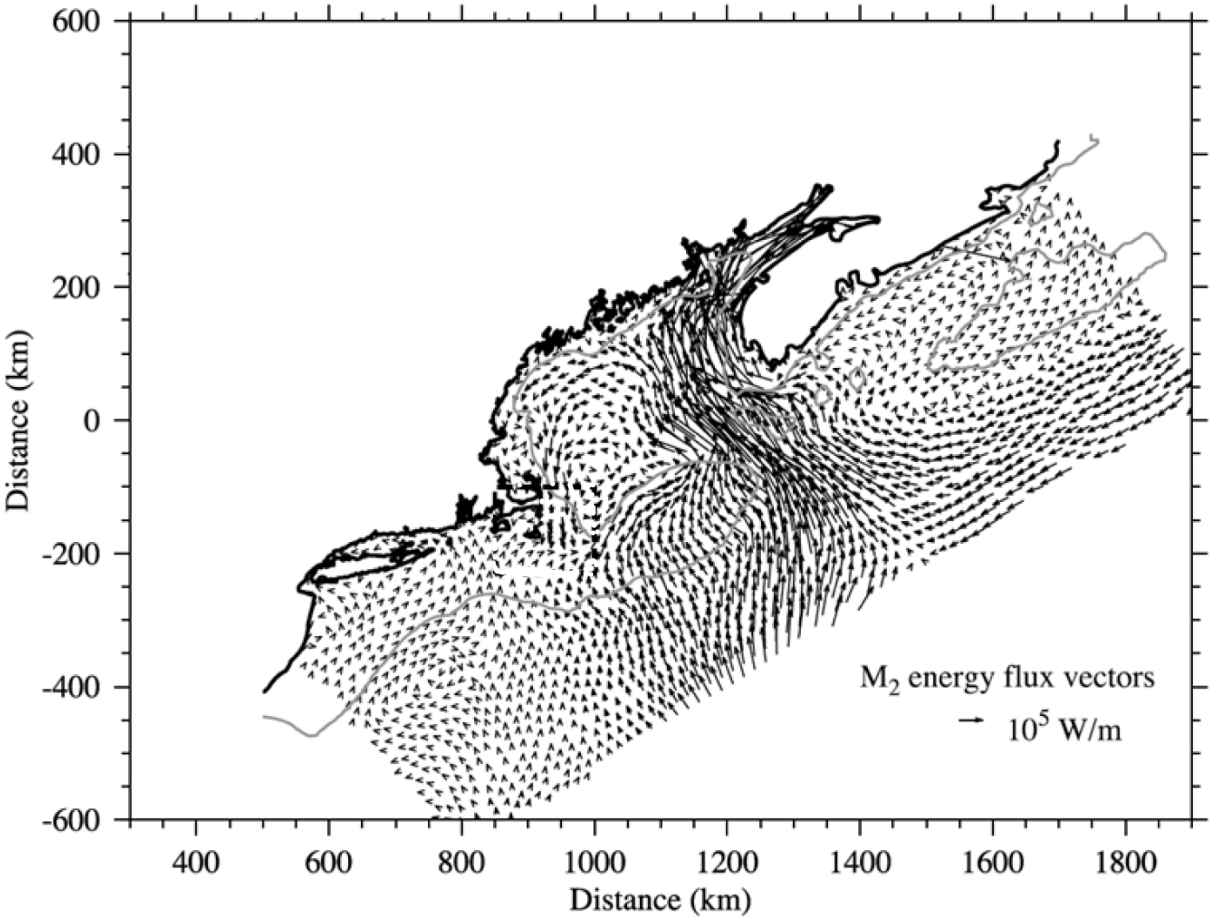

*Figure 15. Map of the M2 tidal energy flux vectors in the region. Adapted from Chen et al., (2011).*

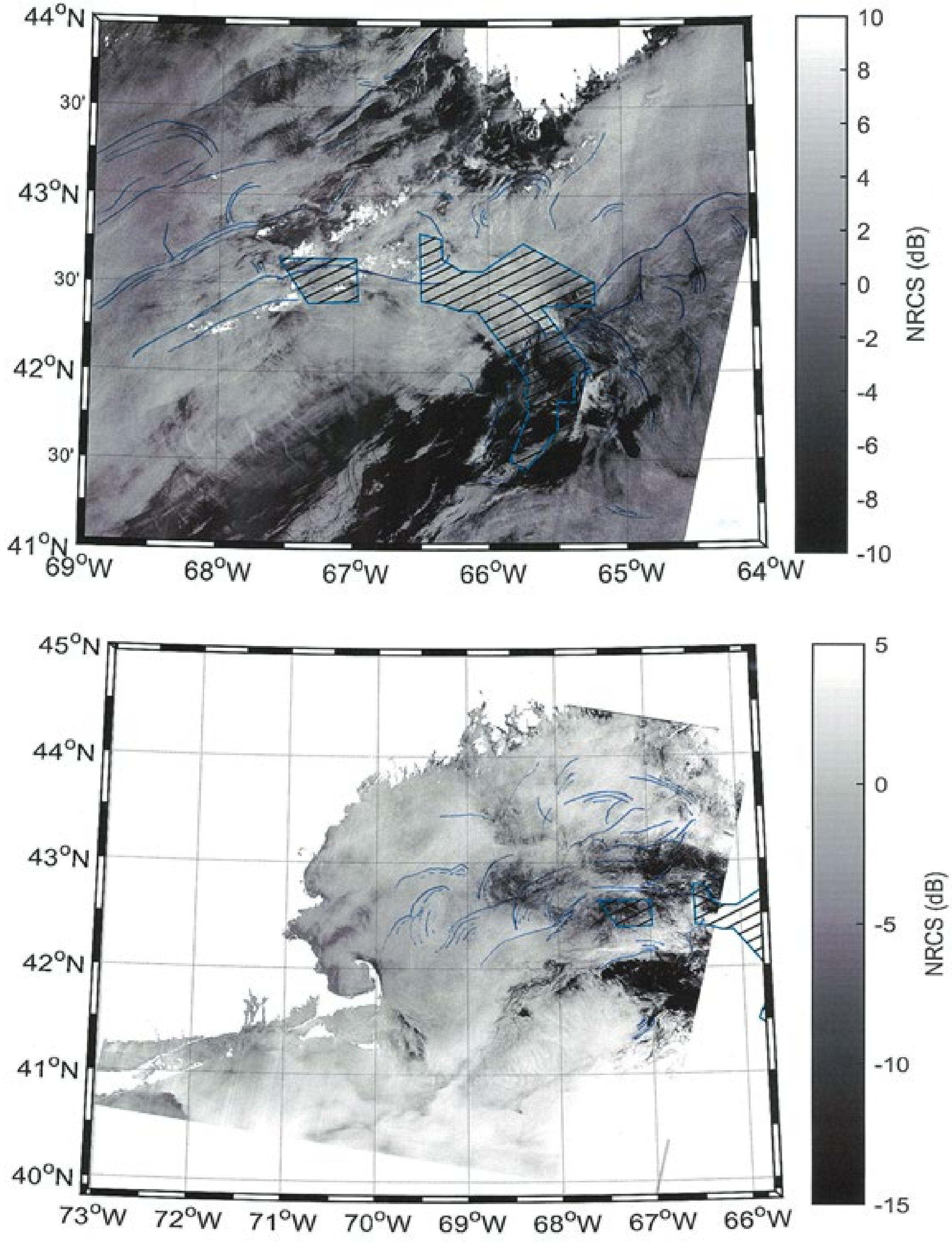

*Figure 16. Internal waves observed by synthetic aperture radar in the Fundian Channel - Browns Bank (upper: Apr.28, 2014; lower: Jul.31, 2012). Colour bar NRCS (dB) stands for Normalized Radar cross Section, and the blue lines highlight internal waves identified in SAR images.*

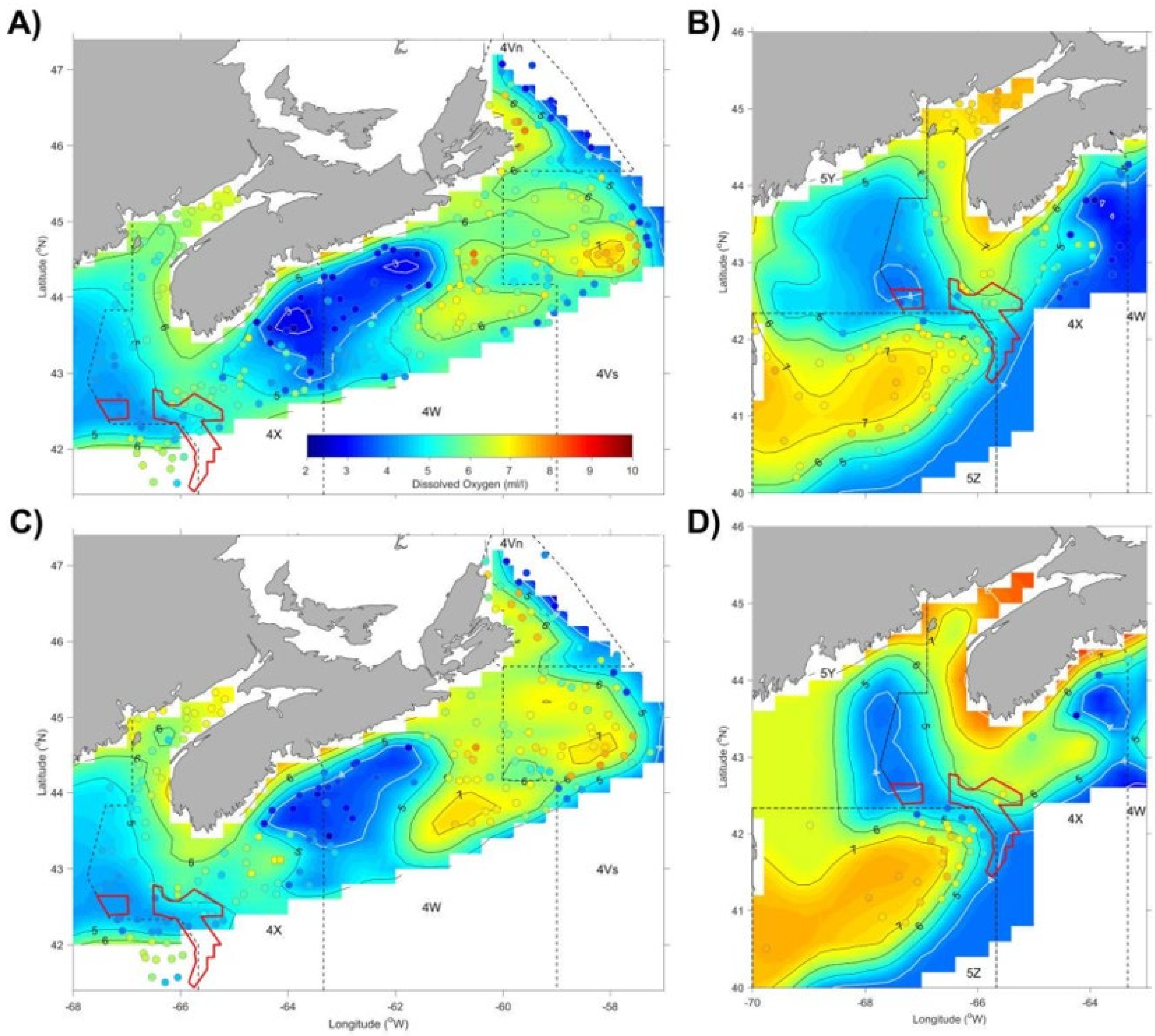

*Figure 17. Dissolved oxygen levels (ml/L) across the Scotian Shelf from the summer (A) and winter (B) in 2016, and summer (C) and winter (D) in 2017. Generally the deeper portions of the Scotian Shelf and Gulf of Maine have lower dissolved oxygen levels. Maps are the result of an interpolated model based on CTD casts measuring dissolved oxygen (filled circles). The Area of Interest study area is outlined in red.*

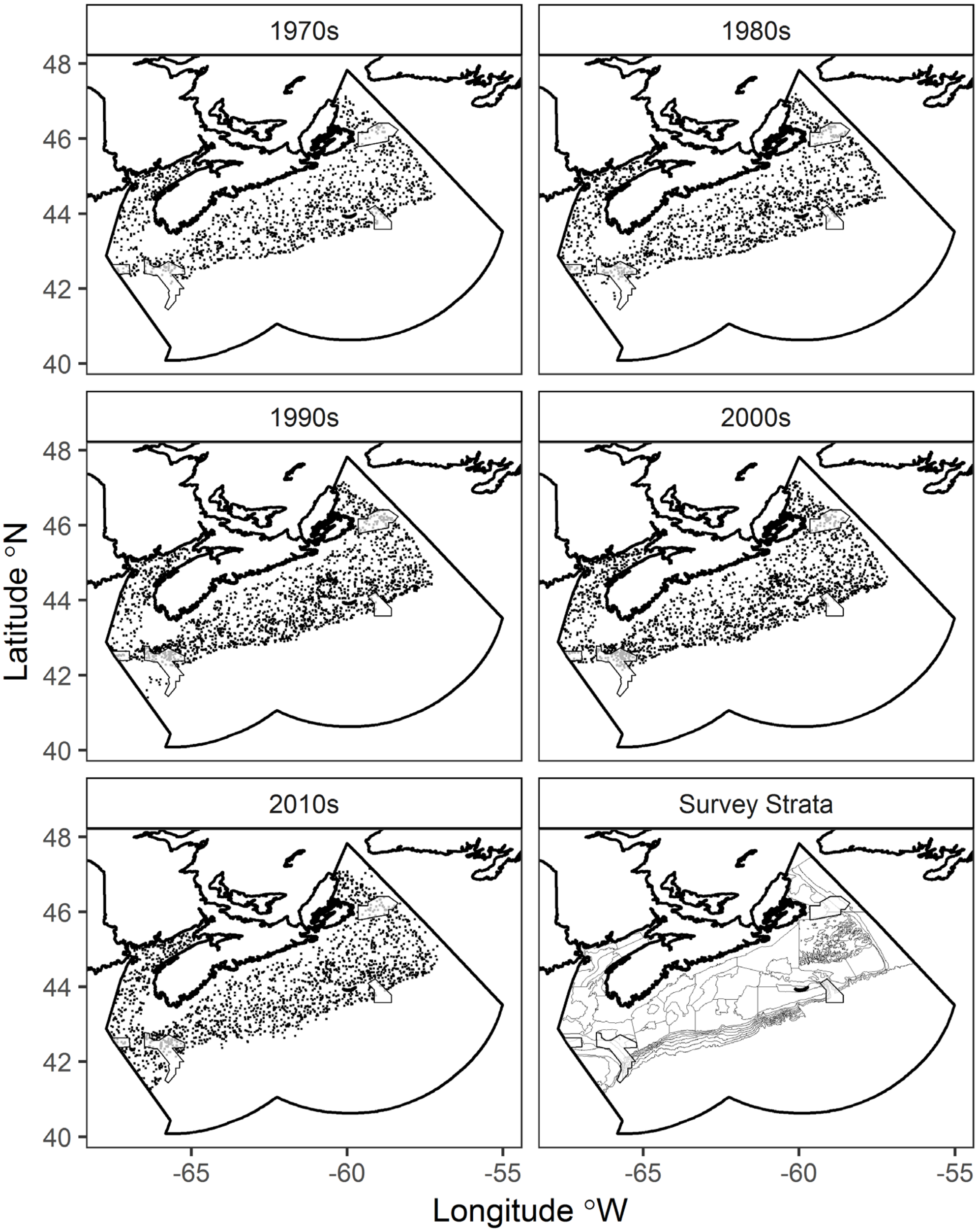

*Figure 18. Summary of sample locations for the Maritimes Region Summer Multispecies Research Vessel Survey aggregated by decade. Current survey strata mapped in bottom right. The Fundian Channel-Browns Bank Area of Interest, along with the Gully and St. Anns Bank Marine Protected Areas, are plotted as transparent polygons.*

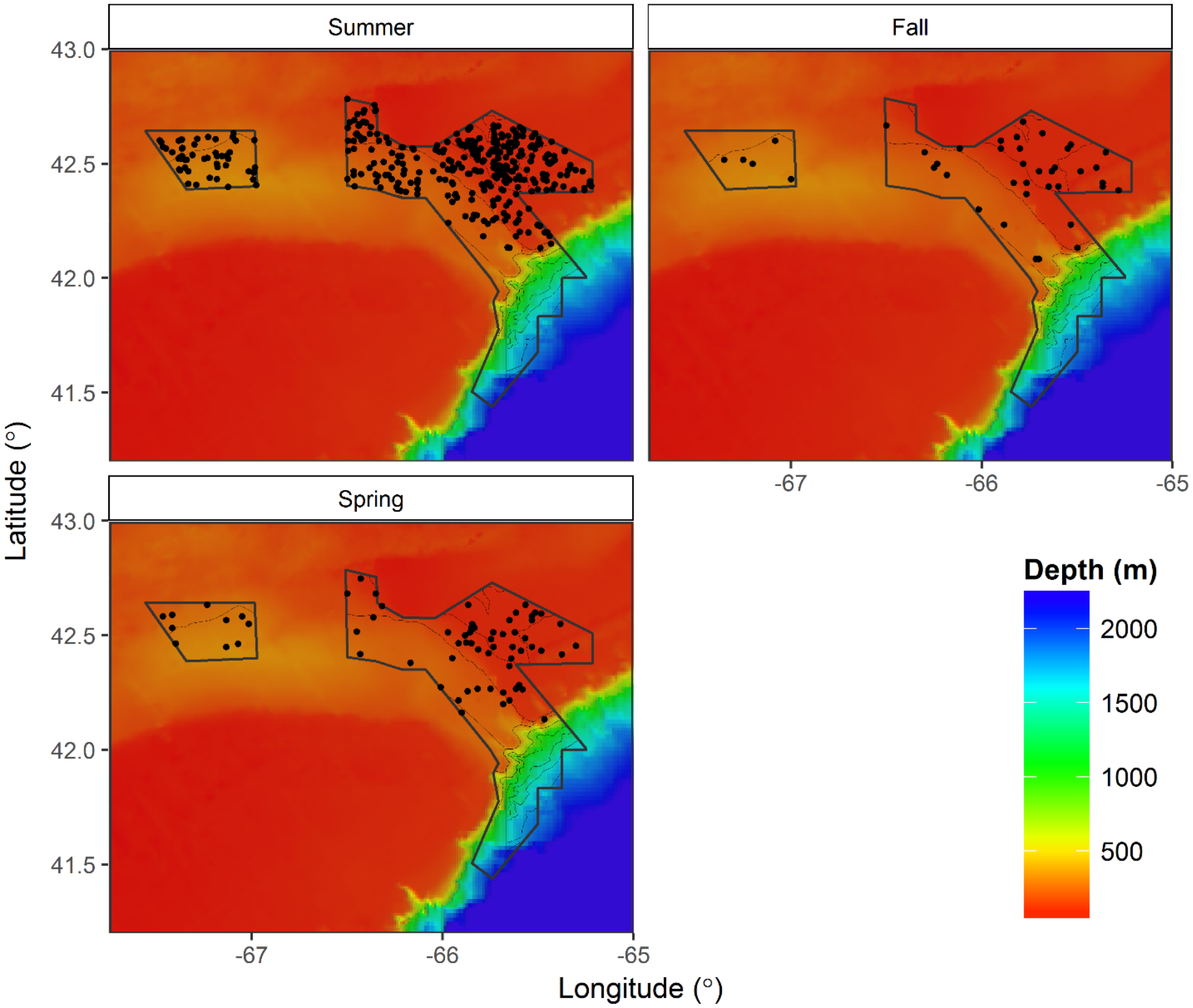

*Figure 19. Distribution of valid sets (duration longer than 20 minutes; n = 467) within the Fundian Channel-Browns Bank Area of Interest boundaries by the Summer, Fall and Spring Multispecies RV Surveys (1970–2017) overlaid on bathymetry scaled to the maximum depth within the Area of Interest (2251 m). Grey lines denote Research Vessel Survey strata that intersect with the Area of Interest.*

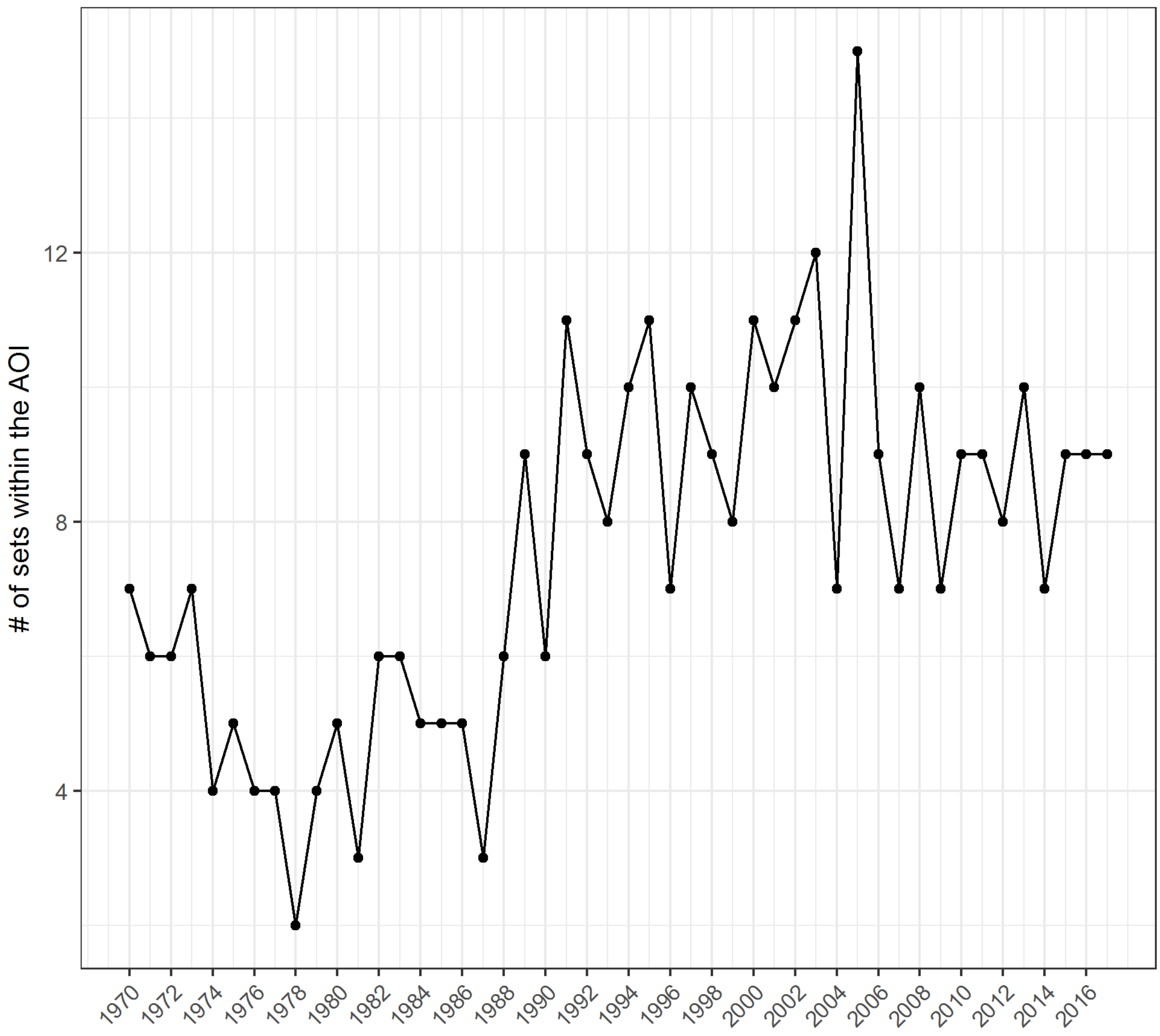

*Figure 20. Number of valid sets (duration longer than 20 minutes) within the Fundian Channel-Browns Bank Area of Interest boundaries by the summer Multispecies Research Vessel Survey (1970–2017).*

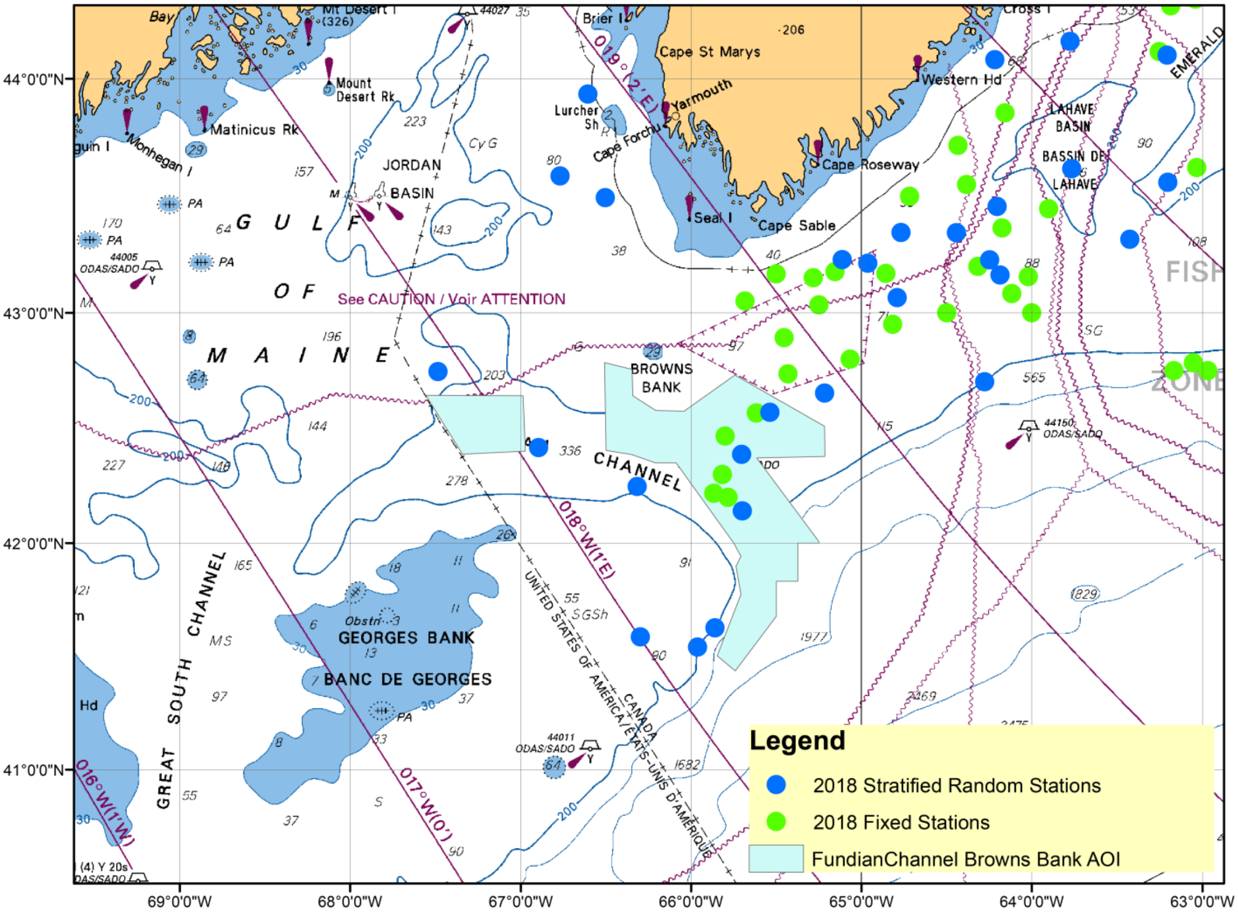

*Figure 21. Example of stratified random and fixed stations from the Industry-DFO Longline Halibut Survey within and in the vicinity of the Area of Interest in 2018.*

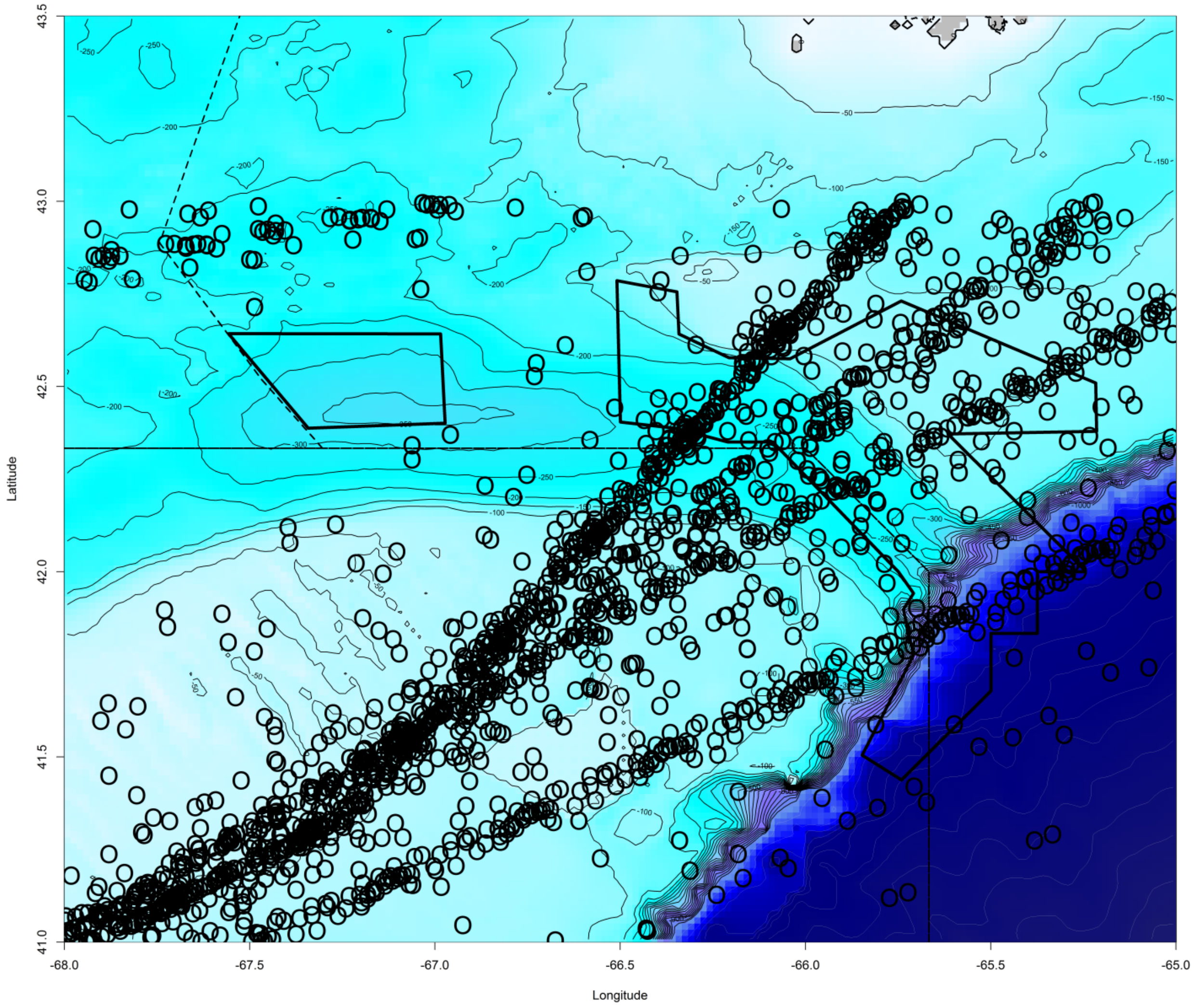

*Figure 22. Sampling locations from the Continuous Plankton Recorder in the vicinity of the Area of Interest from 1971 to 2016. A large gap in data collected by the Continuous Plankton Recorder in this region exists between 1973 and 1991.*

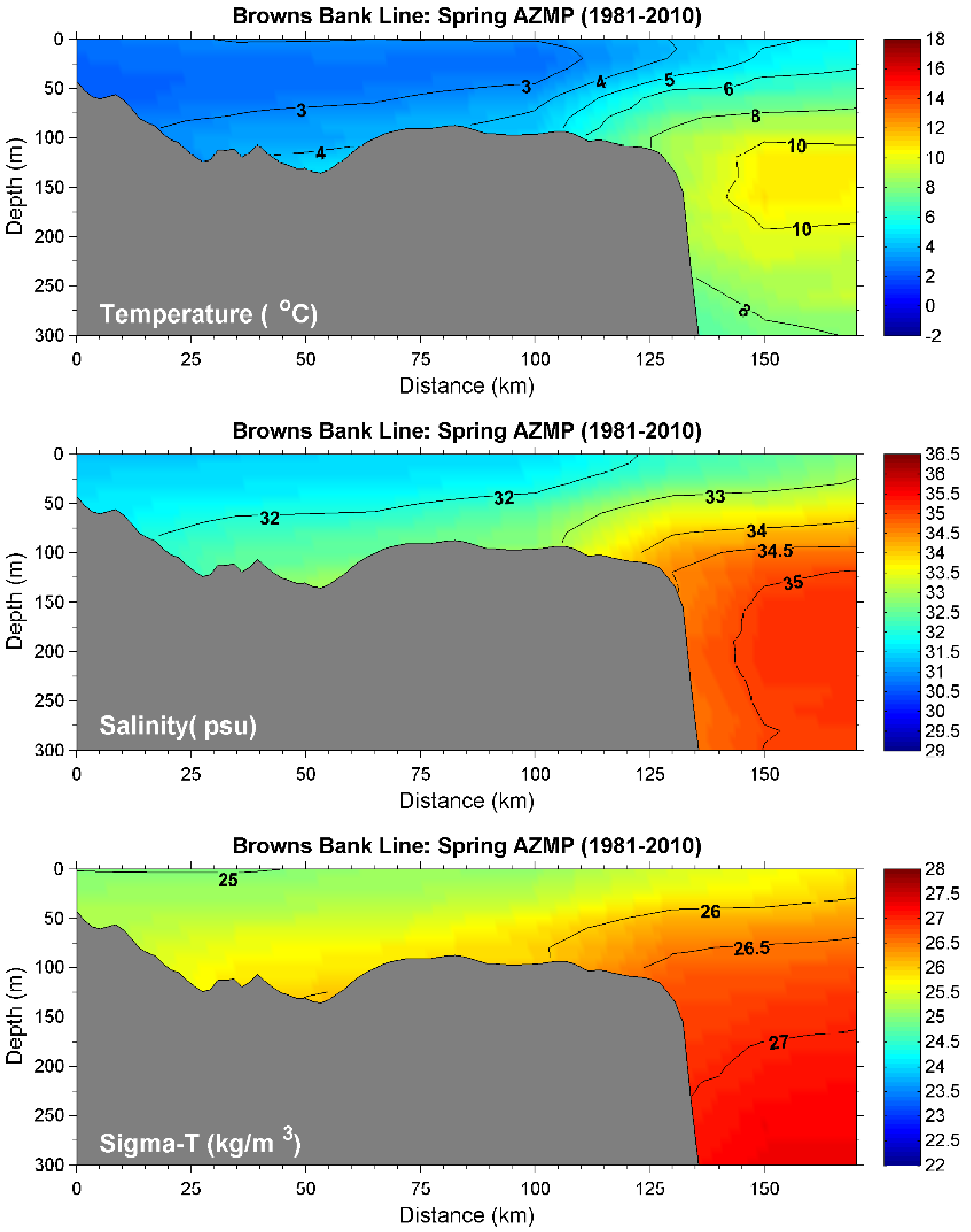

*Figure 23. Atlantic Zone Monitoring Program average temperature, salinity, and sigma-T profiles along the Browns Bank Line from the spring, 1981–2010.*

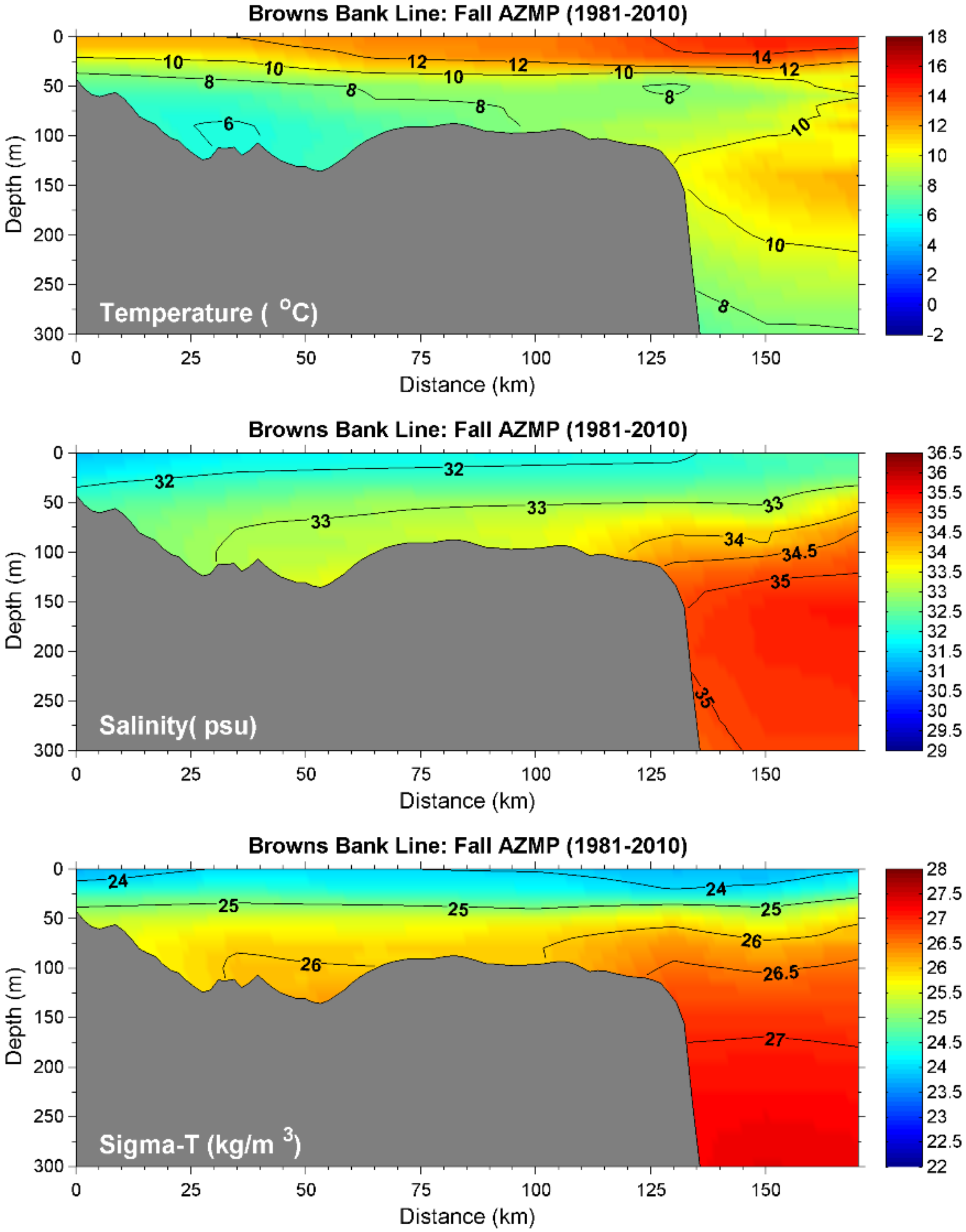

*Figure 24. Atlantic Zone Monitoring Program average temperature, salinity, and sigma-T profiles along the Browns Bank Line from the fall, 1981–2010.*

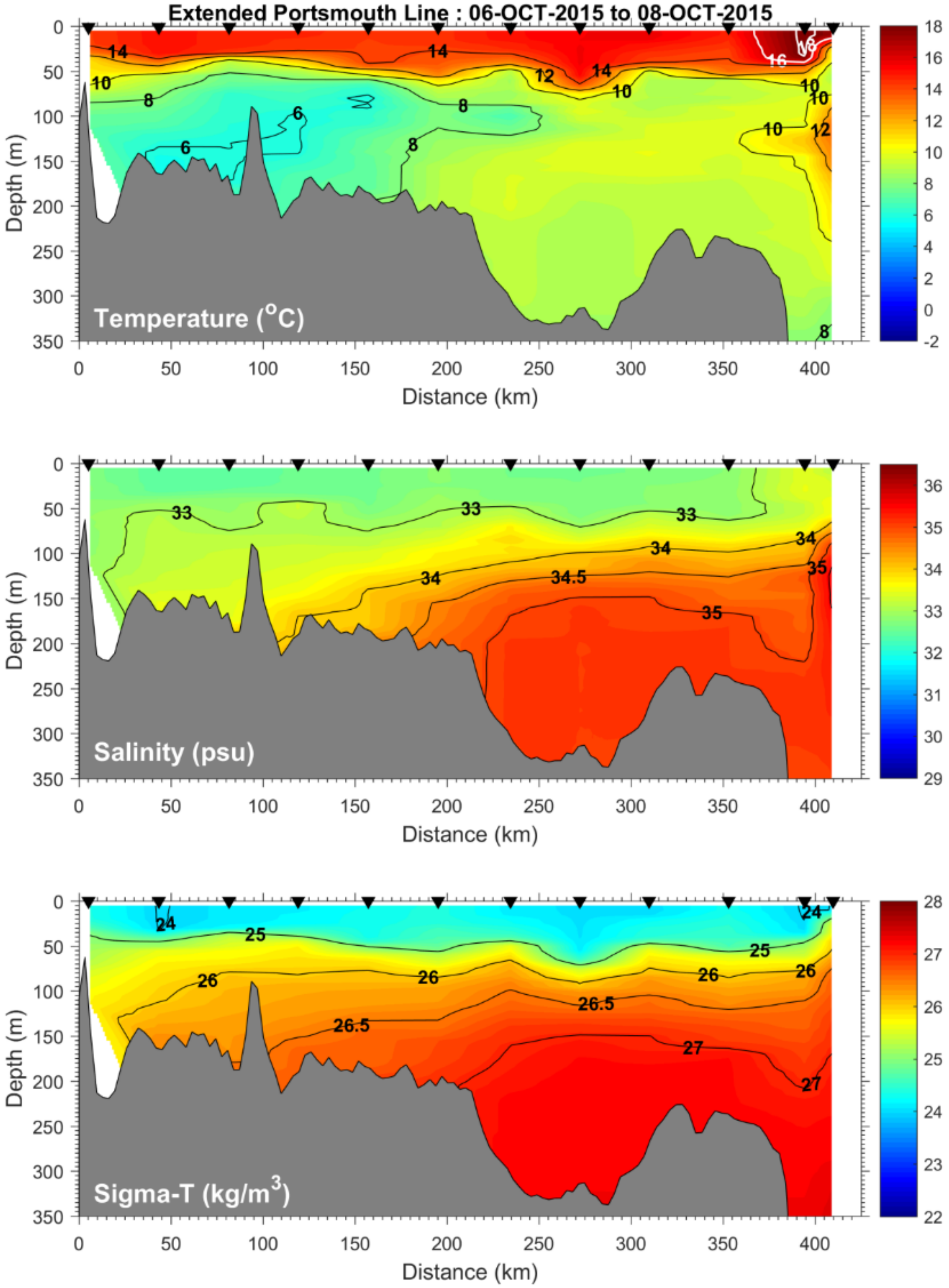

*Figure 25. Atlantic Zone Monitoring Program temperature, salinity, and sigma-T profiles from the extended Portsmouth Line extending into the Fundian Channel from October 6–8, 2015.*

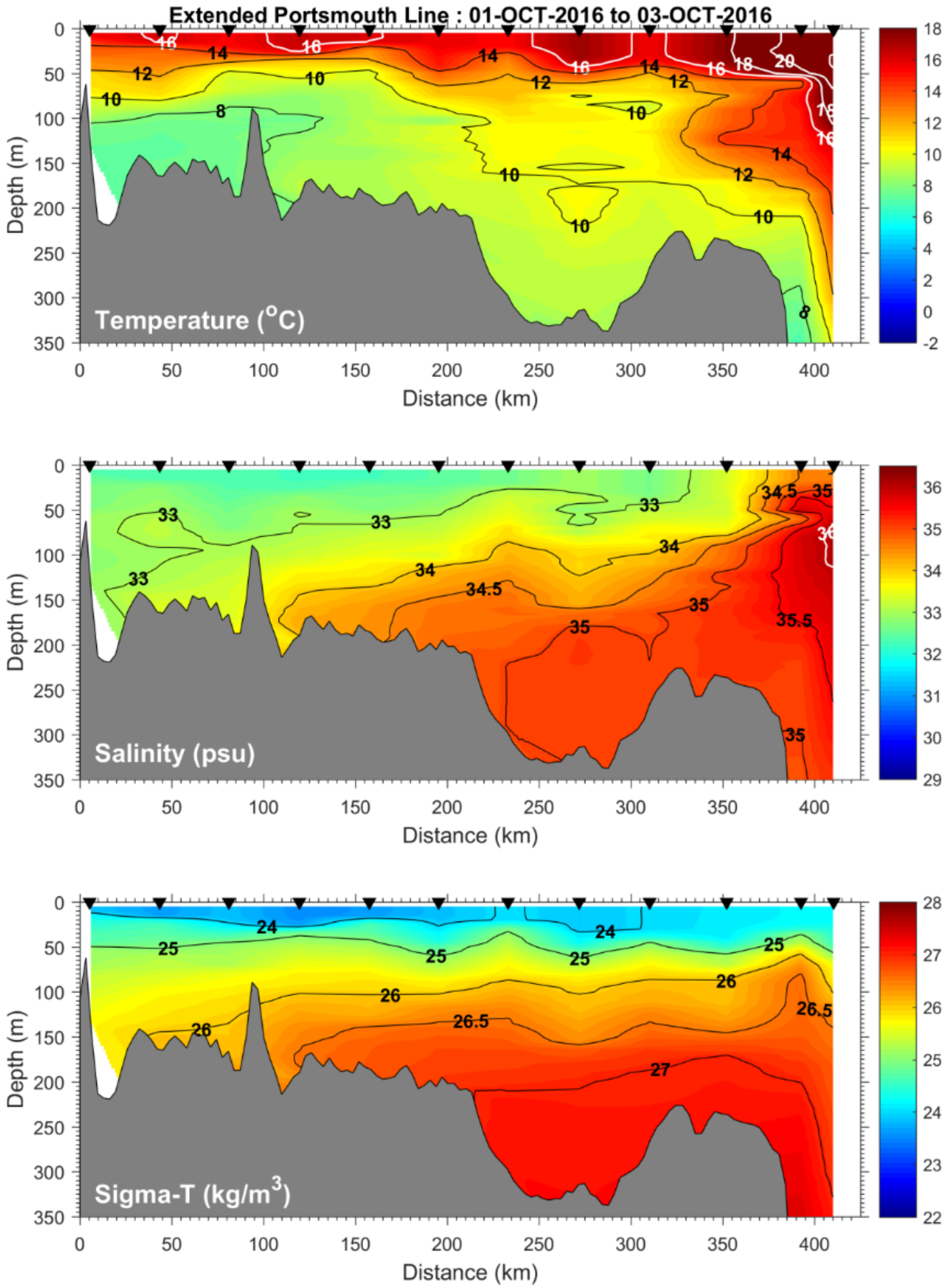

*Figure 26. Atlantic Zone Monitoring Program temperature, salinity, and sigma-T profiles from the extended Portsmouth Line extending into the Fundian Channel from October 1–3, 2016.*

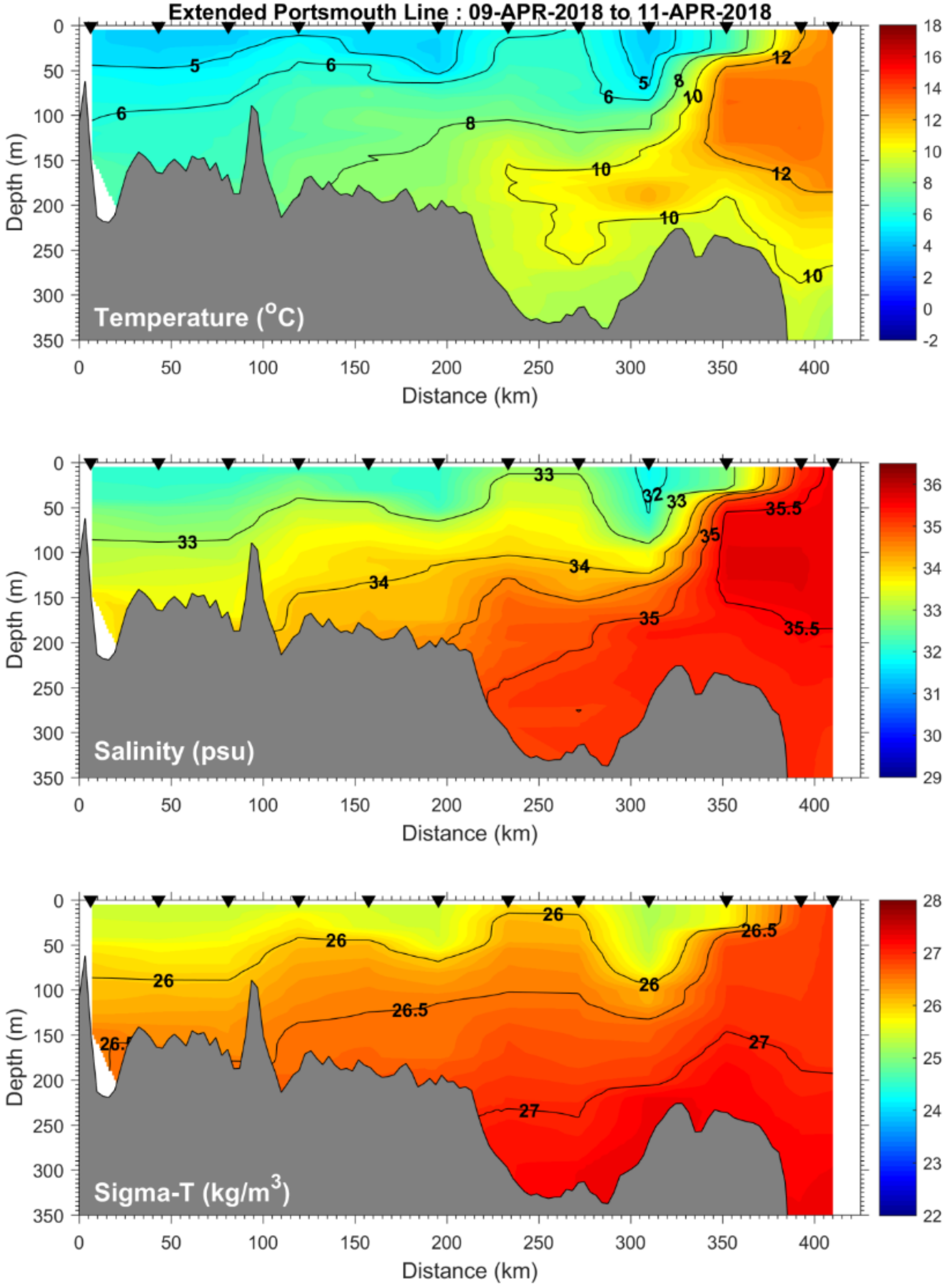

*Figure 27. Atlantic Zone Monitoring Program temperature, salinity, and sigma-T profiles from the extended Portsmouth Line extending into the Fundian Channel from April 9–11, 2018.*

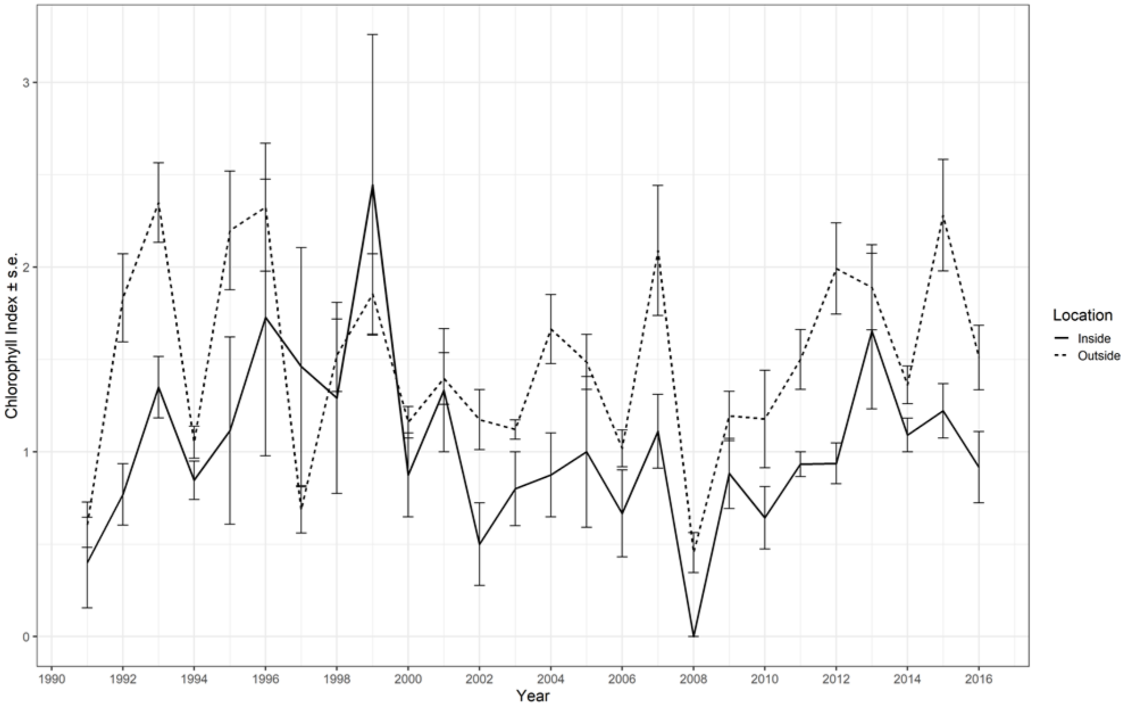

*Figure 28. Chlorophyll Indices from the Continuous Plankton Recorder from 1991 to 2016 within and in the vicinity of the Area of Interest (refer to Figure 22). The Chlorophyll Index is generally higher outside the Area of Interest than within it across the time series ([doi:10.7487/2018.221.1.1137](doi:10.7487/2018.221.1.1137)).*

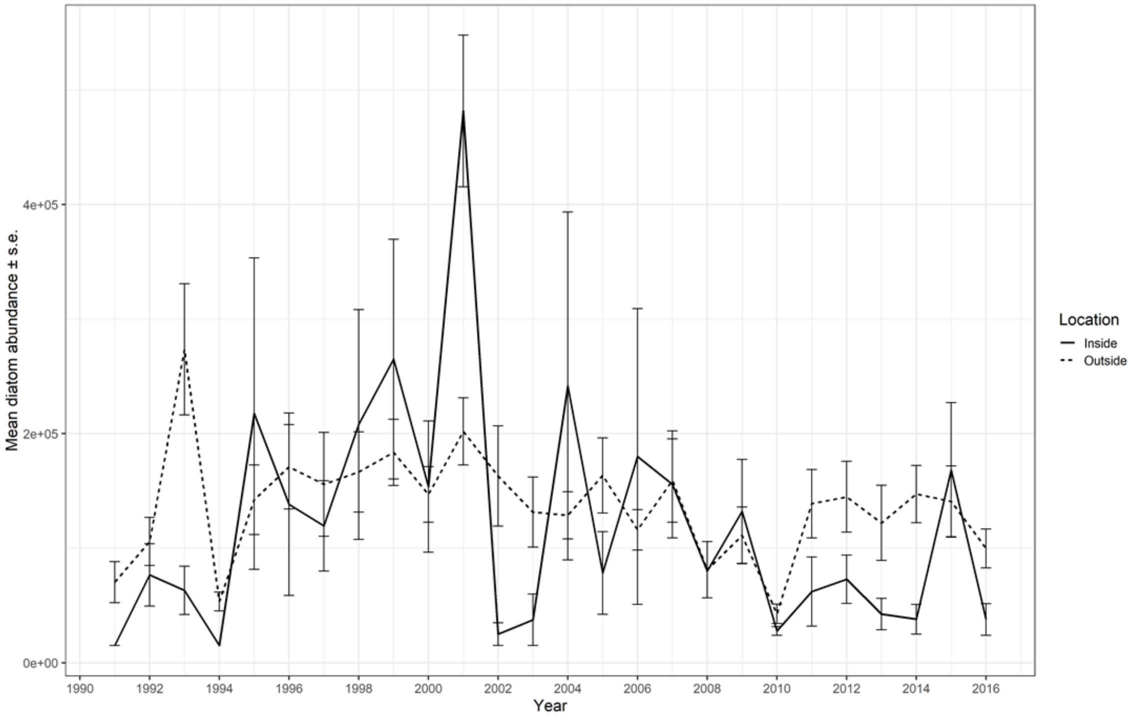

*Figure 29. The mean number of diatoms collected by the Continuous Plankton Recorder averaged by year from 1991 to 2016 within and in the vicinity of the Area of Interest (refer to Figure 22). The number of diatoms within and outside of the Area of Interest is shown (doi:[10.7487/2018.221.1.1137](10.7487/2018.221.1.1137)).*

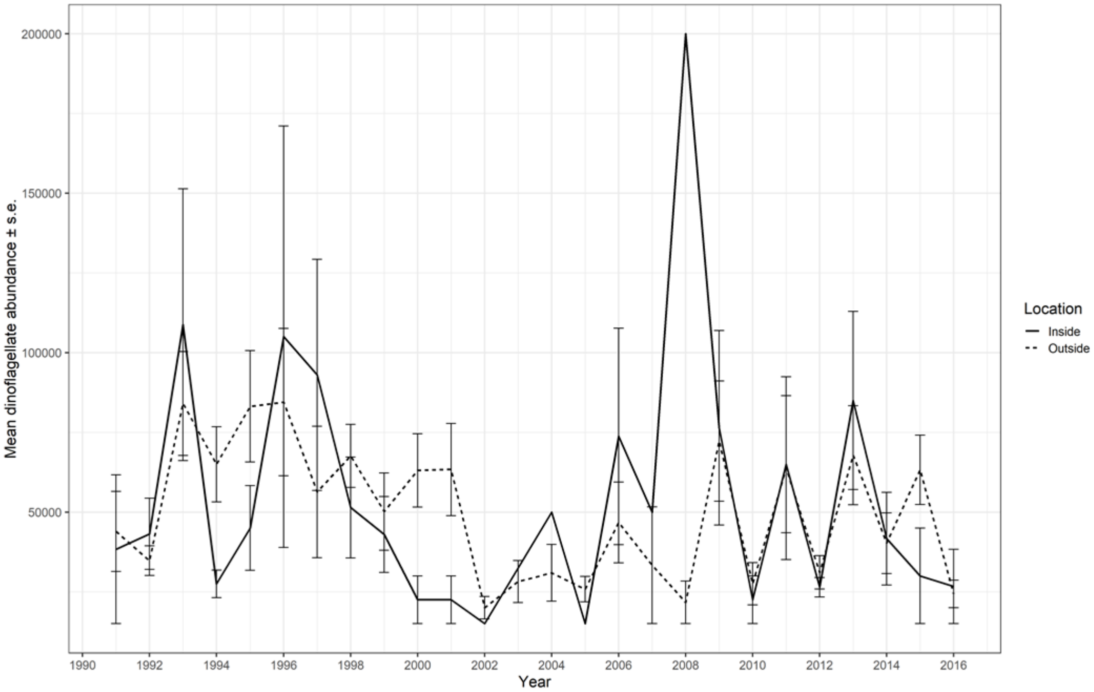

*Figure 30. The mean number of dinoflagellates collected by the Continuous Plankton Recorder averaged by year from 1991 to 2016 within and in the vicinity of the Area of Interest (refer to Figure 22 for sample locations). The number of dinoflagellates within and outside of the Area of Interest is shown. The number of dinoflagellates shows several large peaks within the Area of Interest and a cyclical pattern in abundance overall (doi:[10.7487/2018.221.1.1137](https://doi.org/10.7487/2018.221.1.1137)).*

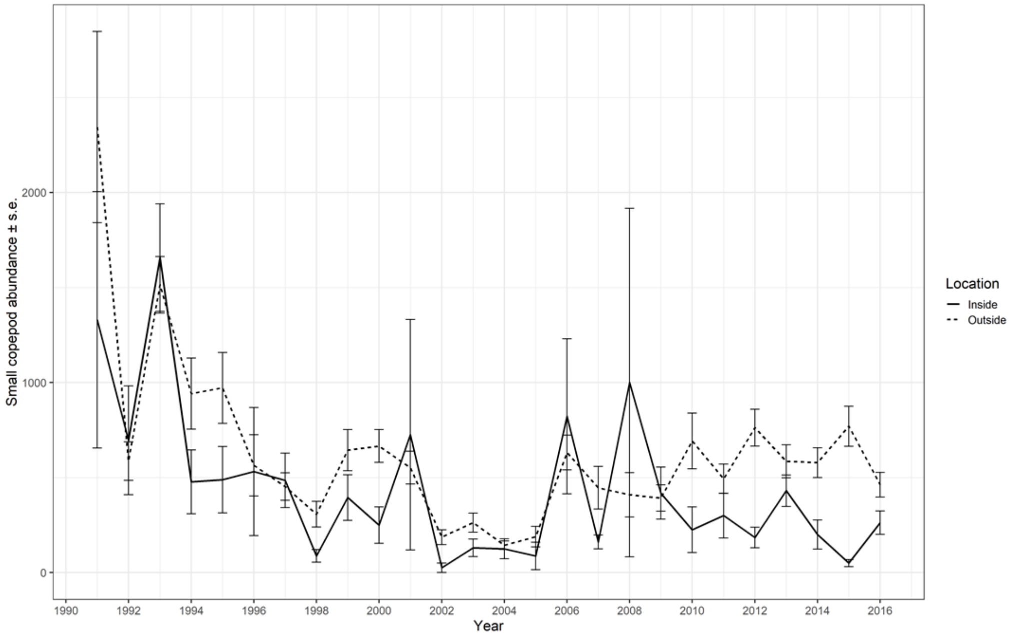

*Figure 31. The mean number of small copepods collected by the Continuous Plankton Recorder averaged by year from 1991 to 2016 within and in the vicinity of the AOI (refer to Figure 22 for sample locations). The number of small copepods within and outside of the AOI shows a general decline from 1991 to 2002, and are similar both inside and outside the AOI (doi:[10.7487/2018.221.1.1137](https://doi.org/10.7487/2018.221.1.1137)).*

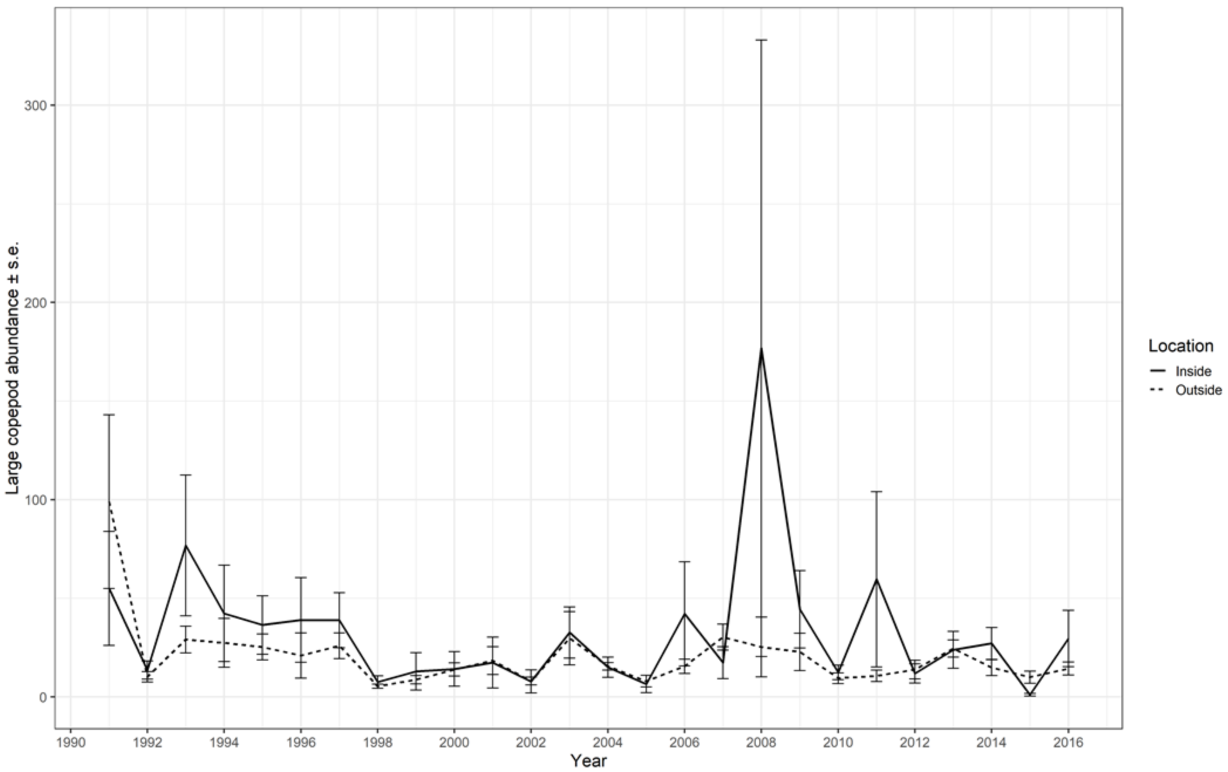

*Figure 32. The mean number of large copepods collected by the Continuous Plankton Recorder averaged by year from 1991 to 2016 within and in the vicinity of the AOI (refer to Figure 22 for sample locations). The number of large copepods within and outside of the AOI is generally constant, with a large increase in large copepods in 2008 within the AOI (doi:10.7487/2018.221.1.1137).*

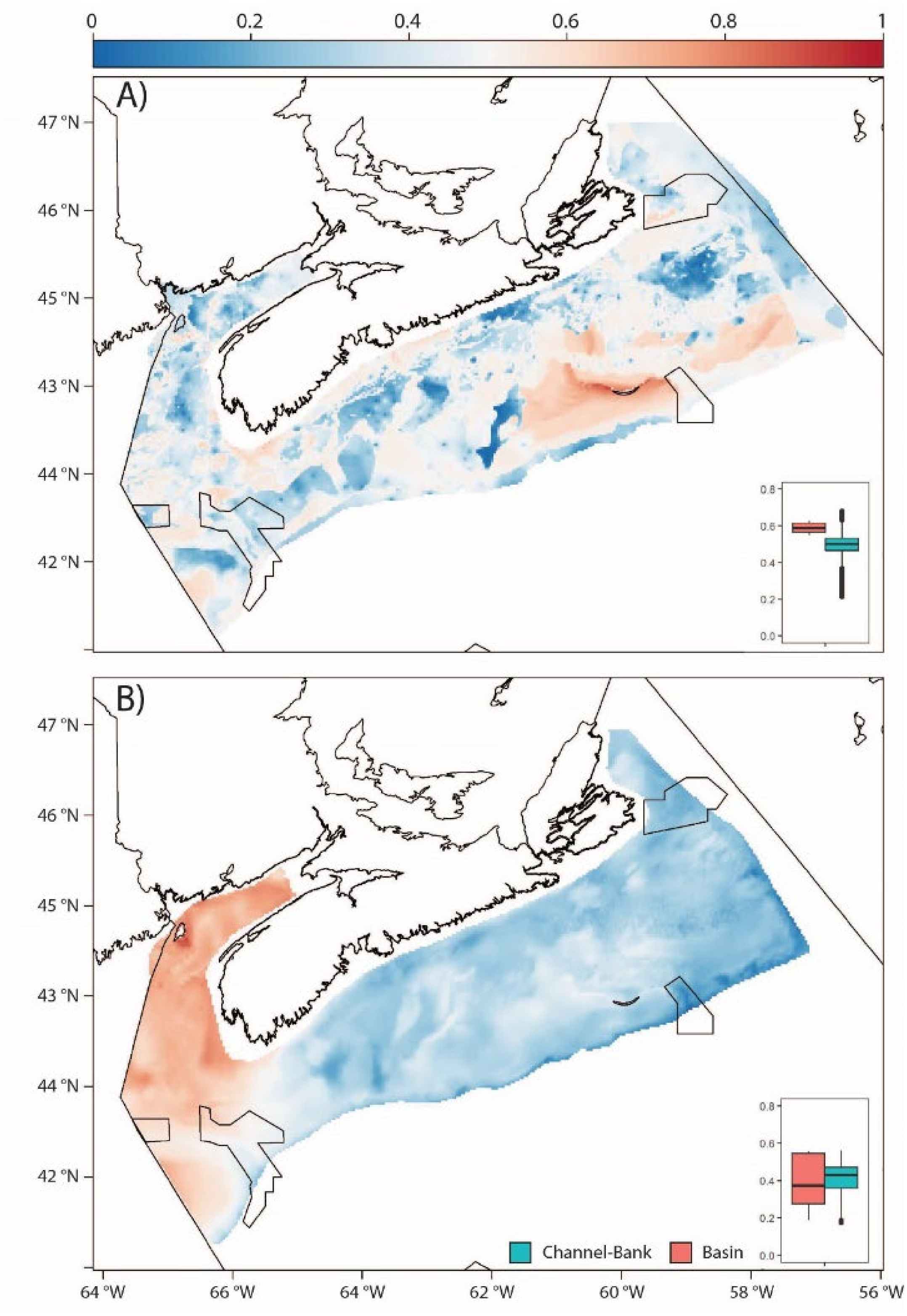

*Figure 33. Summary of seascape axes of the habitat template model by Kostylev and Hannah (2007): A) map of the Natural Disturbance axis and B) Scope for Growth. Insets show the distribution of each axis variable within the AOI subcomponents. Polygons on the map represent St. Anns Bank MPA, the Gully MPA, and the Fundian Channel–Browns Bank AOI.*

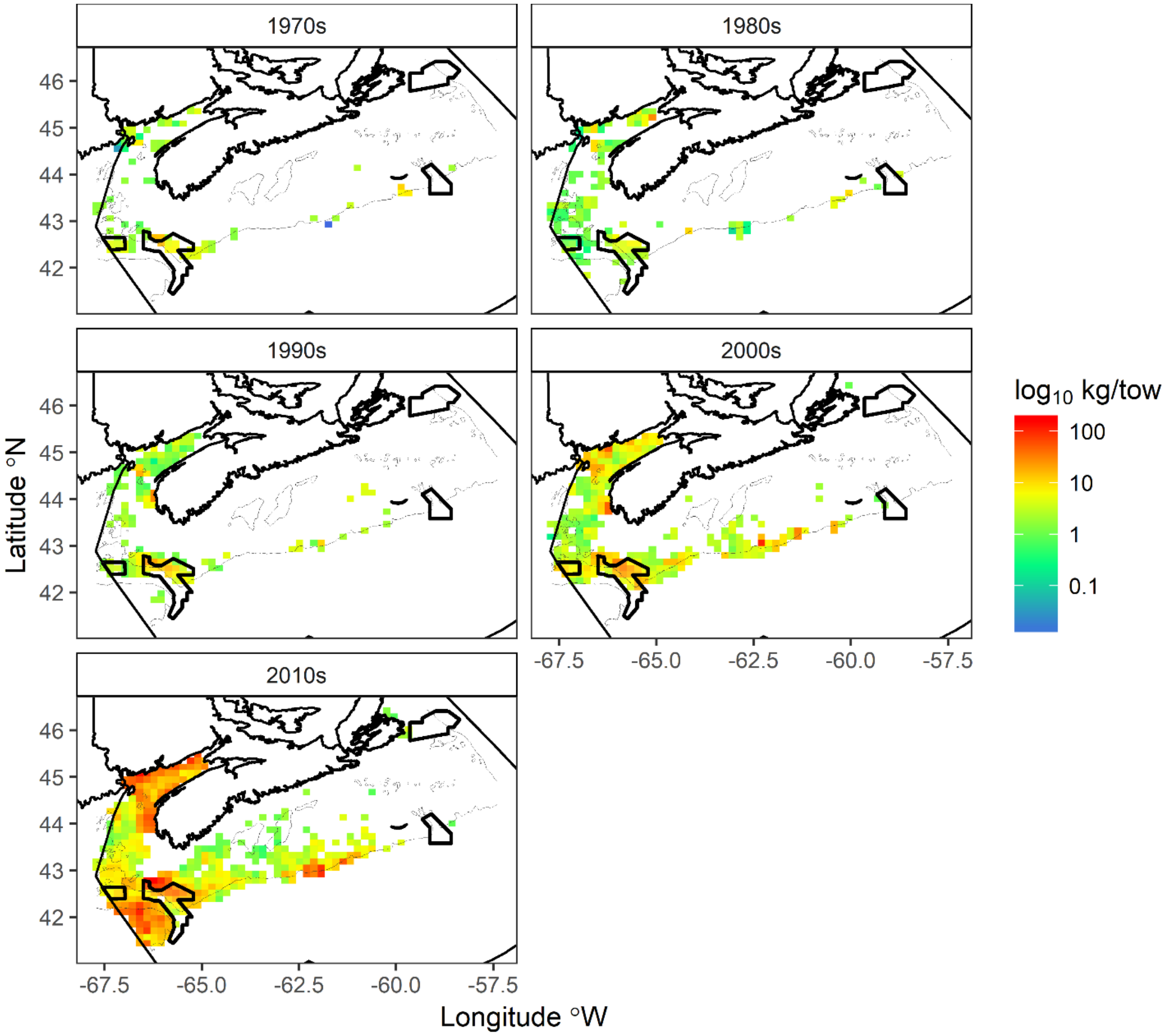

*Figure 34. Distribution of catch for American Lobster (Homarus americanus) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

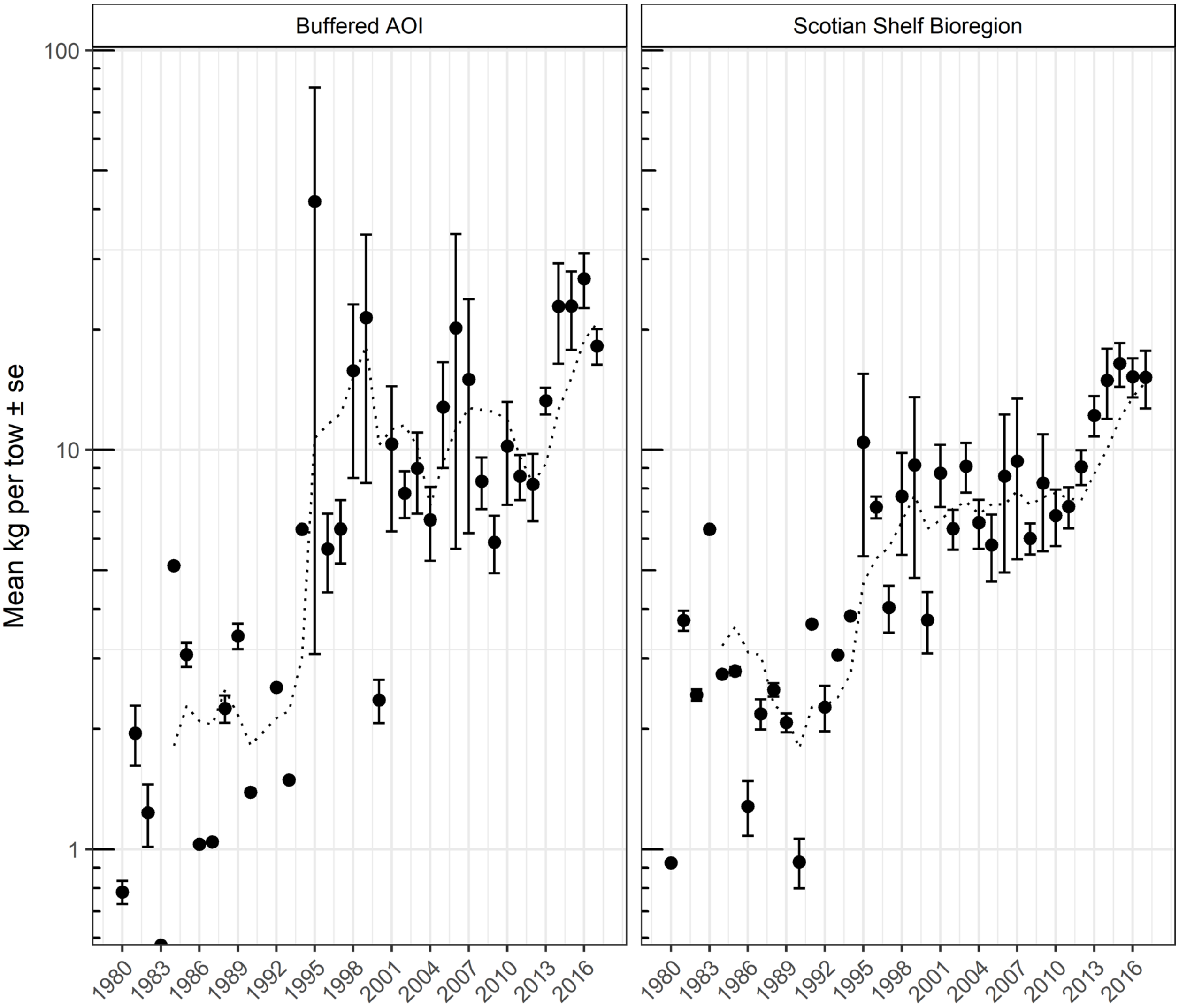

*Figure 35. Mean weight (± se) for American Lobster (Homarus americanus) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

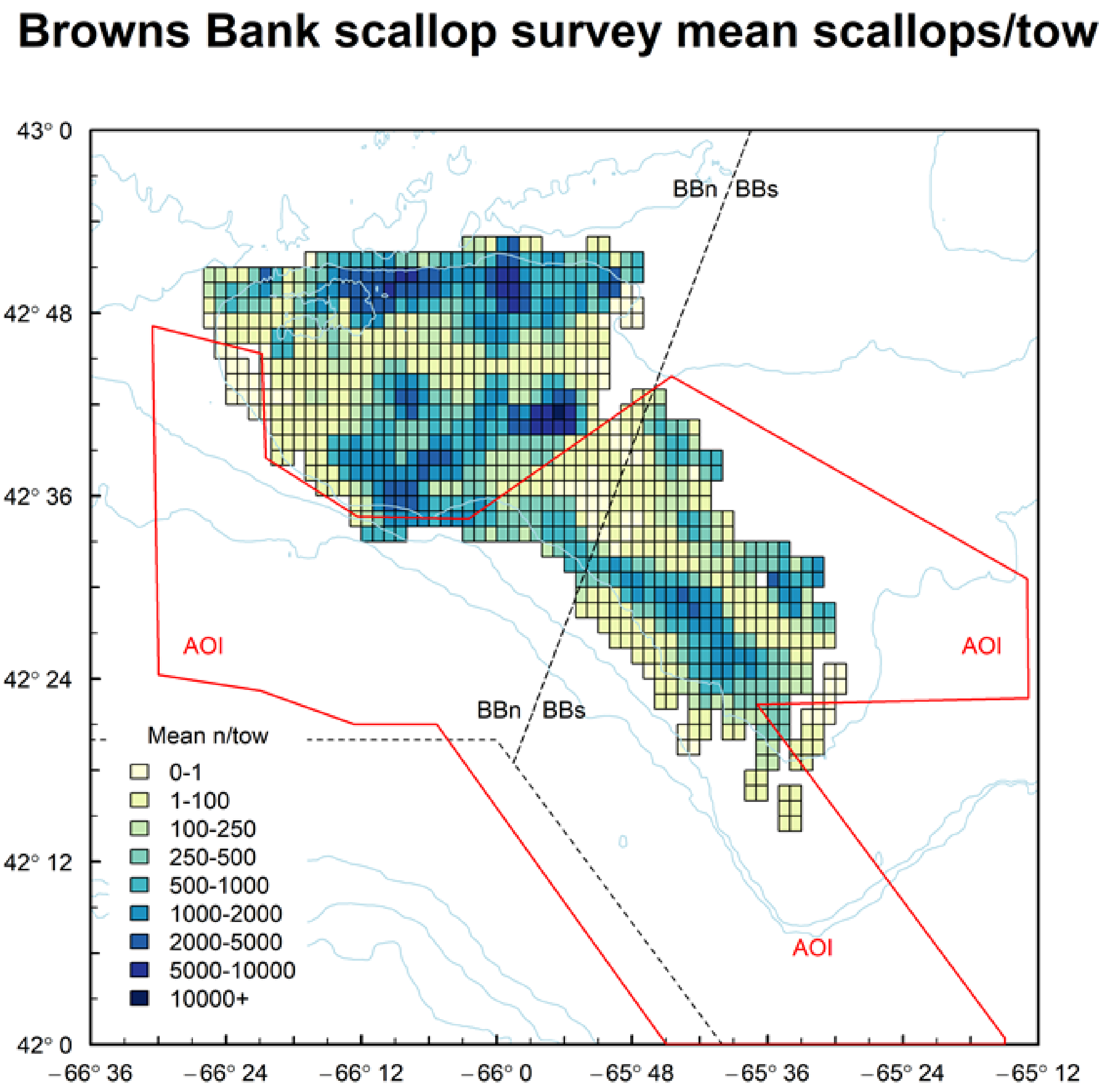

*Figure 36. Gridded scallop abundance in 1-minute by 1-minute cells on Browns Bank from the DFO Offshore Scallop Science Survey. Colours correspond to the mean abundance of scallops per standardized tow. The red line delineates the Fundian Channel AOI, the dashed black lines delineate the boundary for Browns Bank north (BBn) and Browns Bank south (BBs), and blue lines represent the bathymetry. Survey data for BBn from annual surveys between 1991–2018, for BBs the survey data is taken from the 18 surveys which occurred on BBs between 1985 and 2018.*

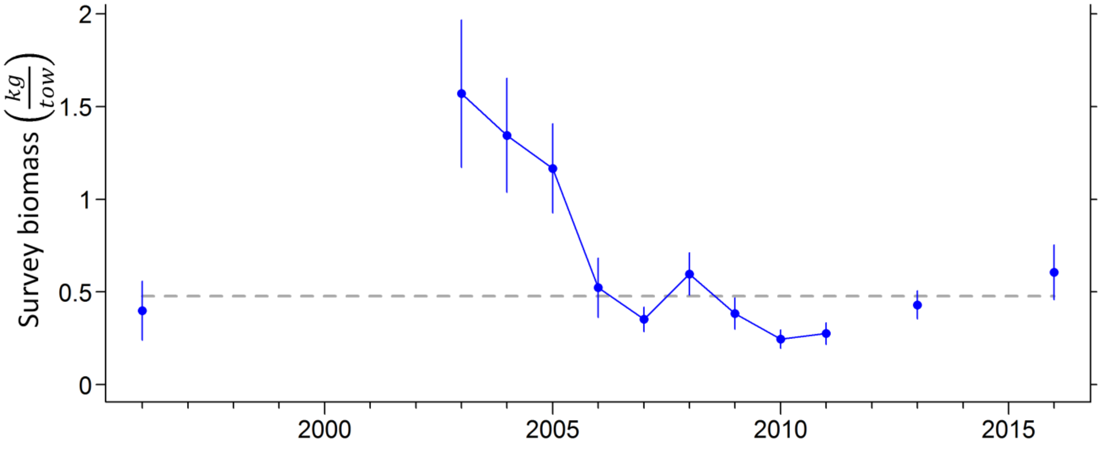

*Figure 37. Survey biomass index (kg/tow) for scallop ≥95 mm on Browns Bank South between 1996 and 2016. The dashed grey line is the median survey biomass index value (based on the years in which a survey occurred).*

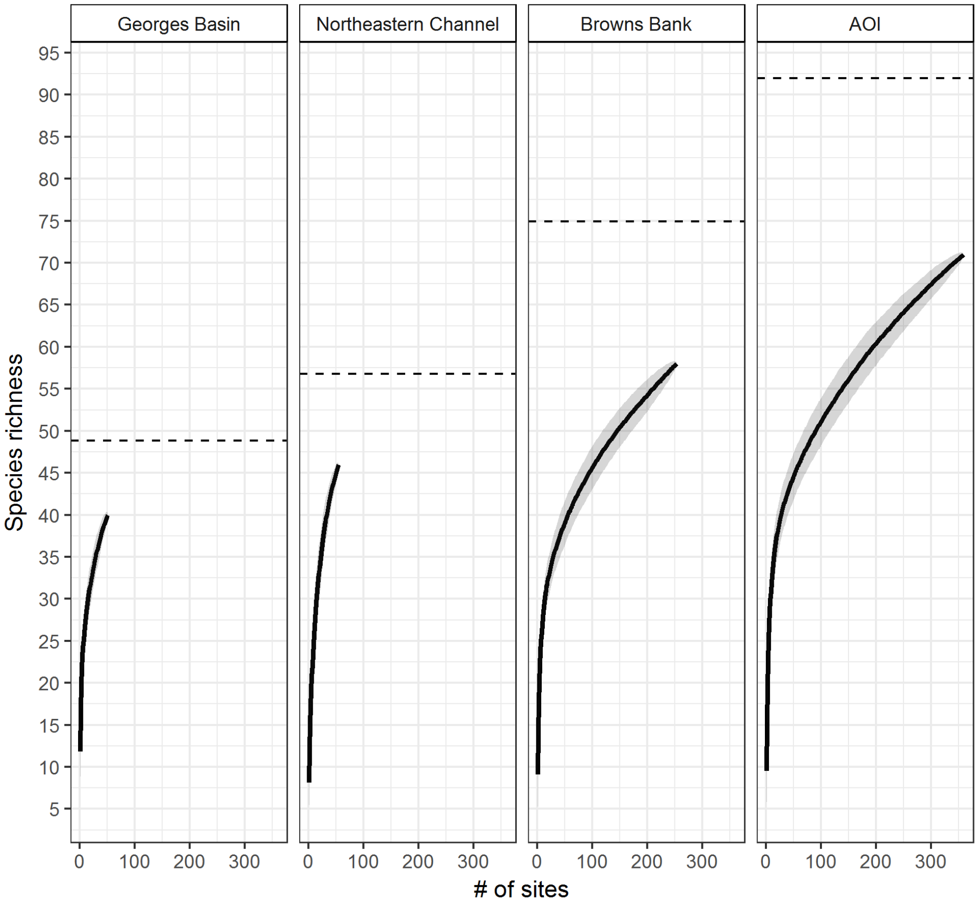

*Figure 38. Species accumulation curves estimated by resampling using 1000 randomizations of the survey data. Shaded grey areas denote the estimated standard deviation for species richness estimated for the respective number of sites. Data grouped according to Area of Interest subcomponents and delineation of fish communities along the 207.4 m transect (see Figure 41). Dashed lines denote estimated richness for each area based on the first-order Jackknife extrapolation.*

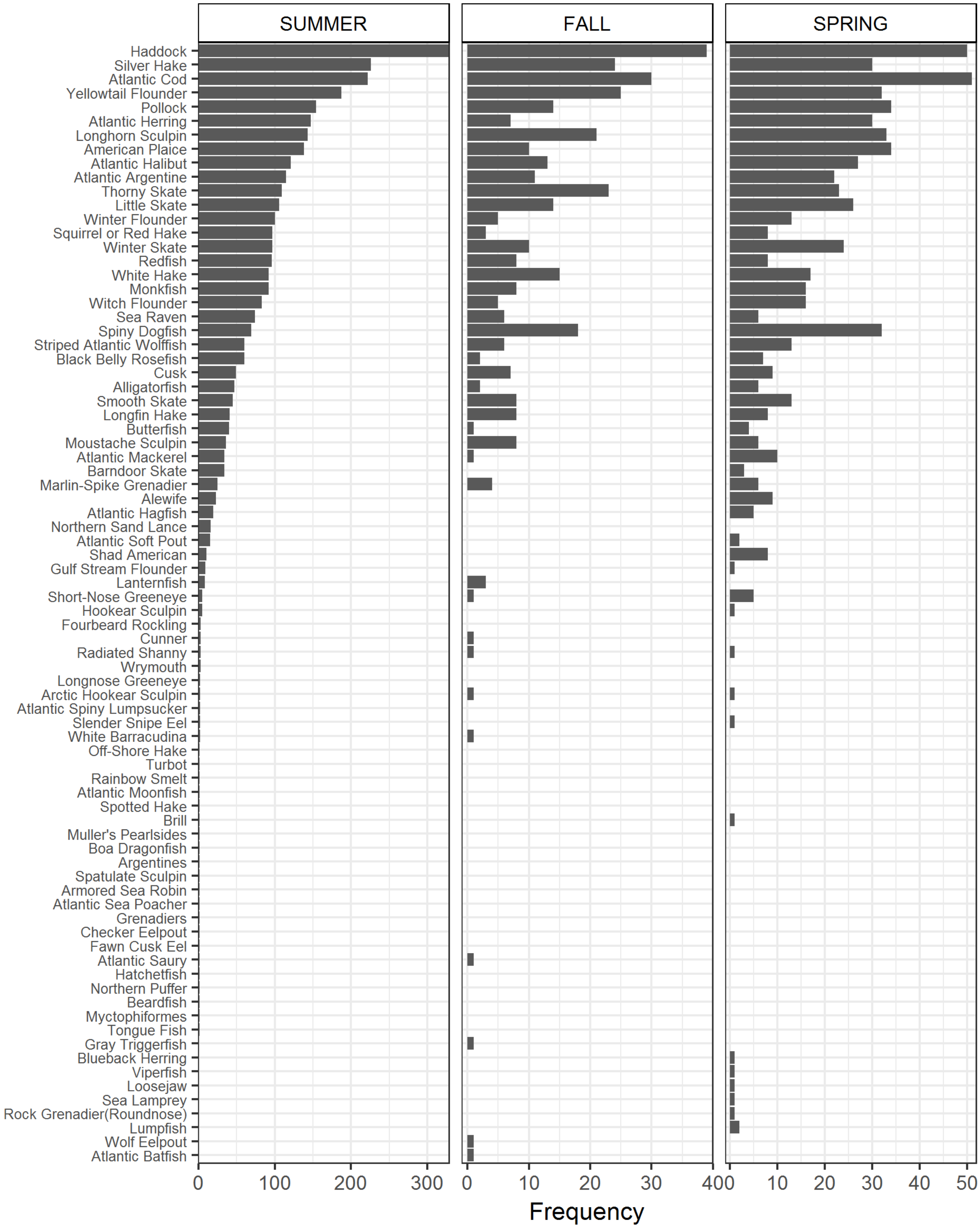

*Figure 39. Number of observations for each finfish species among 467 trawl sets within the Area of Interest boundaries (Figure 19) during the Summer, Fall and Spring research Vessel Surveys (1970–2017).*

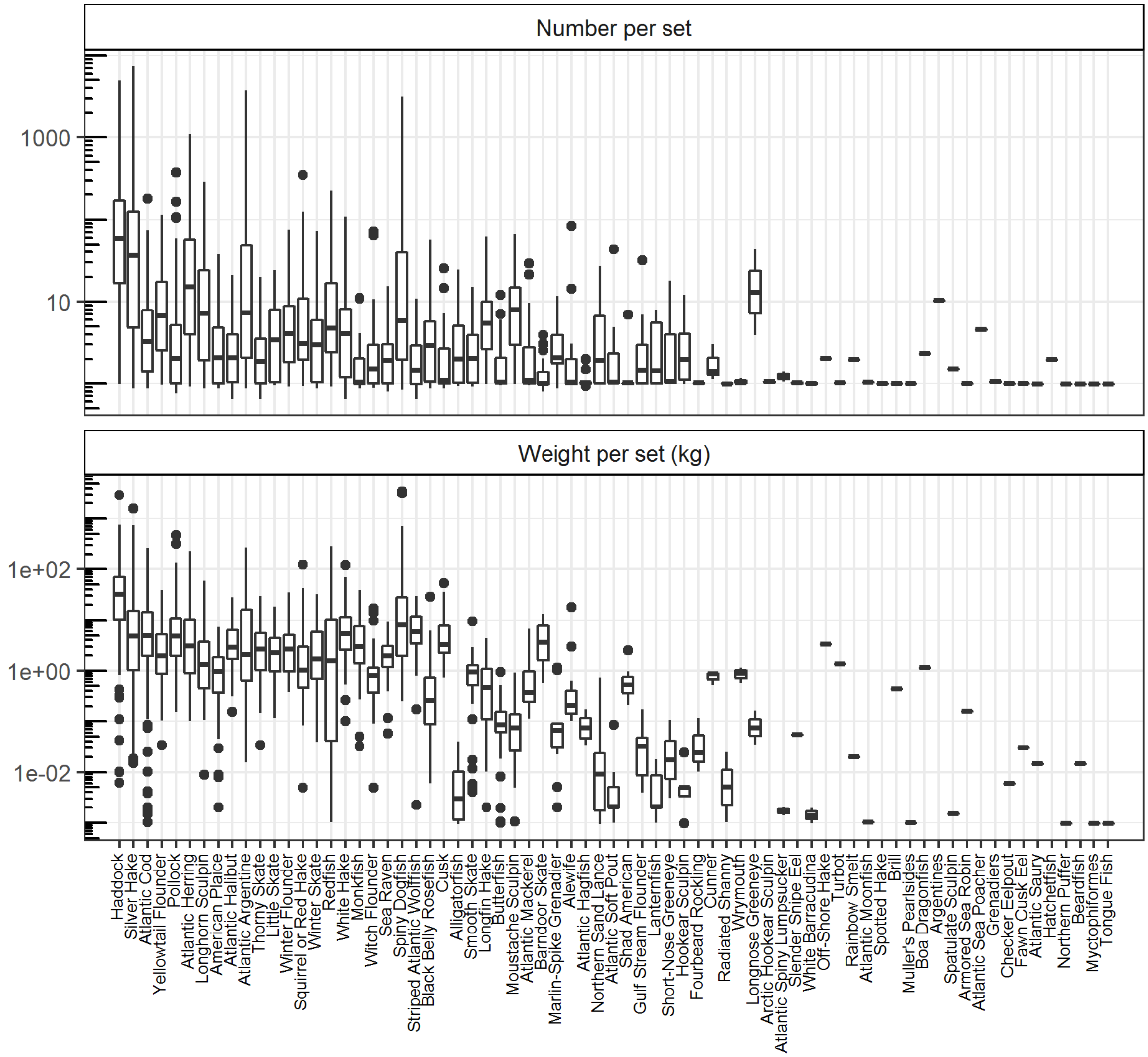

*Figure 40. Boxplot describing the weight and number per standardized trawl set (1.75 nautical miles) for finfish species captured during the summer Research Vessel Survey (1970–2017) within the Area of Interest (360 sets – Figure 19).*

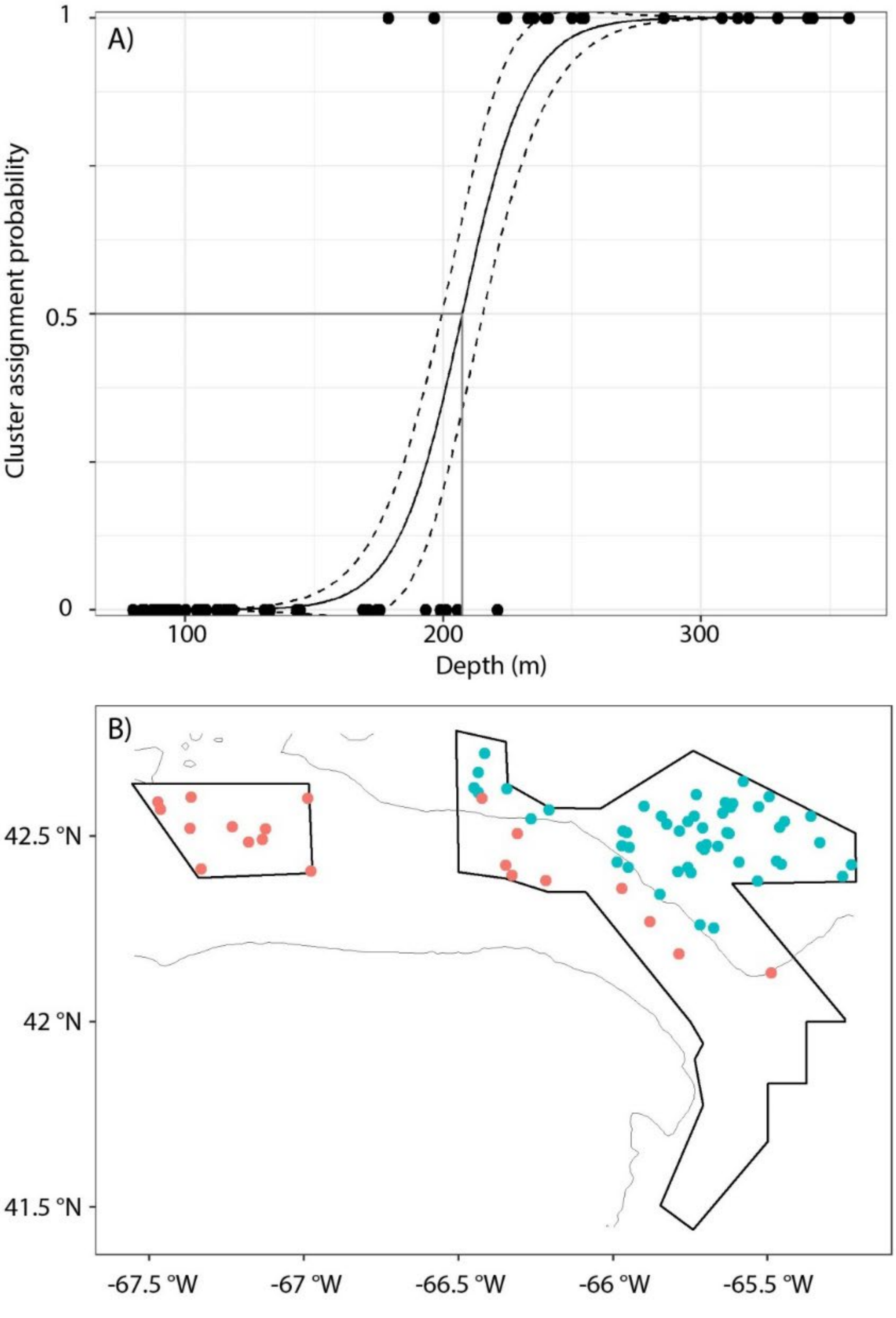

*Figure 41. Distribution of fish community partitions (n = 2) with depth. Panel A) shows a binary logistic regression noting a transition (inflection) point of 207.4 m between the two dominant finfish partitions identified by k-means clustering. Panel B) shows the distribution of these partitions overlaid on the boundaries of the Area of Interest and the 207.4 m bathymetry contour.*

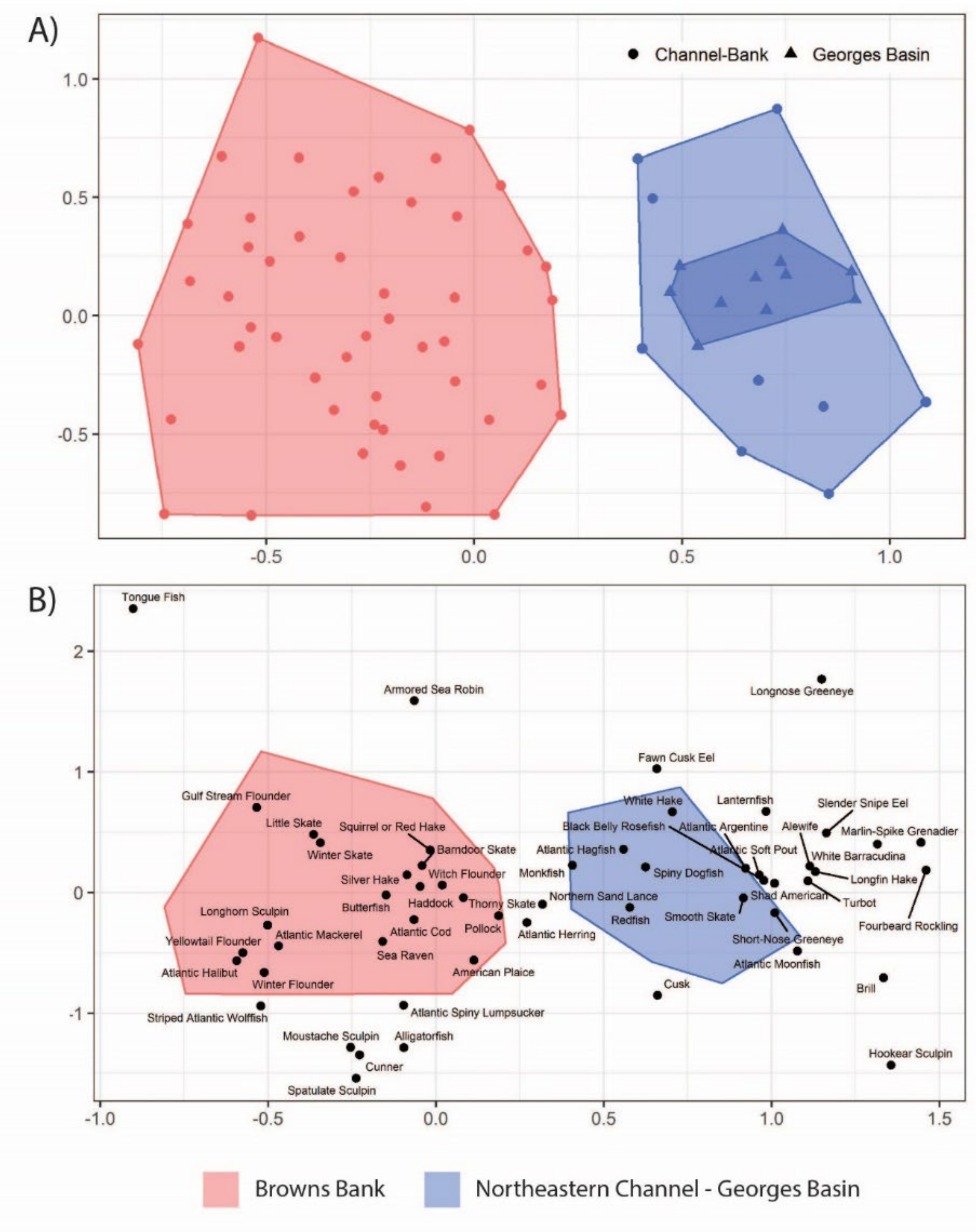

*Figure 42. Nonmetric multidimensional scaling of finfish community using a Jaccard dissimilarity index on presence-absence data. Panel A) shows the distribution of sample site centroids coloured by their assignment to one of two partitions identified using k-means clustering. Panel B) shows the distribution of species centroids. Shaded areas represent minimum convex polygons around the clusters. Panel A) also partitions site centroids among the two Area of Interest components on Georges Bank and the Northeastern Channel. All sample sites (n = 70) were sampled between 2010 and 2017 on the Summer Multispecies Research Vessel Survey (see Figure FD1b for distribution of samples relative to Area of Interest boundaries.*

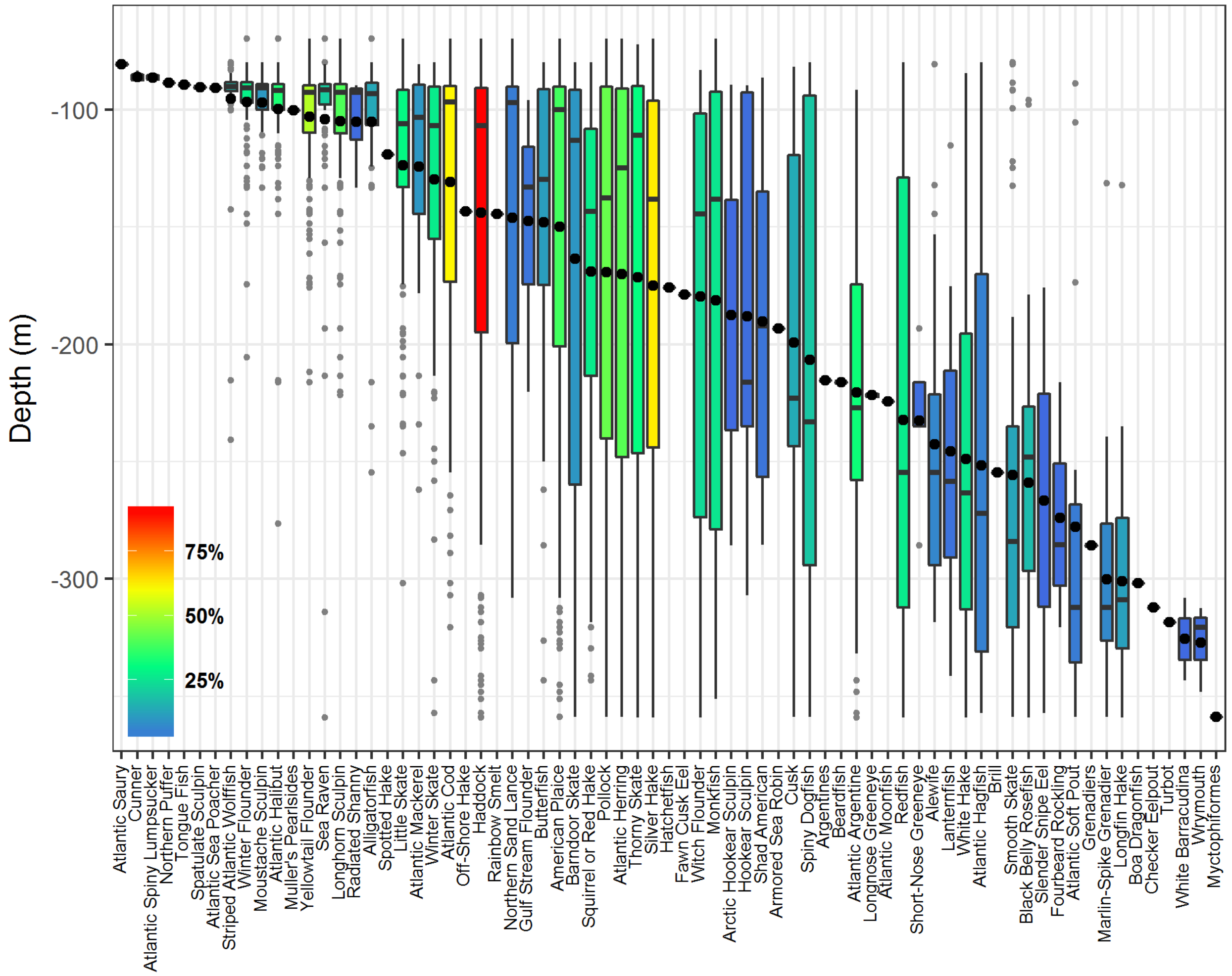

*Figure 43. Boxplot depicting the depth distribution of each of the fish species (n = 71) captured during the summer Research Vessel Survey in the Area of Interest. Species are ordered by mean depth (points) and the colour denotes the frequency of which that species was captured among the 360 trawl sets within the Area of Interest boundaries between 1970 and 2017.*

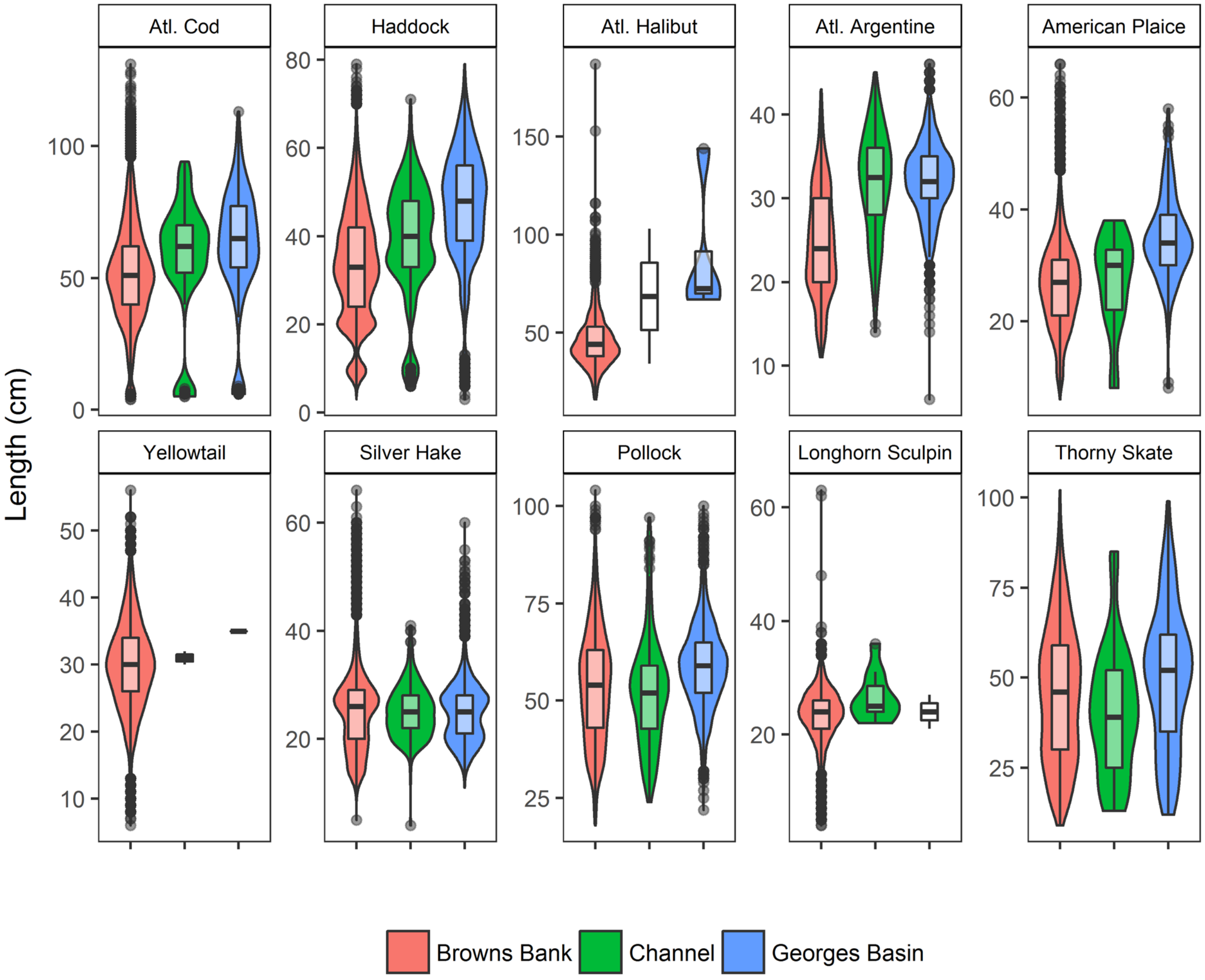

*Figure 44. Length distributions of ten fish species across different geographic portions of the Area of Interest. Browns Bank is the shallowest portion of the Area of Interest, with the Channel habitat intermediate in depth, and Georges Basin being the deepest portion of the Area of Interest. In general, larger individuals are found in the deeper portions of the Area of Interest.*

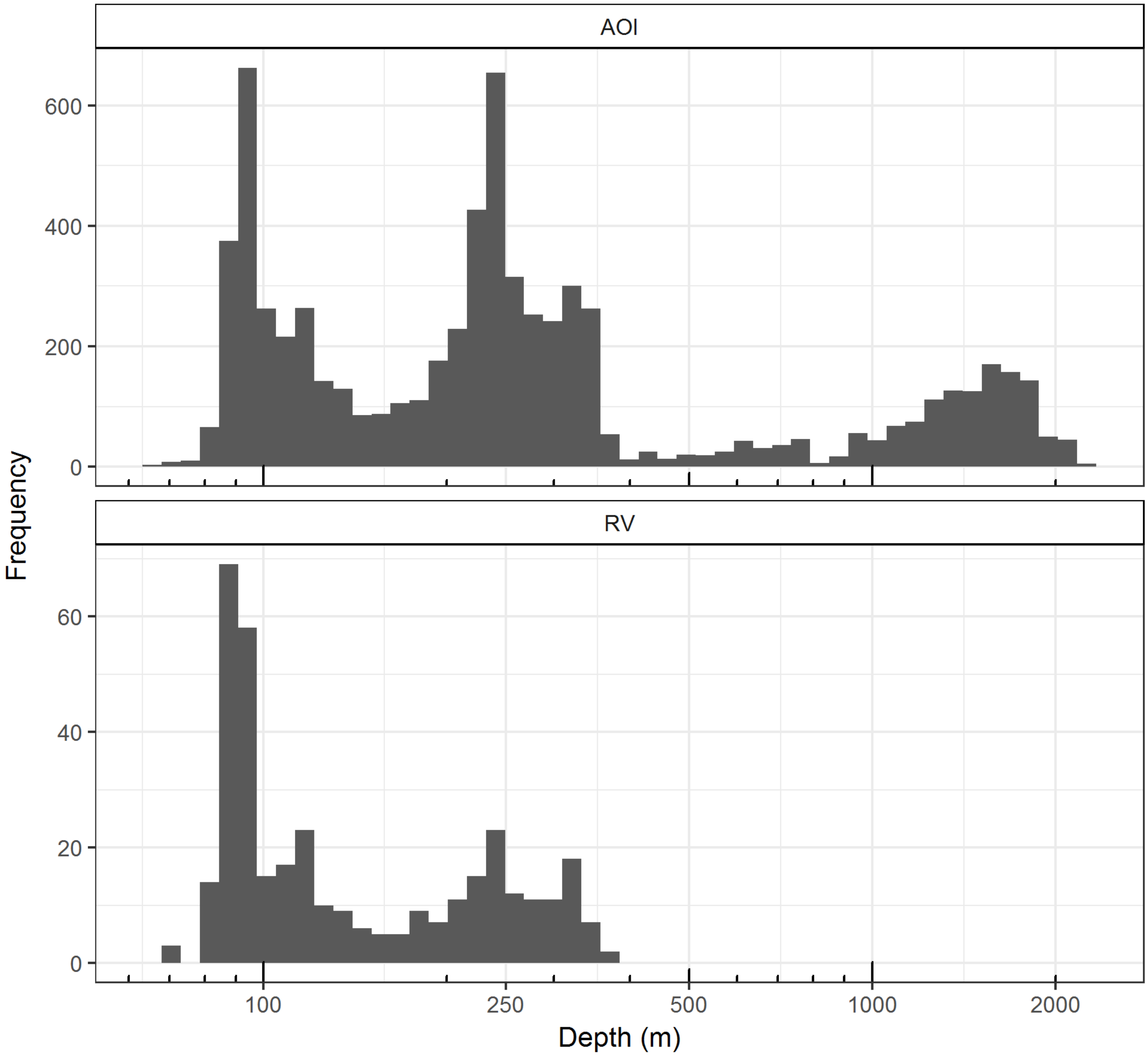

*Figure 45. Depth distribution in the Area of Interest (gridded at 1 km resolution) and the summer Multispecies Research Vessel Survey (360 sets between 1970 and 2017). The X axis is presented on a $log_{10}$ scale.*

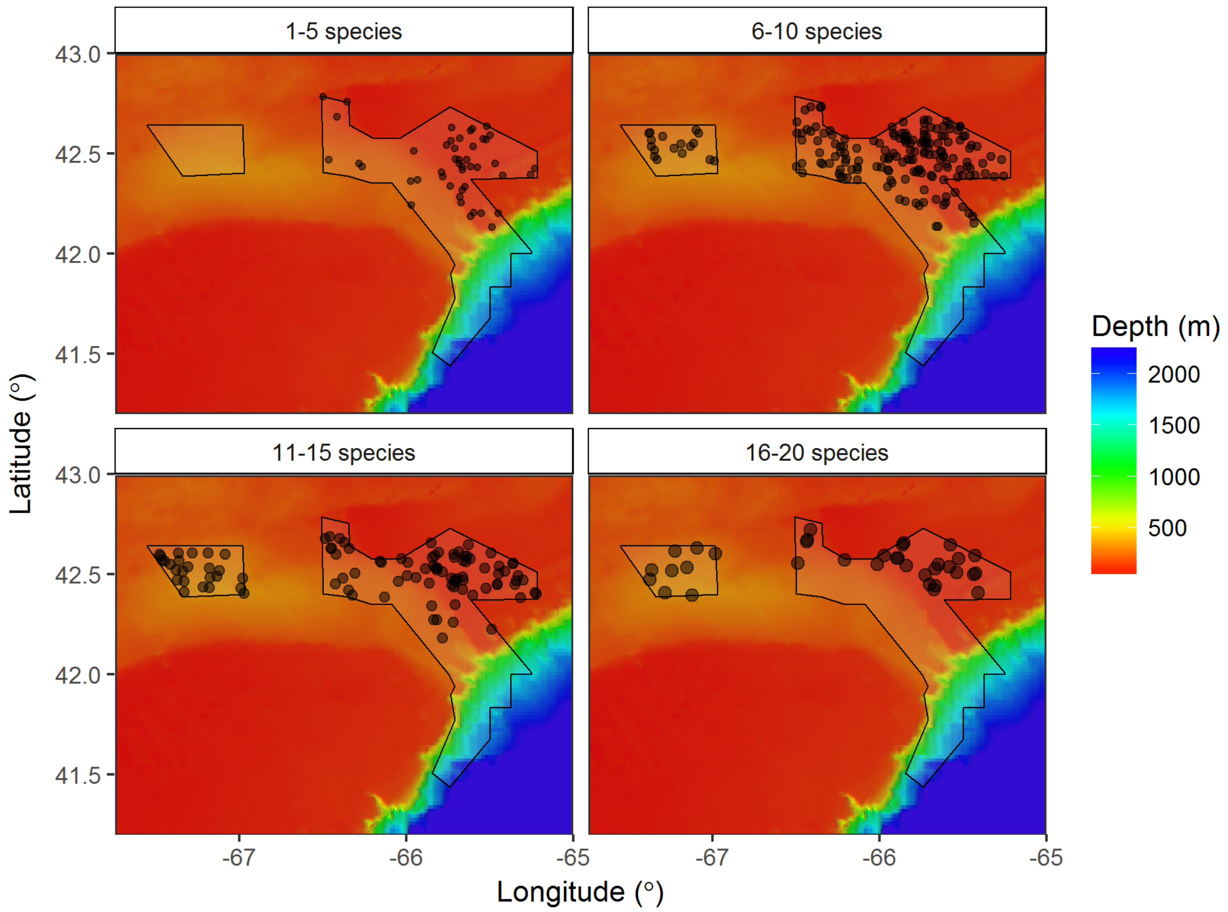

*Figure 46. Distribution of species richness based on the Summer Multispecies RV survey sets (n = 360) since 1970 within the Area of Interest. Sets are overlaid on bathymetry scaled to the maximum depth within the Area of Interest (2251 m) and portioned into four discrete intervals.*

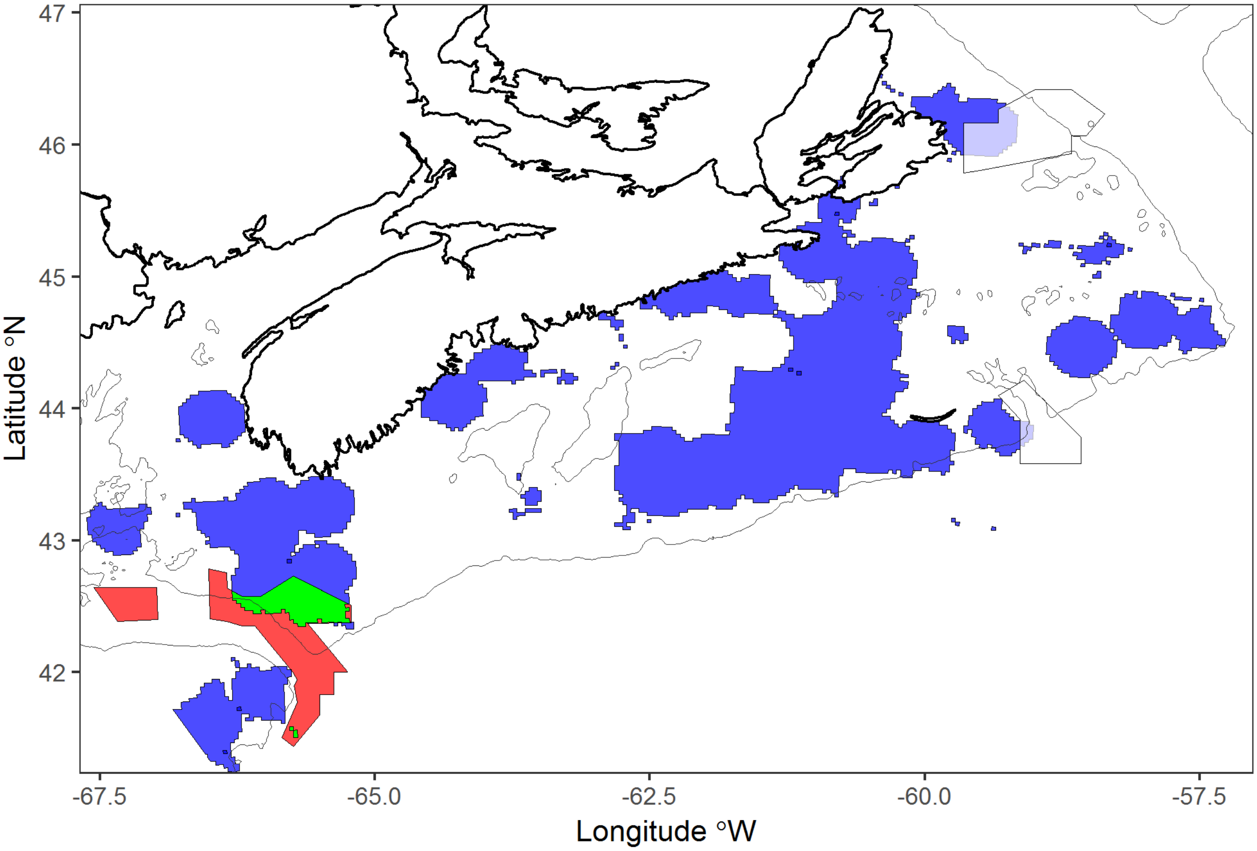

*Figure 47. Ichthyoplankton genus richness presented as the top 20th percentile enumerated in Shackell and Frank (2000). Samples were collected as part of the Scotian Shelf Ichthyoplankton Program from 1978–1982. The Fundian Channel-Browns Bank Area of Interest is shaded red and other Marine Protected Areas are shaded white. Blue polygons represent the genus richness percentile and green colouration represents overlap between this diversity layer and the Area of Interest boundaries.*

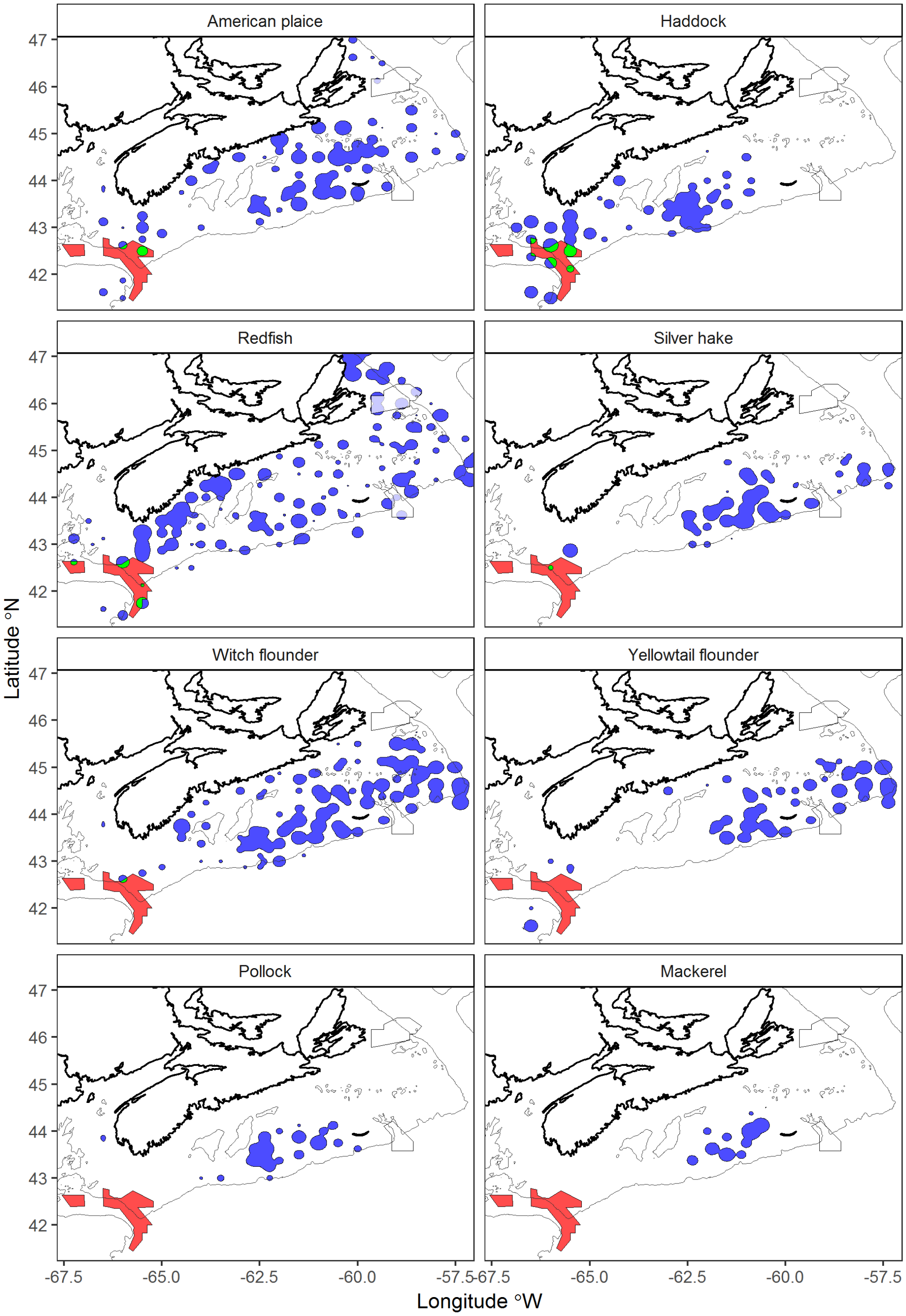

*Figure 48. Larval fish distributions presented as the top 20th percentile log abundance. Samples were collected as part of the Scotian Shelf Ichthyoplankton Program from 1978–1982. The Fundian Channel-Browns Bank Area of Interest is shaded red and other Marine Protected Areas are shaded white. Blue polygons represent the species distribution and green colouration represents overlap between this distribution layer and the Area of Interest boundaries.*

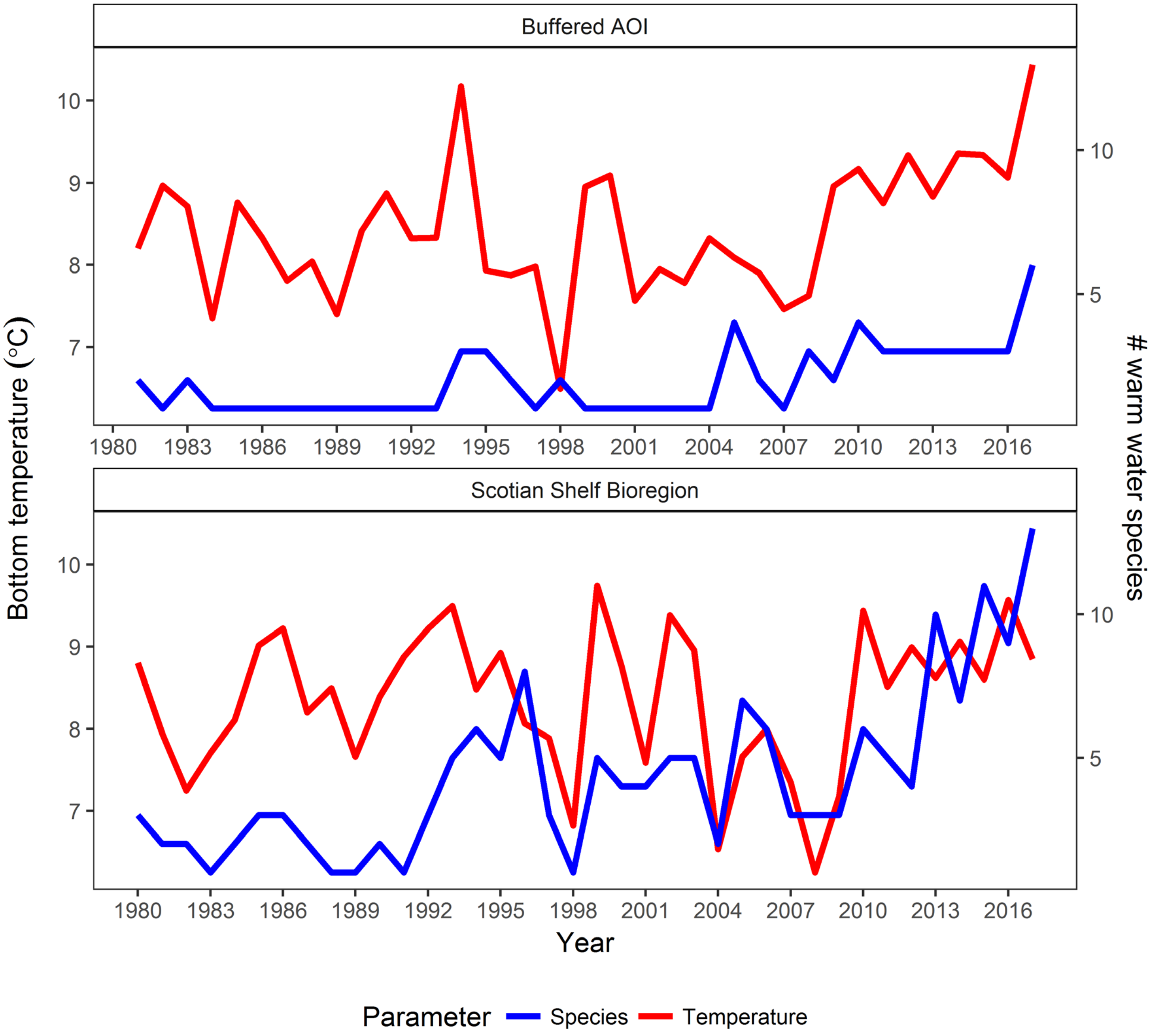

*Figure 49. Average annual bottom temperature from the summer Research Vessel Survey and the total number of warm water species captured in the Area of Interest buffered by 25 km and for the Maritimes Bioregion.*

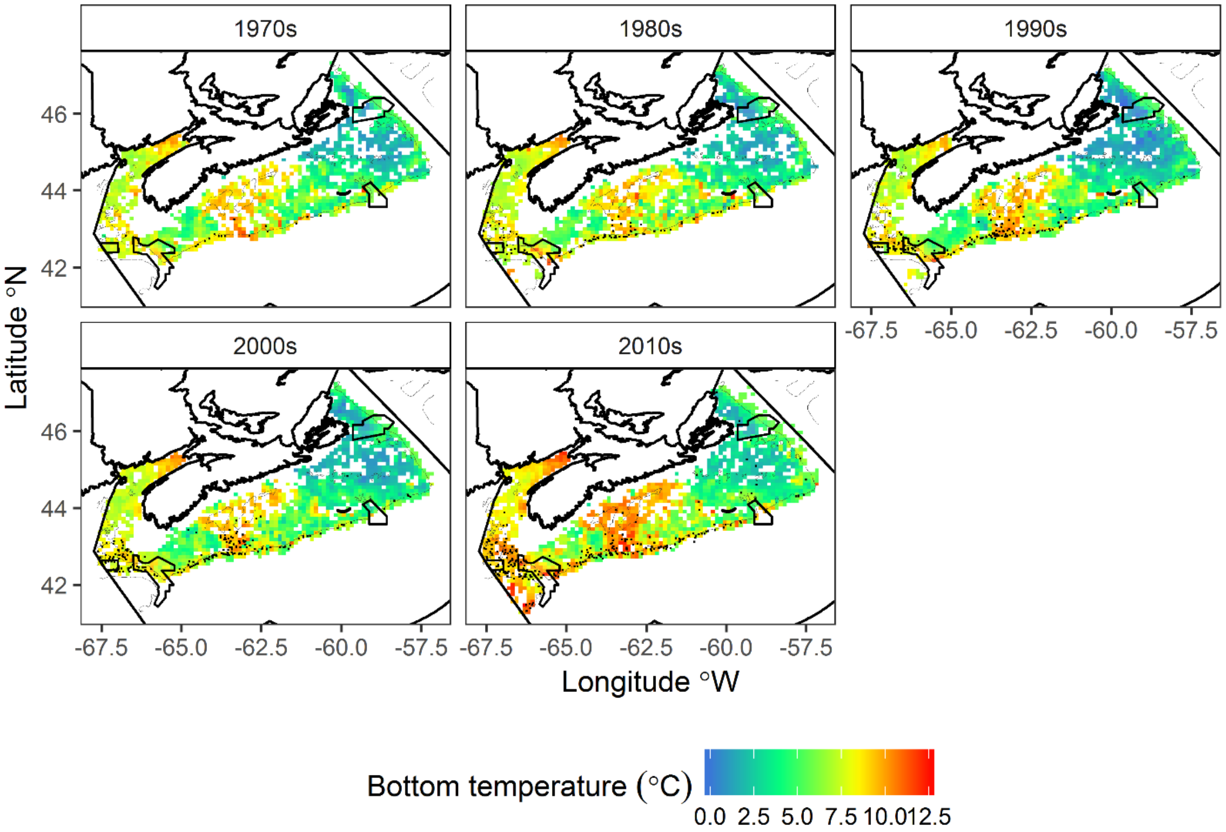

*Figure 50. Distribution of trawl sets containing warm water species (see Table 7) from the summer Research Vessel Survey (1970–2017). Points are overplayed on bottom temperature recoded during each set aggregated at a resolution of 10 km$^2$.*

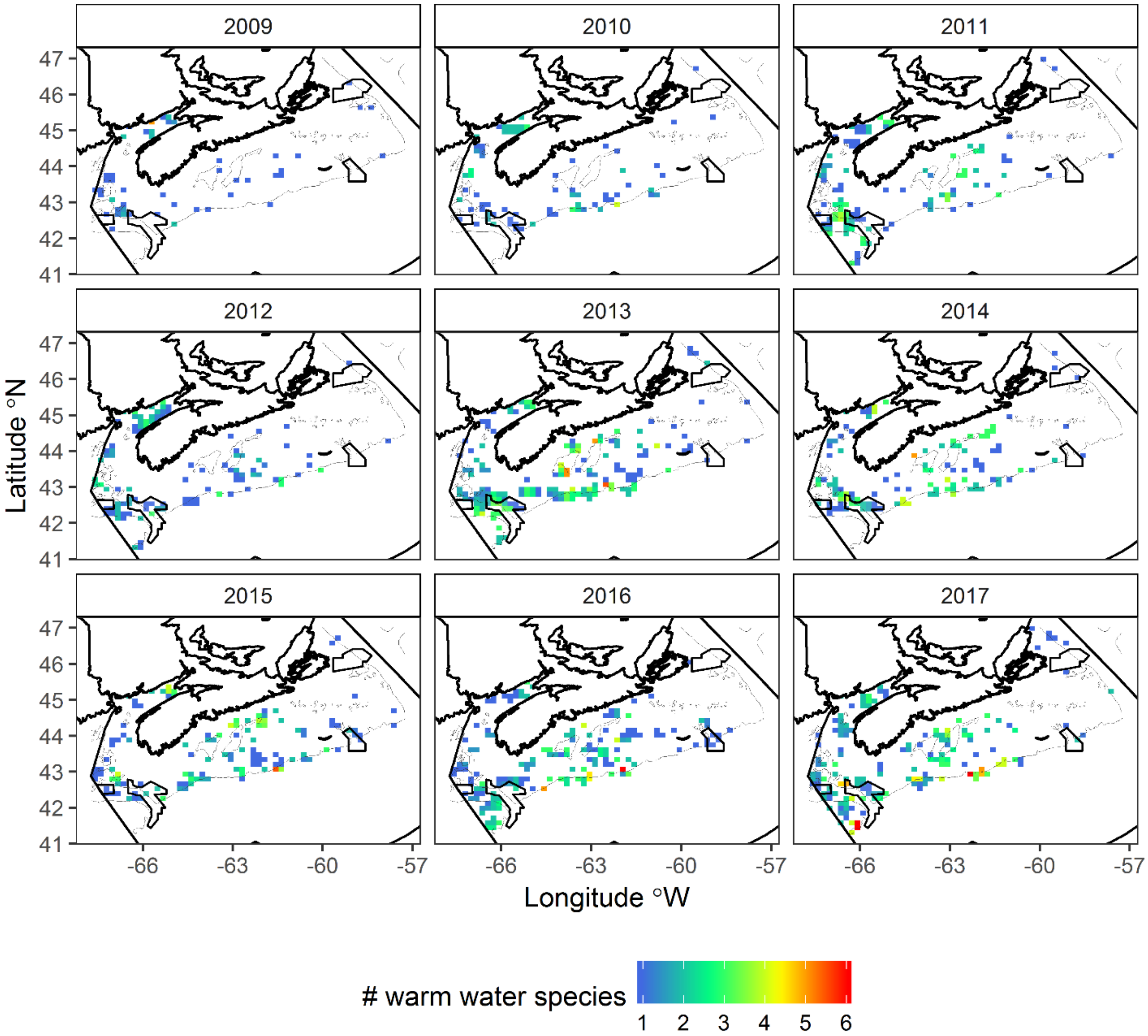

*Figure 51. Distribution of warm water species (see Table 7) from the summer Research Vessel Survey (2008–2017). Number is the absolute number per valid Research Vessel set (20 minutes tow length or longer) aggregated at 15 km$^2$ per survey year.*

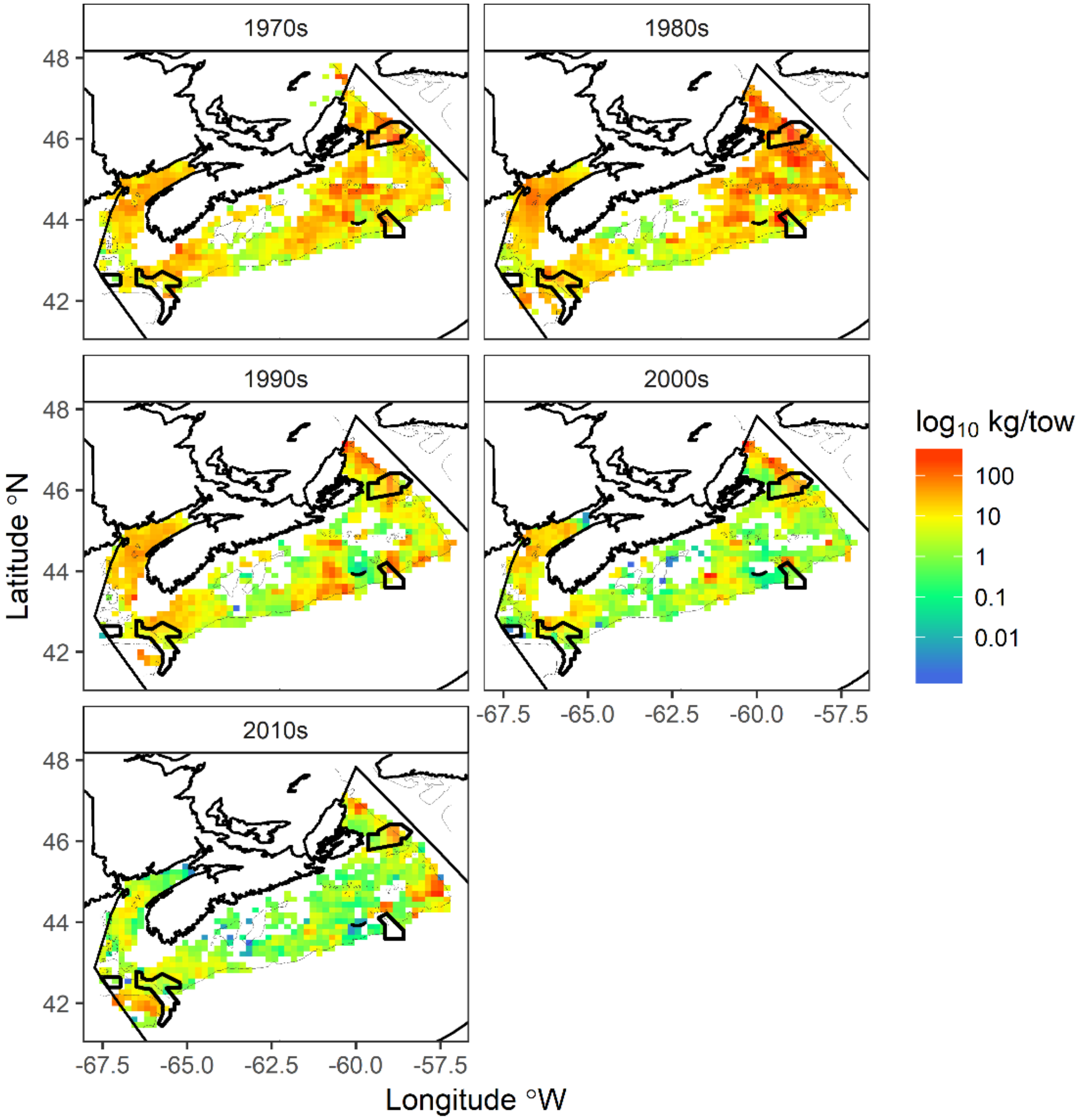

*Figure 52. Distribution of catch for Atlantic Cod (*Gadus morhua*) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

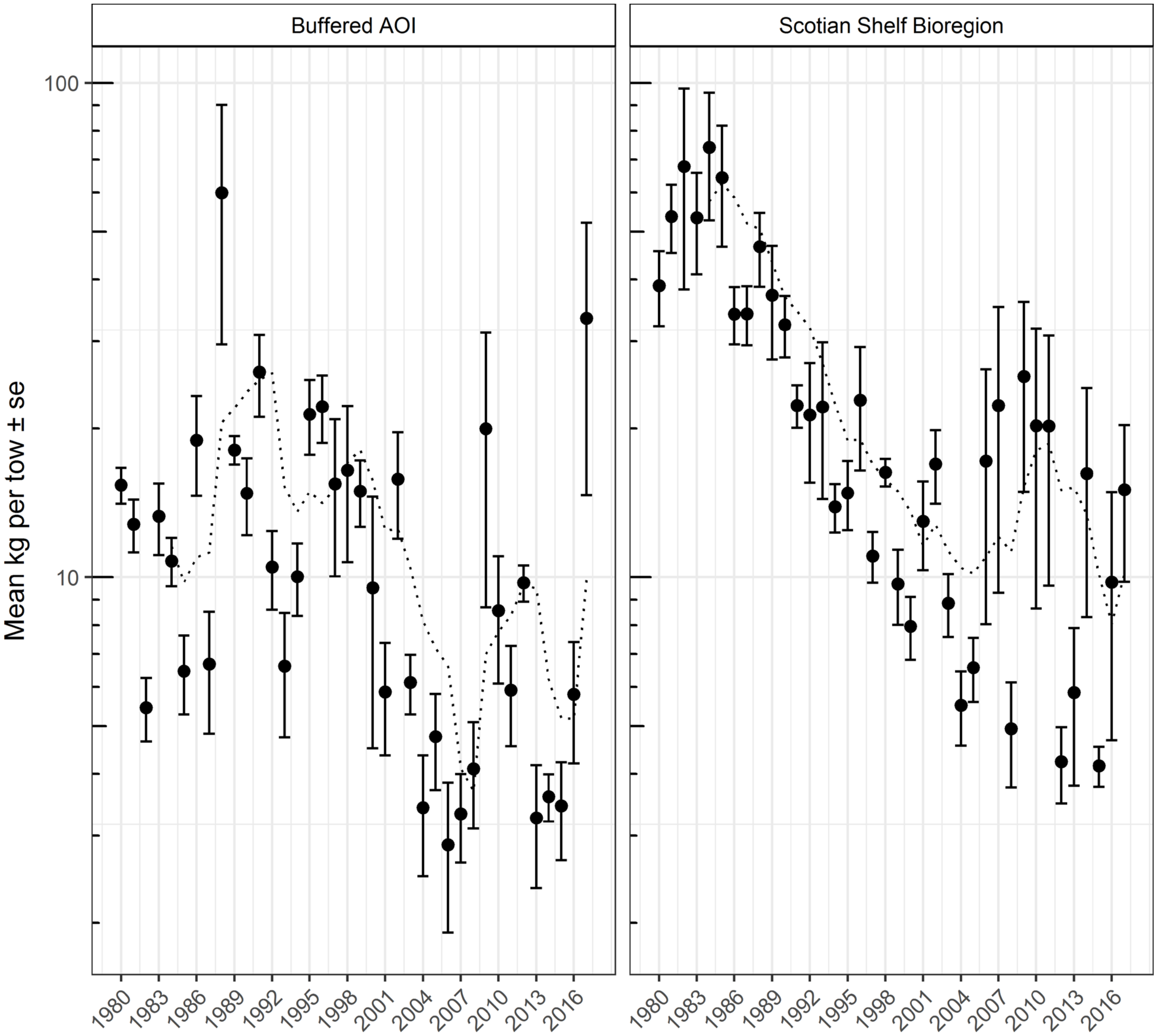

*Figure 53. Mean weight (± se) for Atlantic Cod (*Gadus morhua*) captured during the summer Research Vessel Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

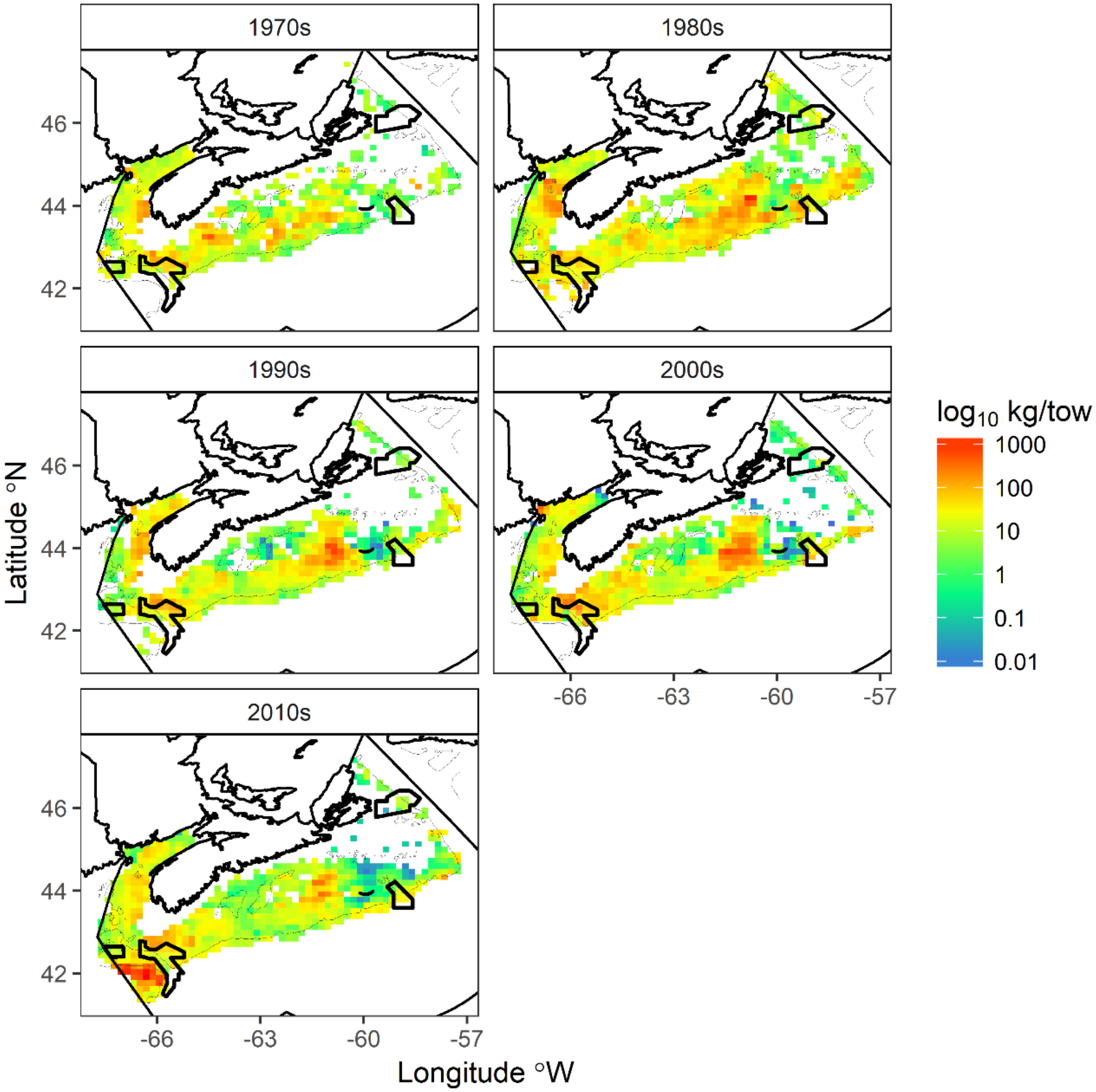

*Figure 54. Distribution of catch for Haddock (*Melanogrammus aeglefinus*) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

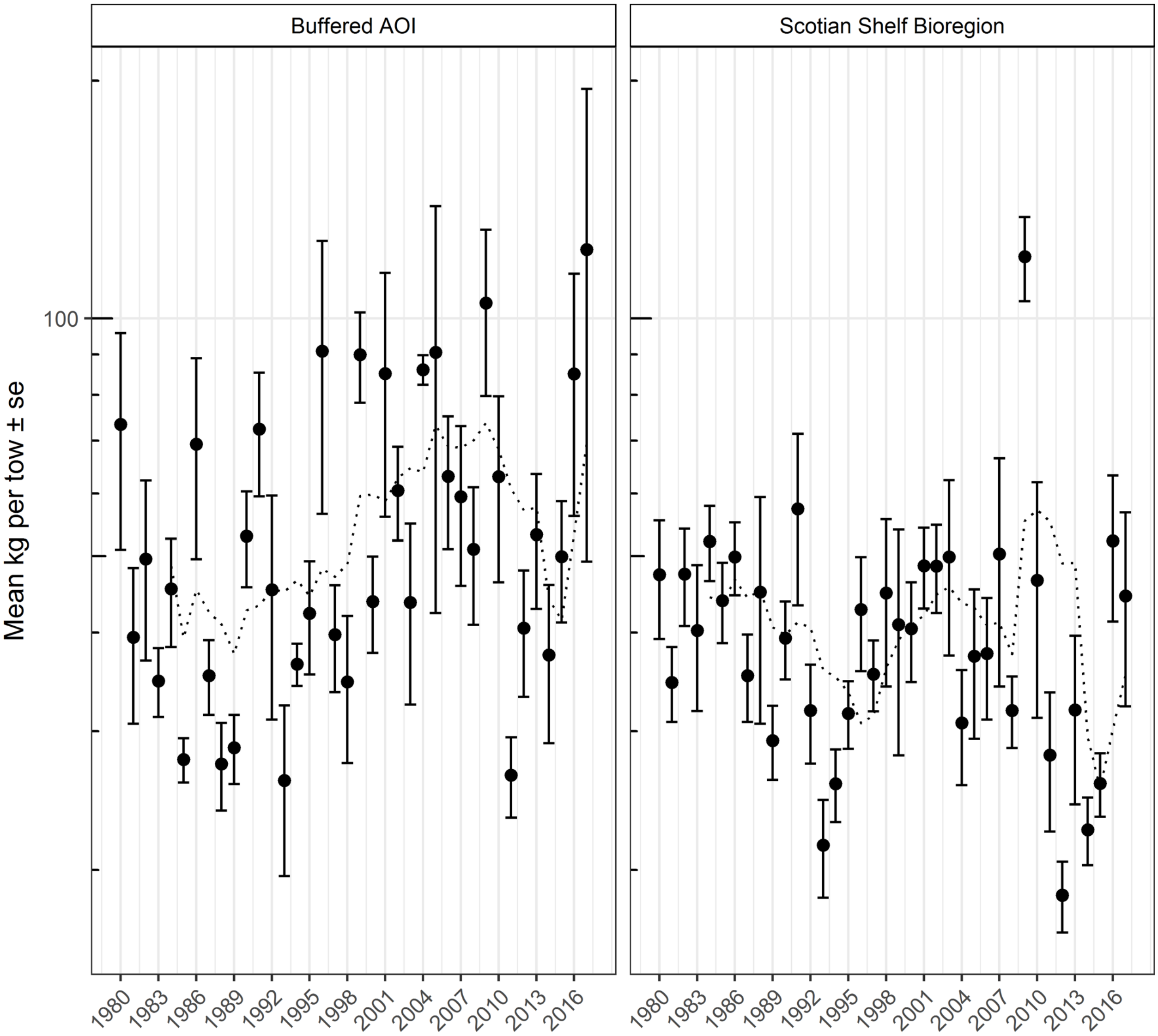

*Figure 55. Mean weight (± se) for Haddock (*Melannogrammus aeglefinus*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nm trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

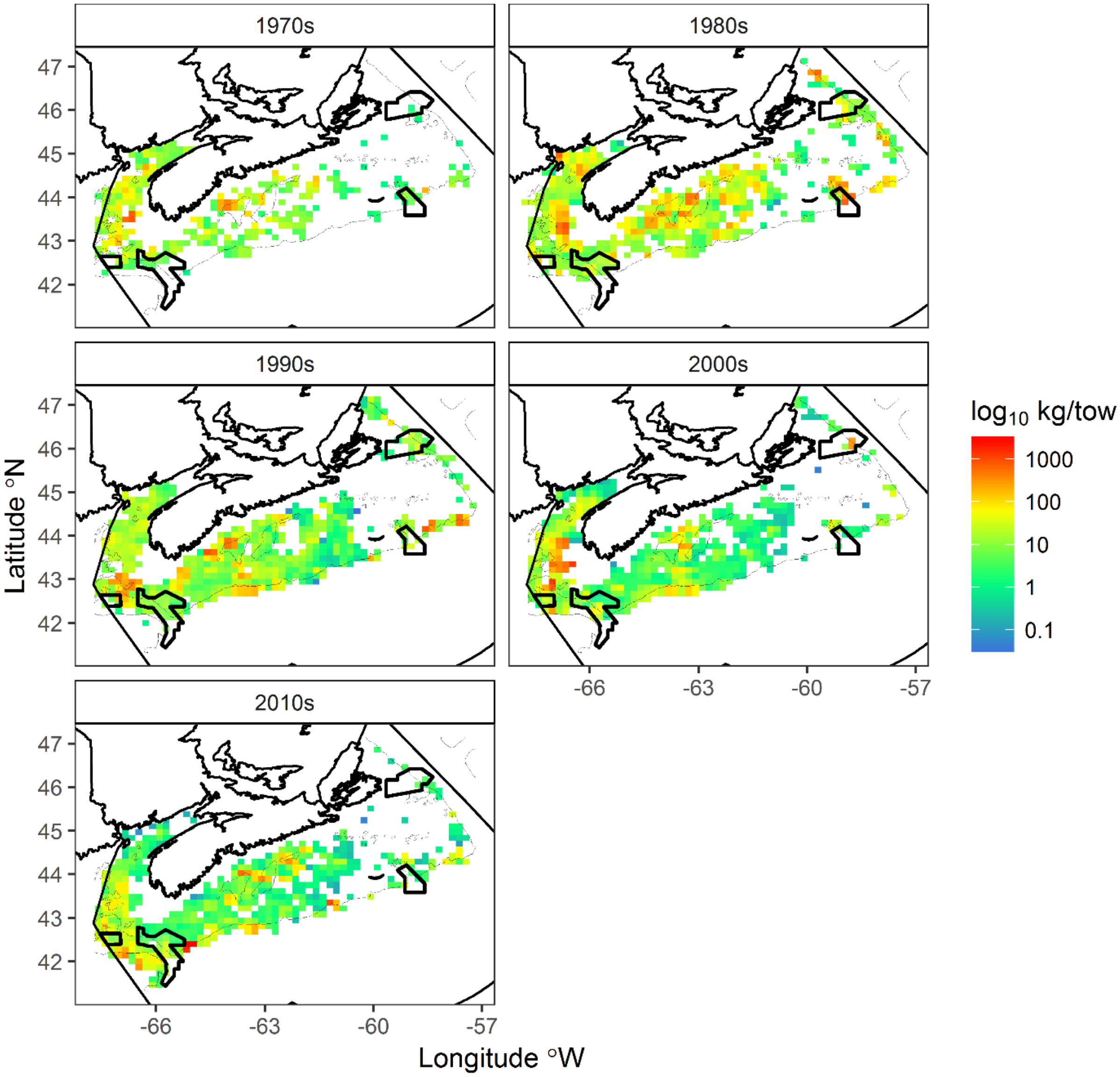

*Figure 56. Distribution of catch for Pollock (*Pollachius virens*) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

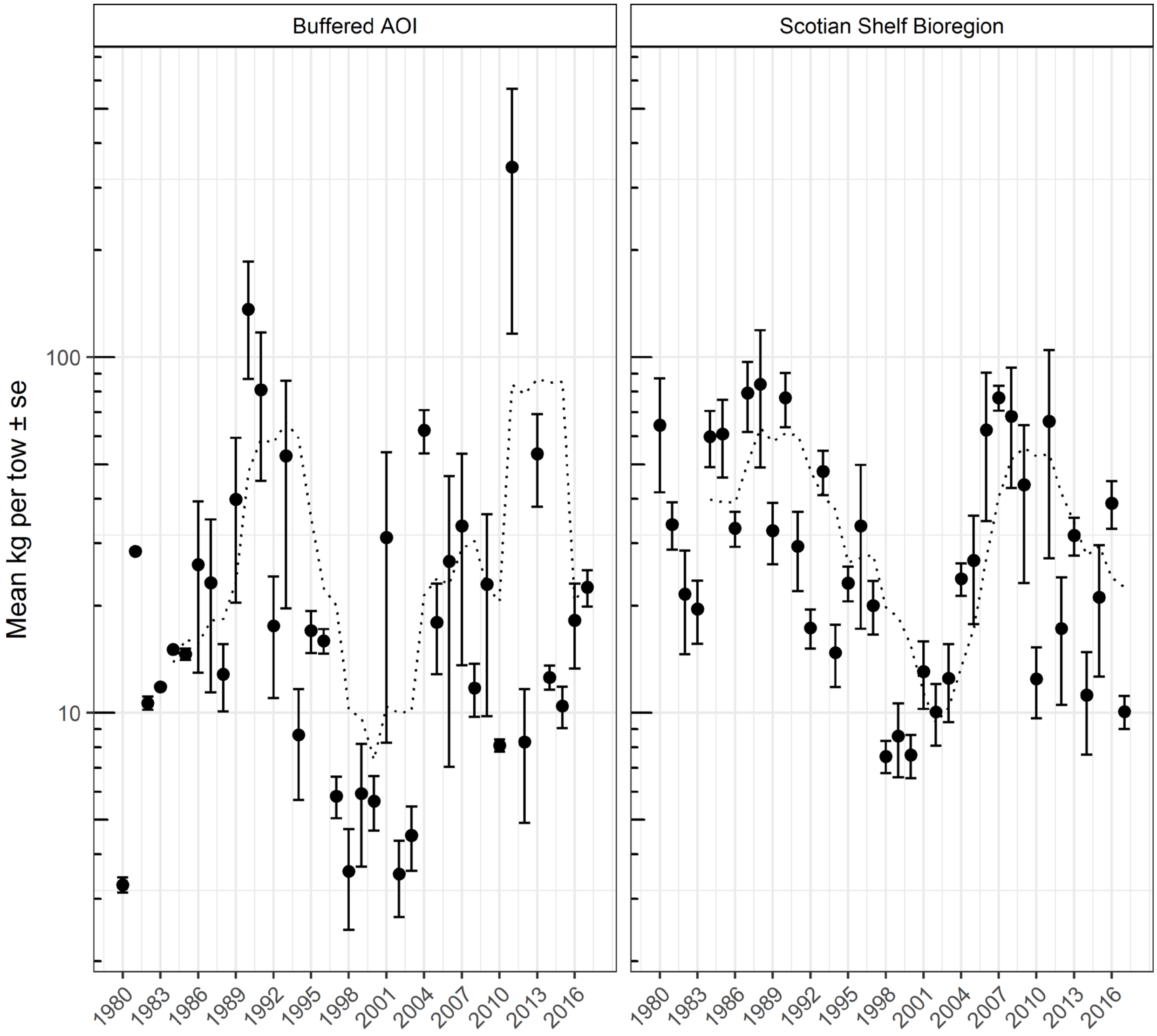

*Figure 57. Mean weight (± se) for Pollock (*Pollachius virens*) captured during the summer research Vessel Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nm trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

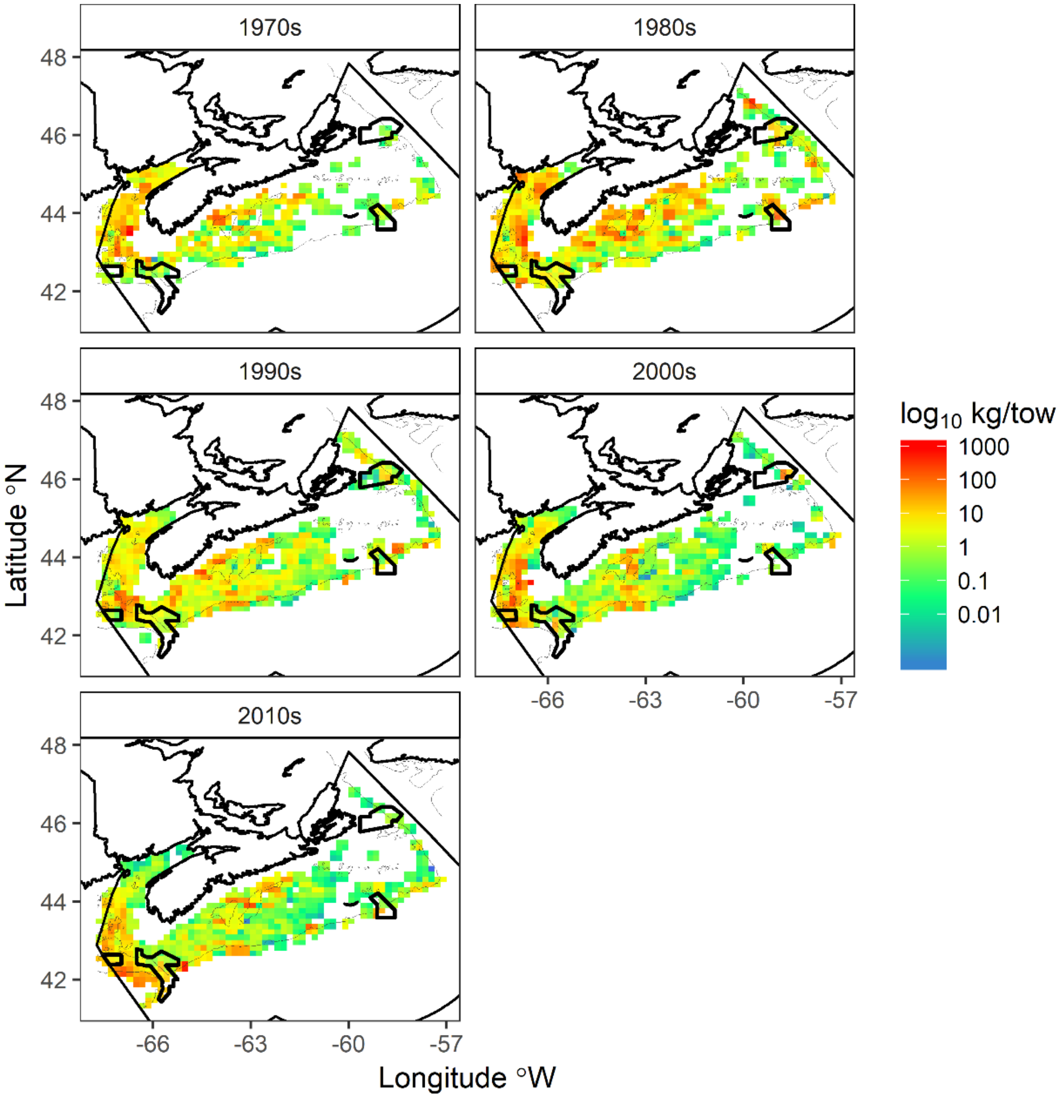

*Figure 58. Distribution of catch for Silver Hake (*Merluccius bilinearis*) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nm trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

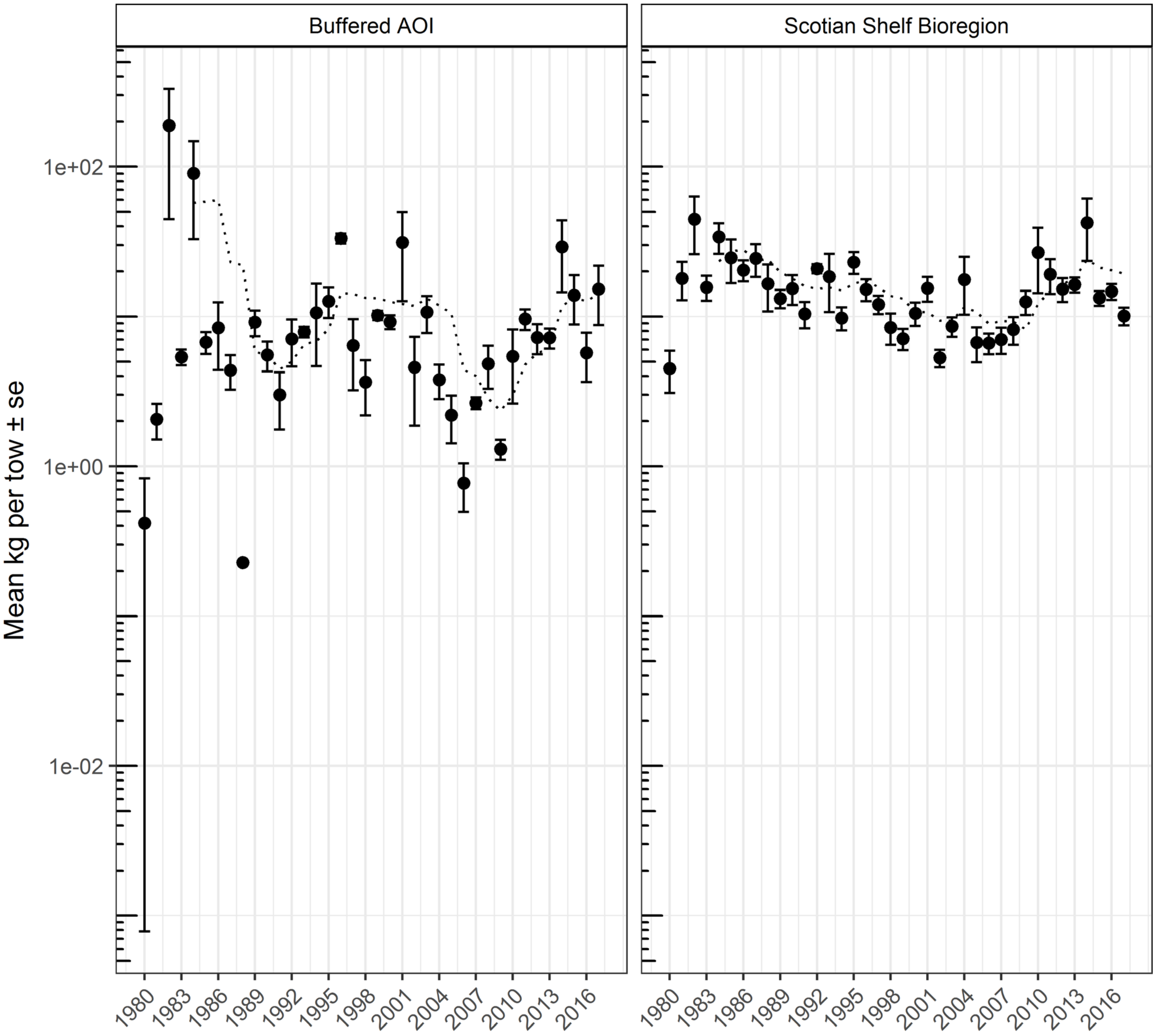

*Figure 59. Mean weight (± se) for Silver Hake (*Merluccius bilinearis*) captured during the summer Research Vessel Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nm trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

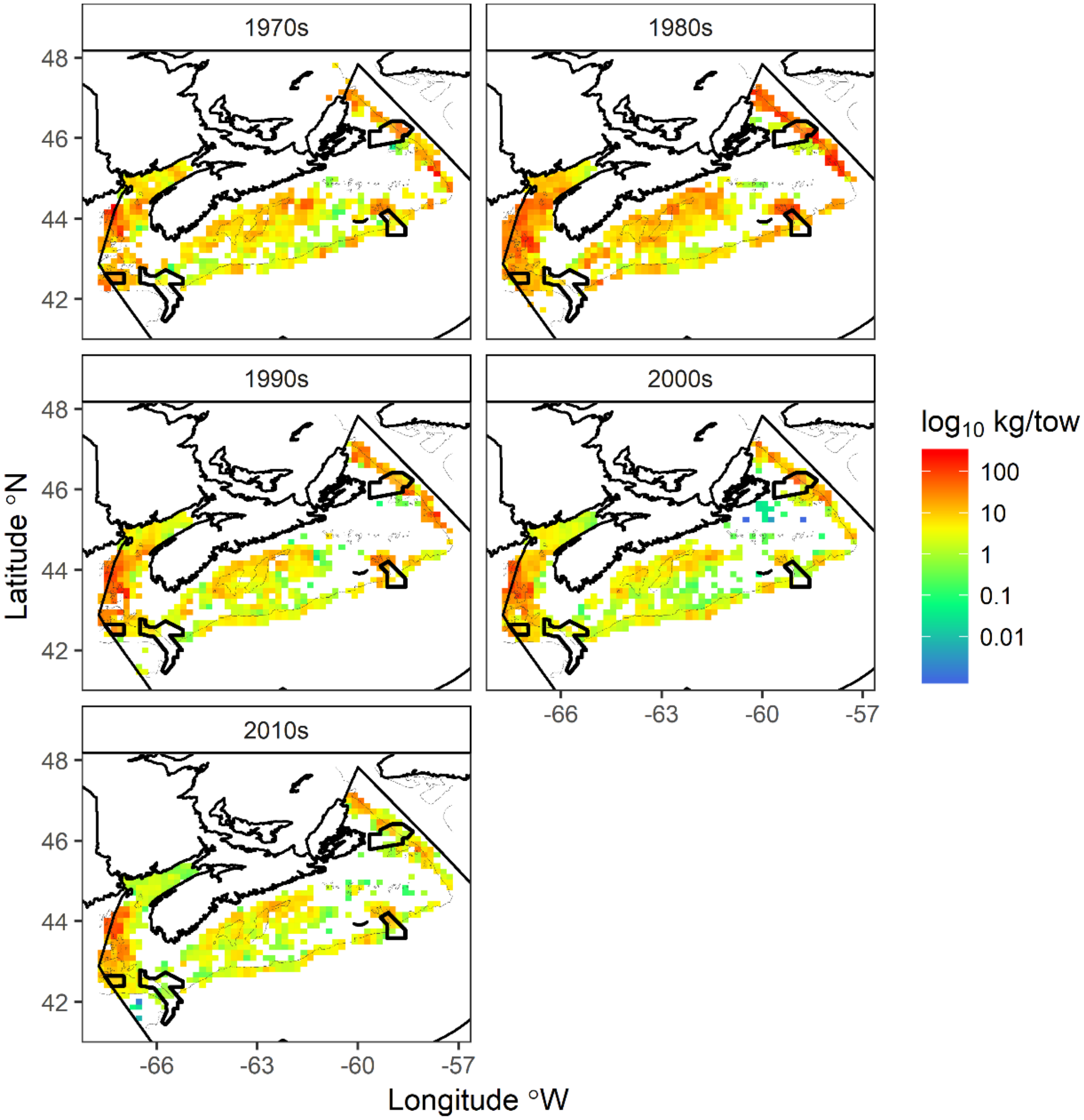

*Figure 60. Distribution of catch for White Hake (*Urophycis tenuis*) captured during the summer Research Vessel Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nm trawl set at a resolution of 15 km$^2$. Offshore polygons represent the Area of Interest and current Oceans Act Marine Protected Areas in the Maritimes Bioregion.*

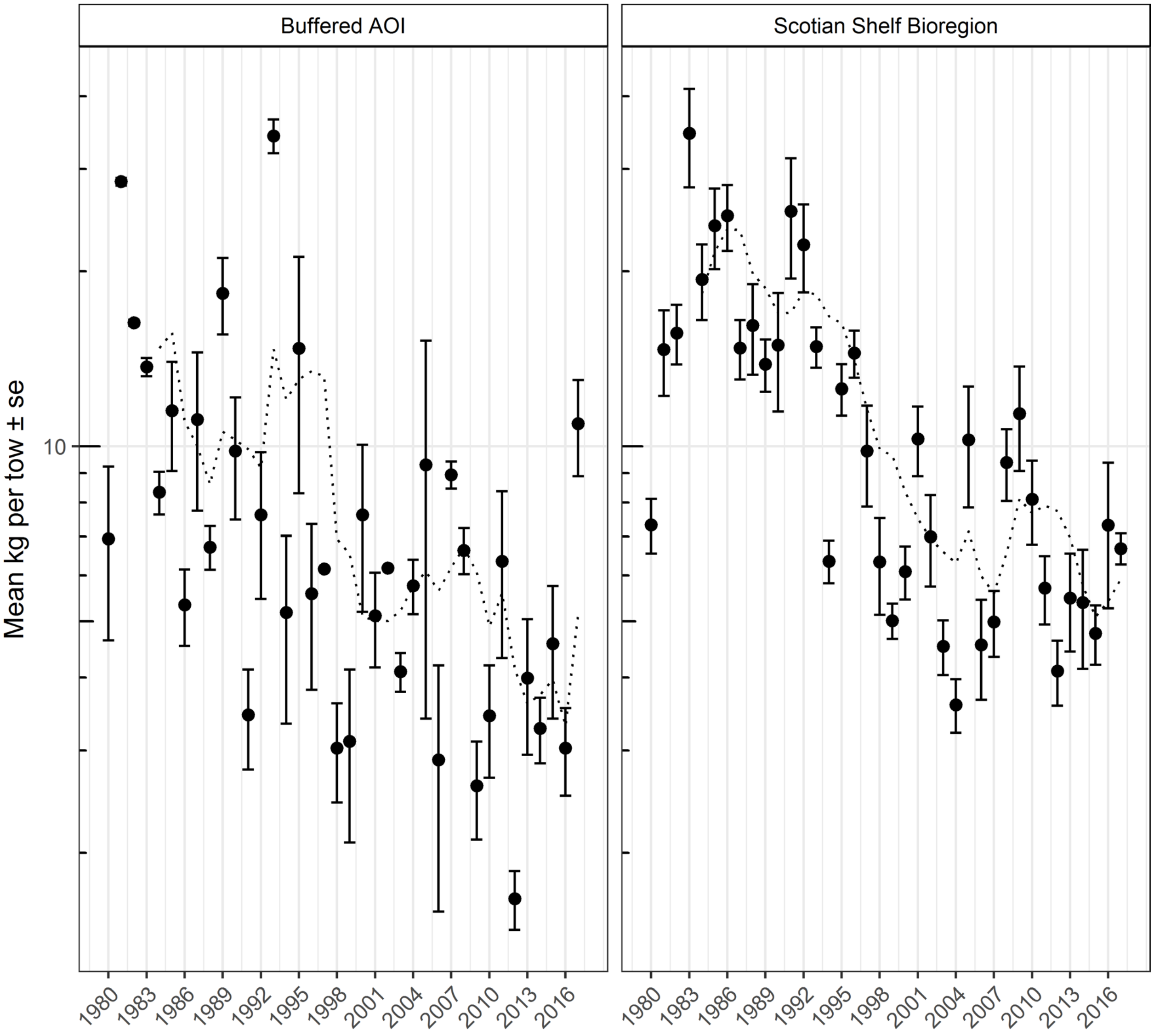

*Figure 61. Mean weight (± se) for White Hake (*Urophycis tenuis*) captured during the summer Research Vessel Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nm trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the Area of Interest (AOI) were aggregated within a 25 km buffer of the AOI boundaries.*

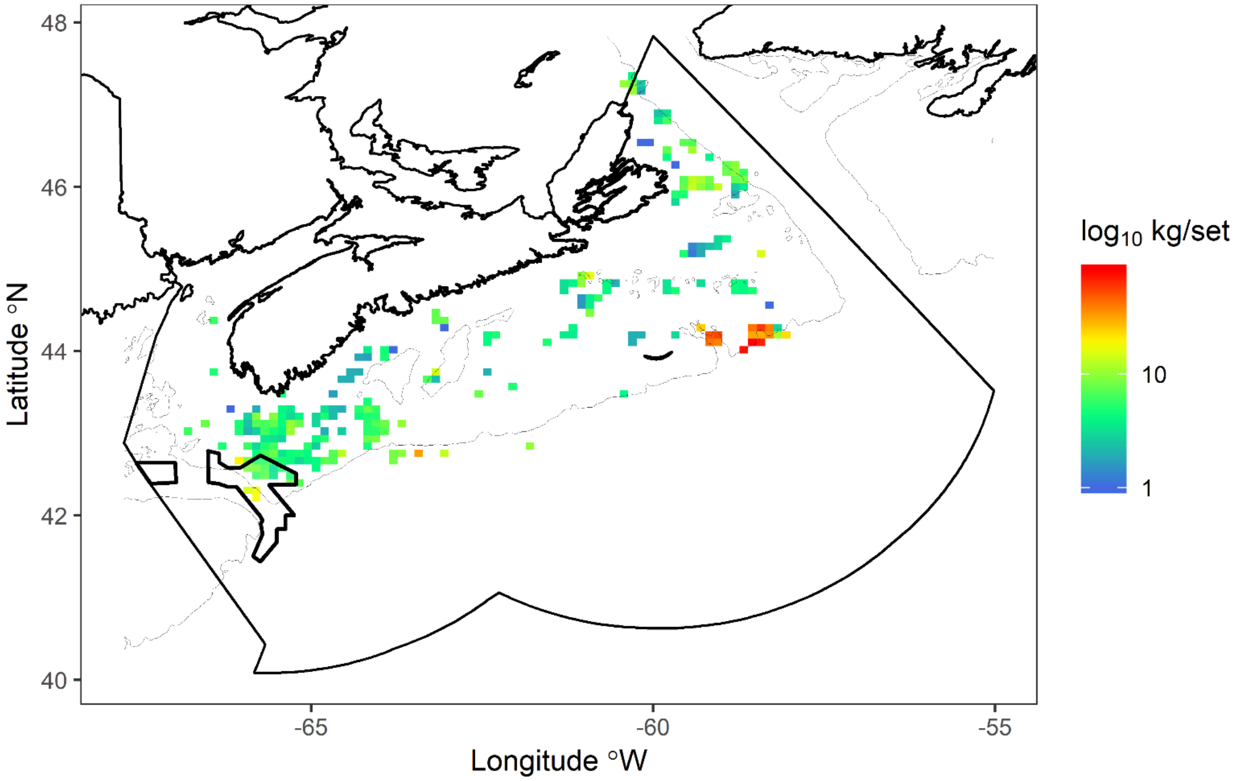

*Figure 62. Distribution of catch for Atlantic Wolffish (*Anarhichas lupus*) captured during the DFO-Industry Longline Halibut Survey between 1998 and 2018. Data was aggregated as the mean weight (kg) standardized to a resolution of 10 km$^2$. The offshore polygon represents the Area of Interest.*

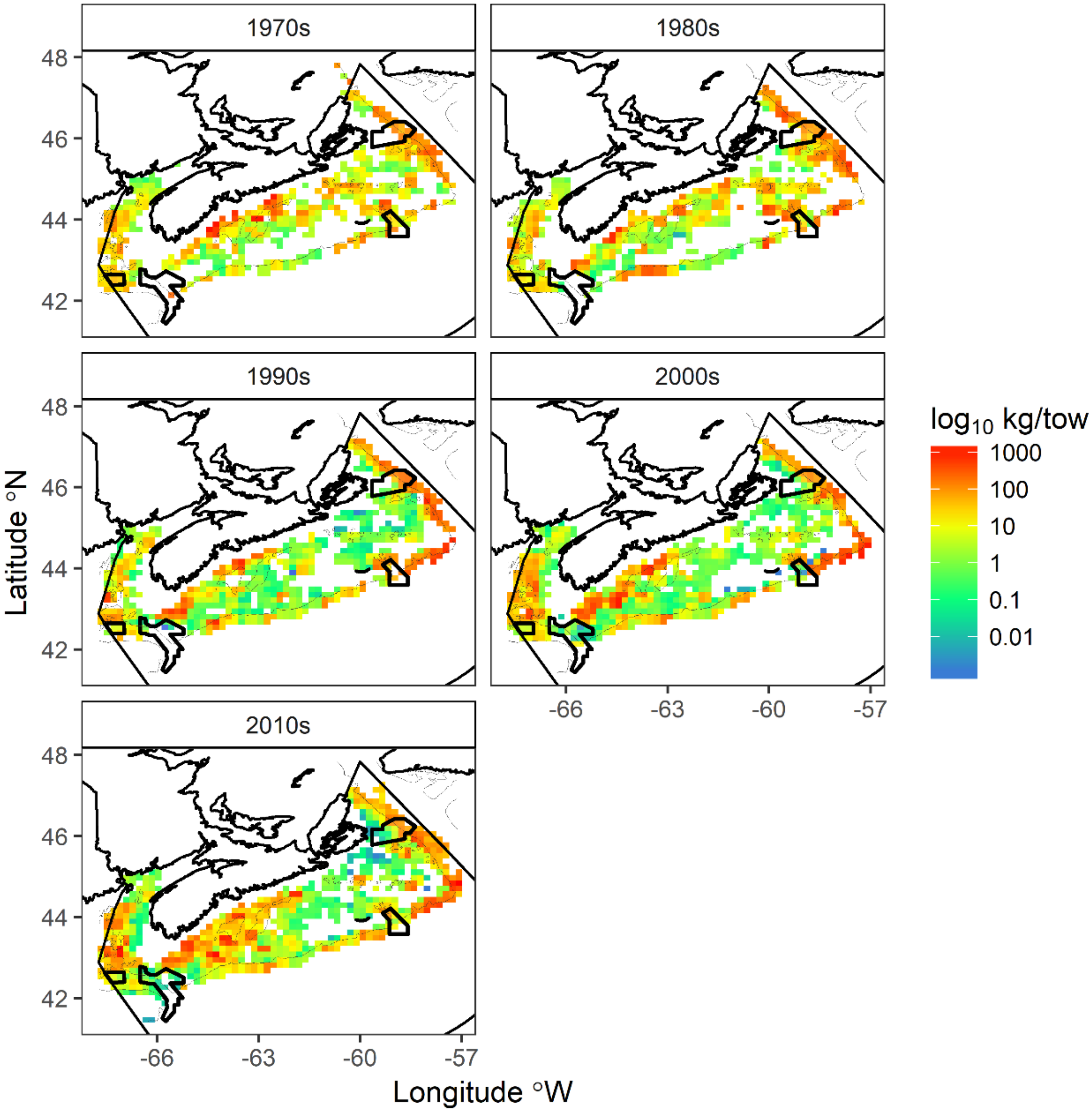

*Figure 63. Distribution of catch for Redfish (*Sebastes *spp.) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km*$^2$*. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

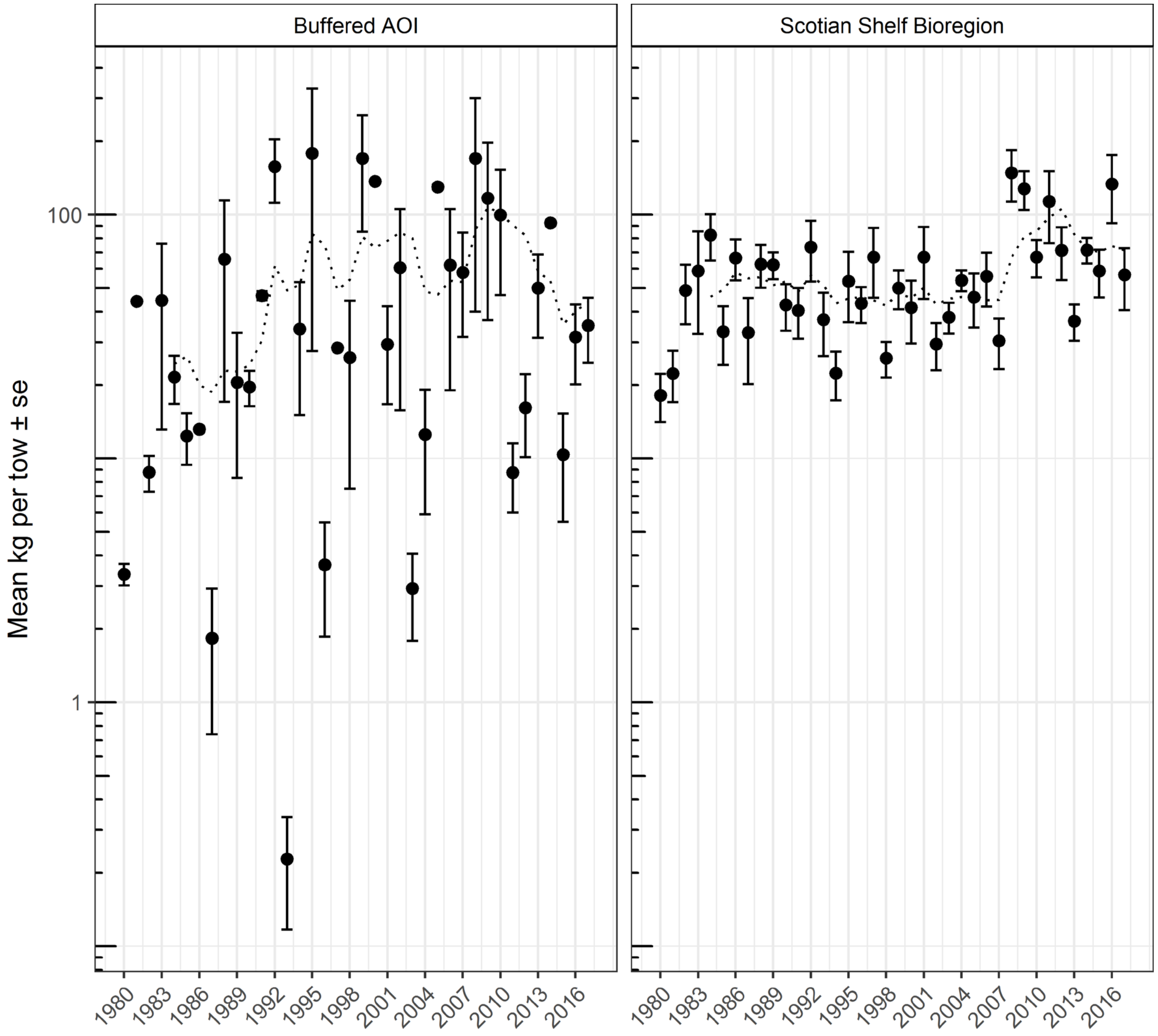

*Figure 64. Mean weight (± se) for Redfish* (Sebastes *spp.) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25km buffer of the AOI boundaries.*

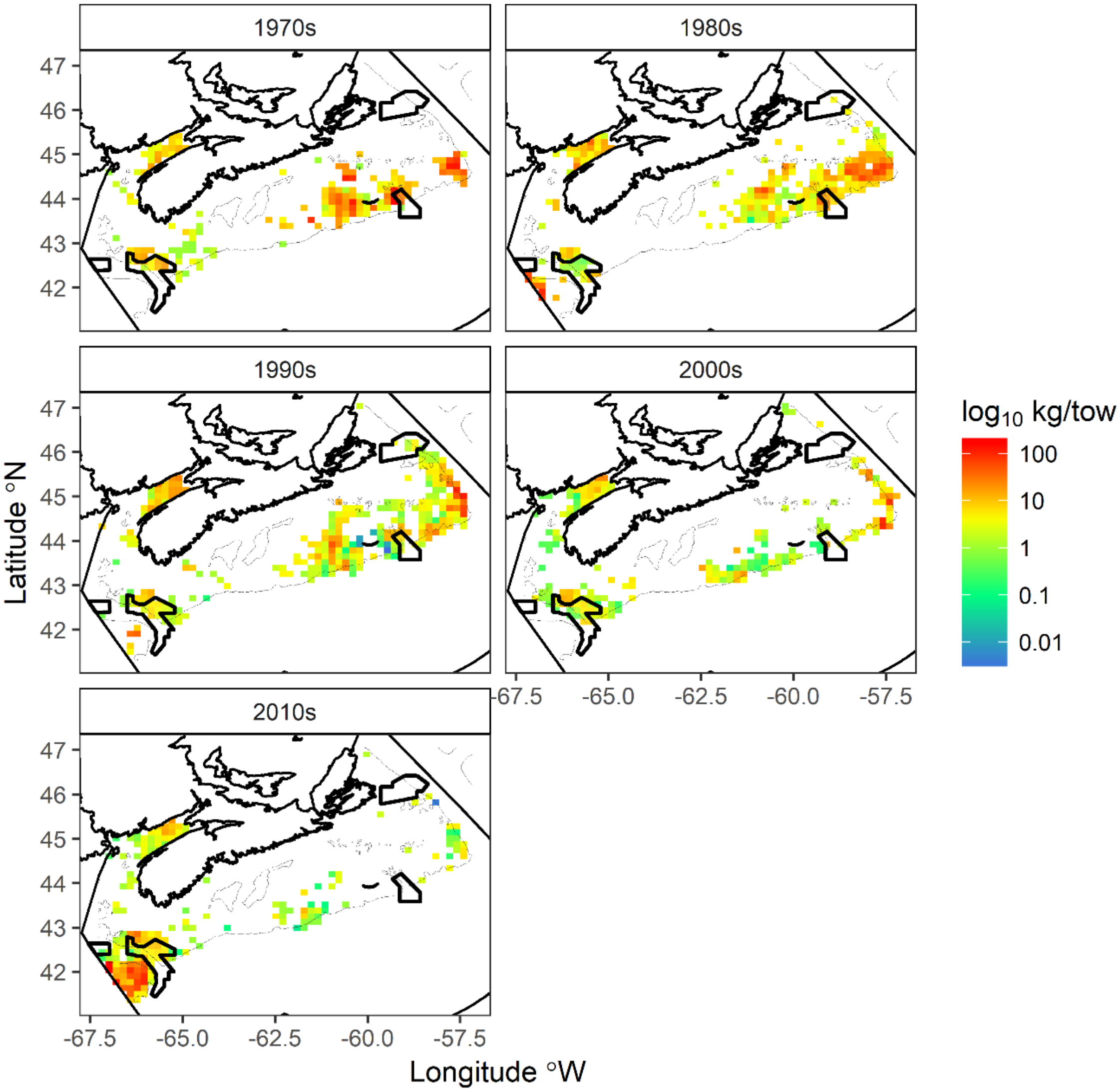

*Figure 65. Distribution of catch for Winter Skate (*Leucoraja ocellata*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

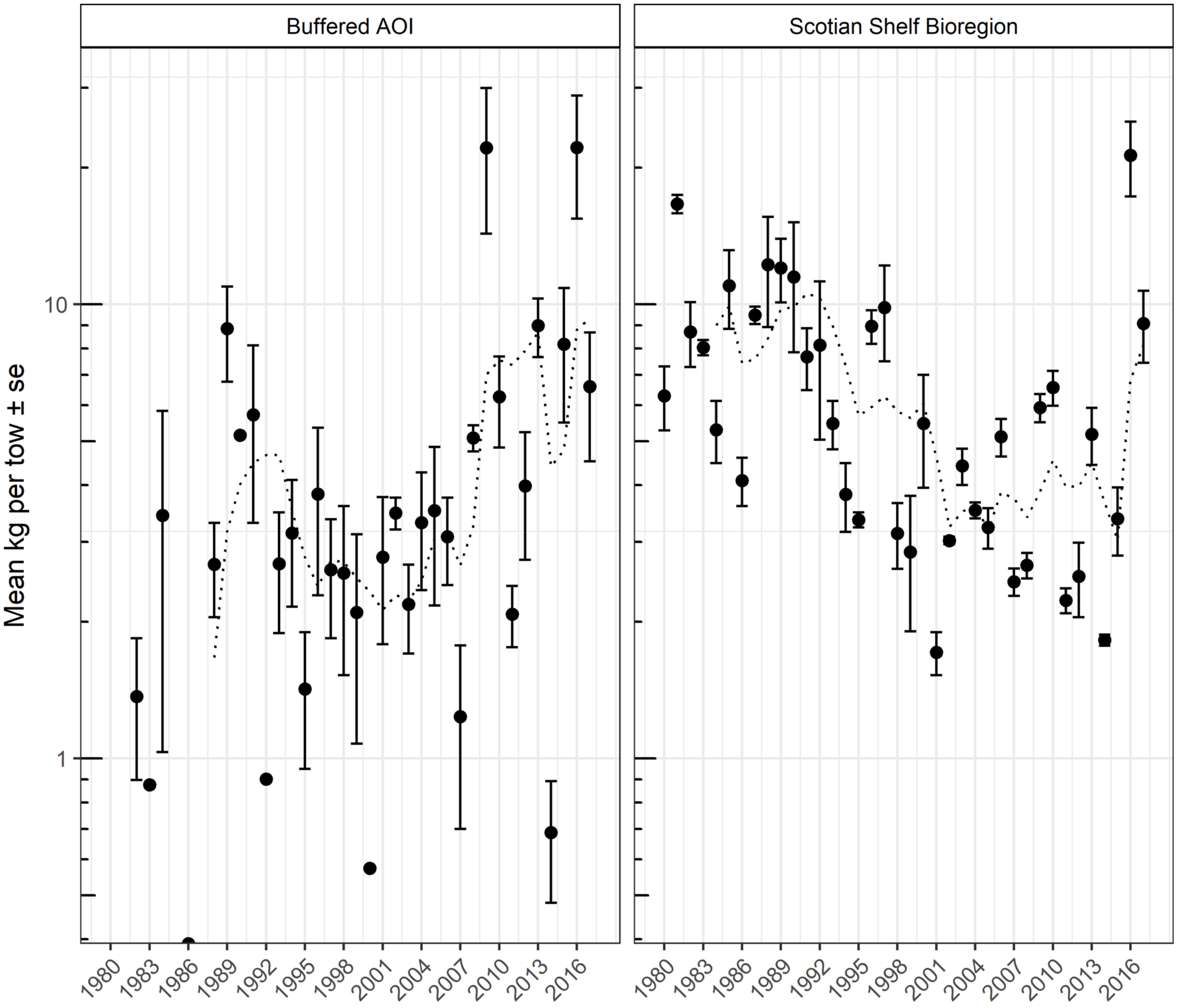

*Figure 66. Mean weight (± se) for Winter Skate (*Leucoraja ocellata*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25km buffer of the AOI boundaries.*

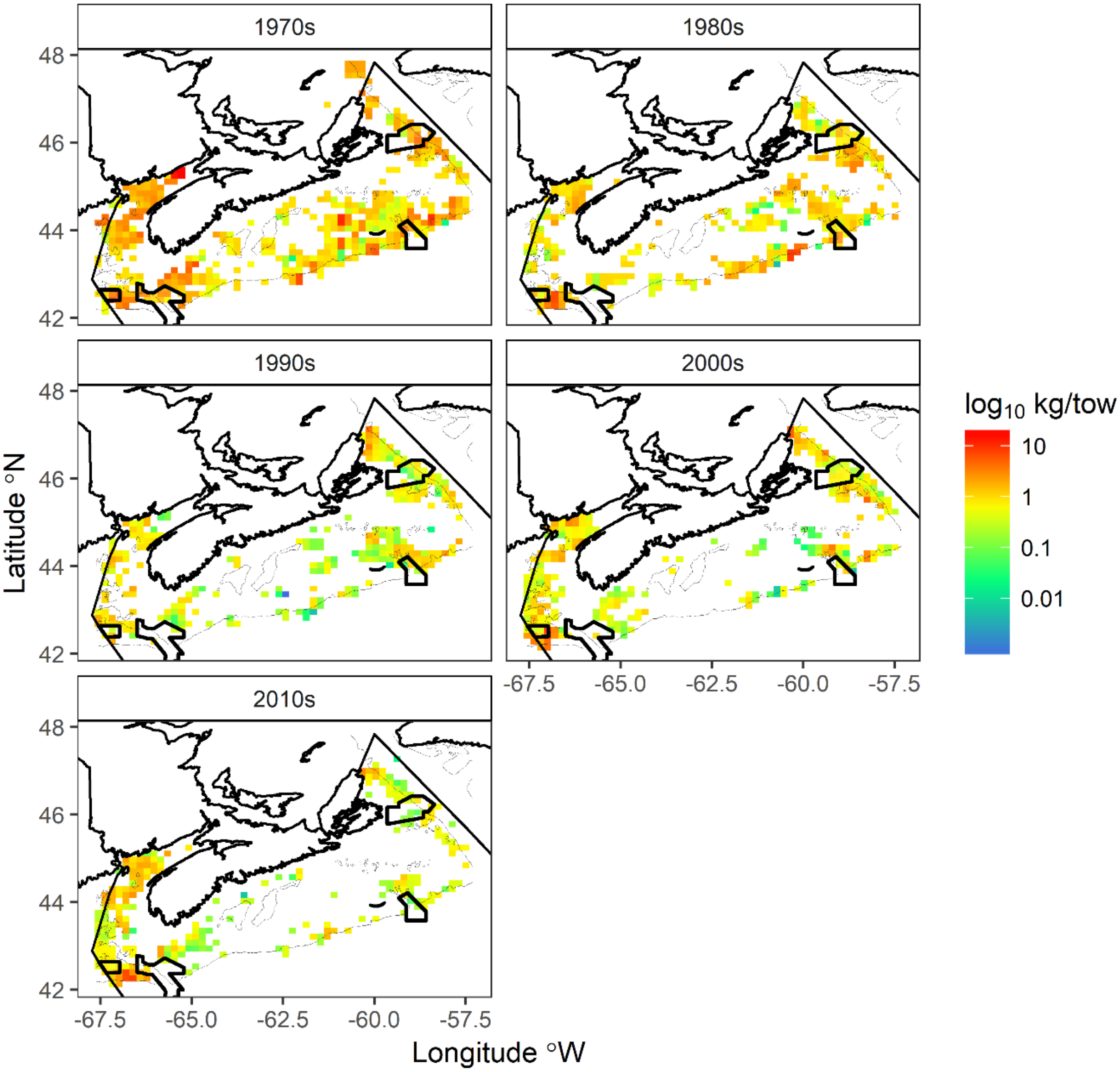

*Figure 67. Distribution of catch for Smooth Skate (*Malacoraja senta*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km*$^{2}$*. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

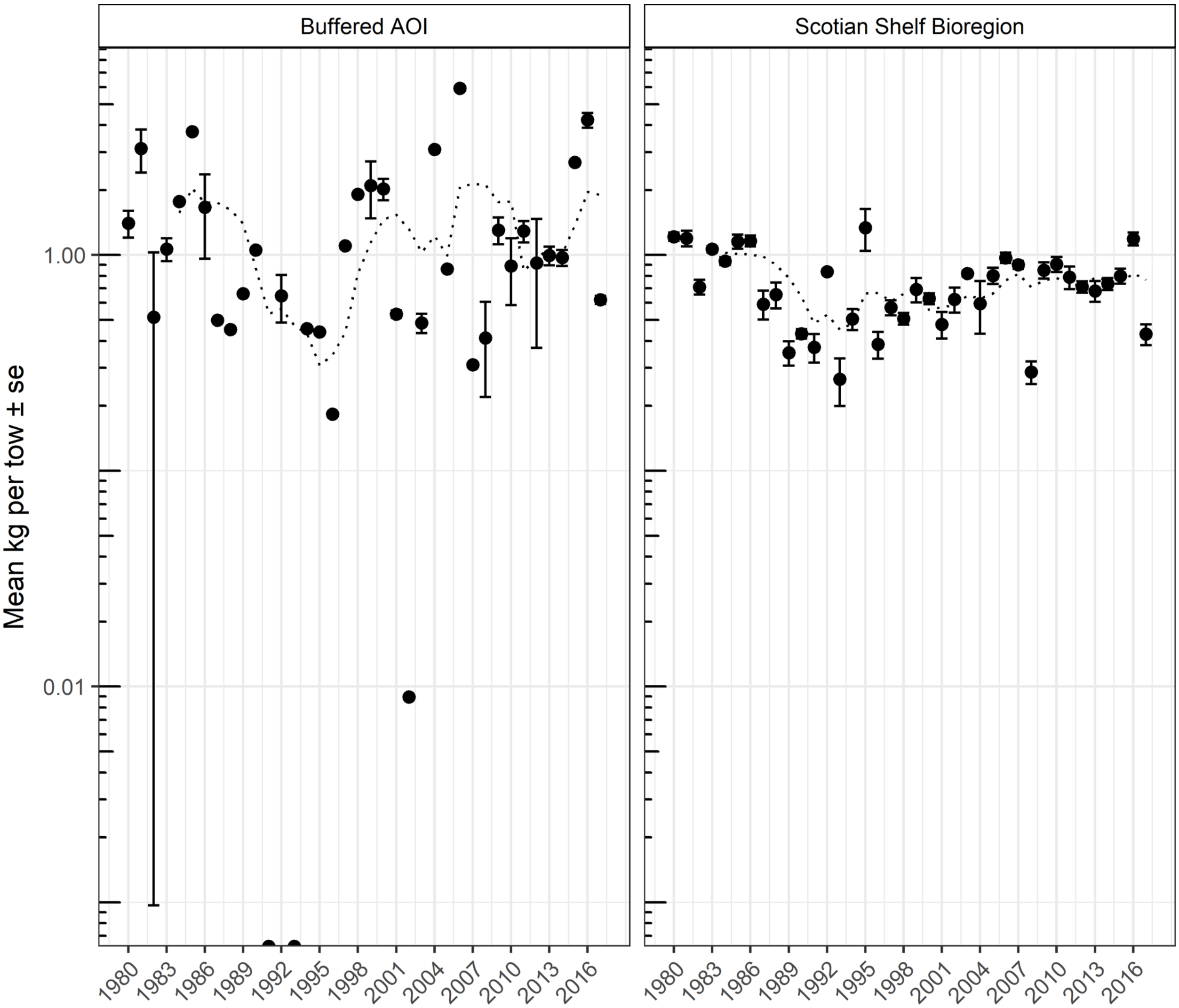

*Figure 68. Mean weight (± se) for Smooth Skate (*Malacoraja senta*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25km buffer of the AOI boundaries.*

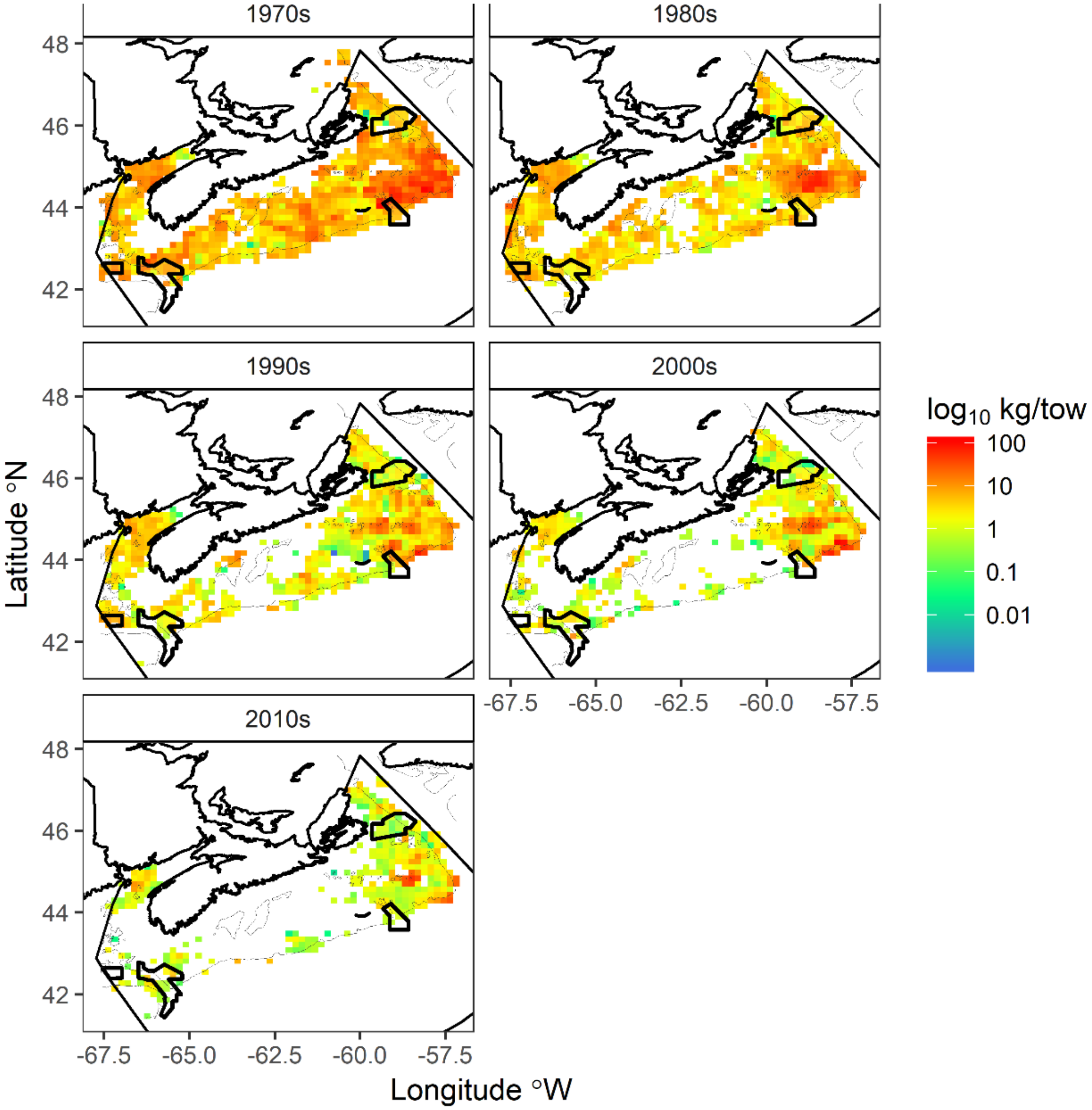

*Figure 69. Distribution of catch for Thorny Skate (*Amblyraja radiata*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

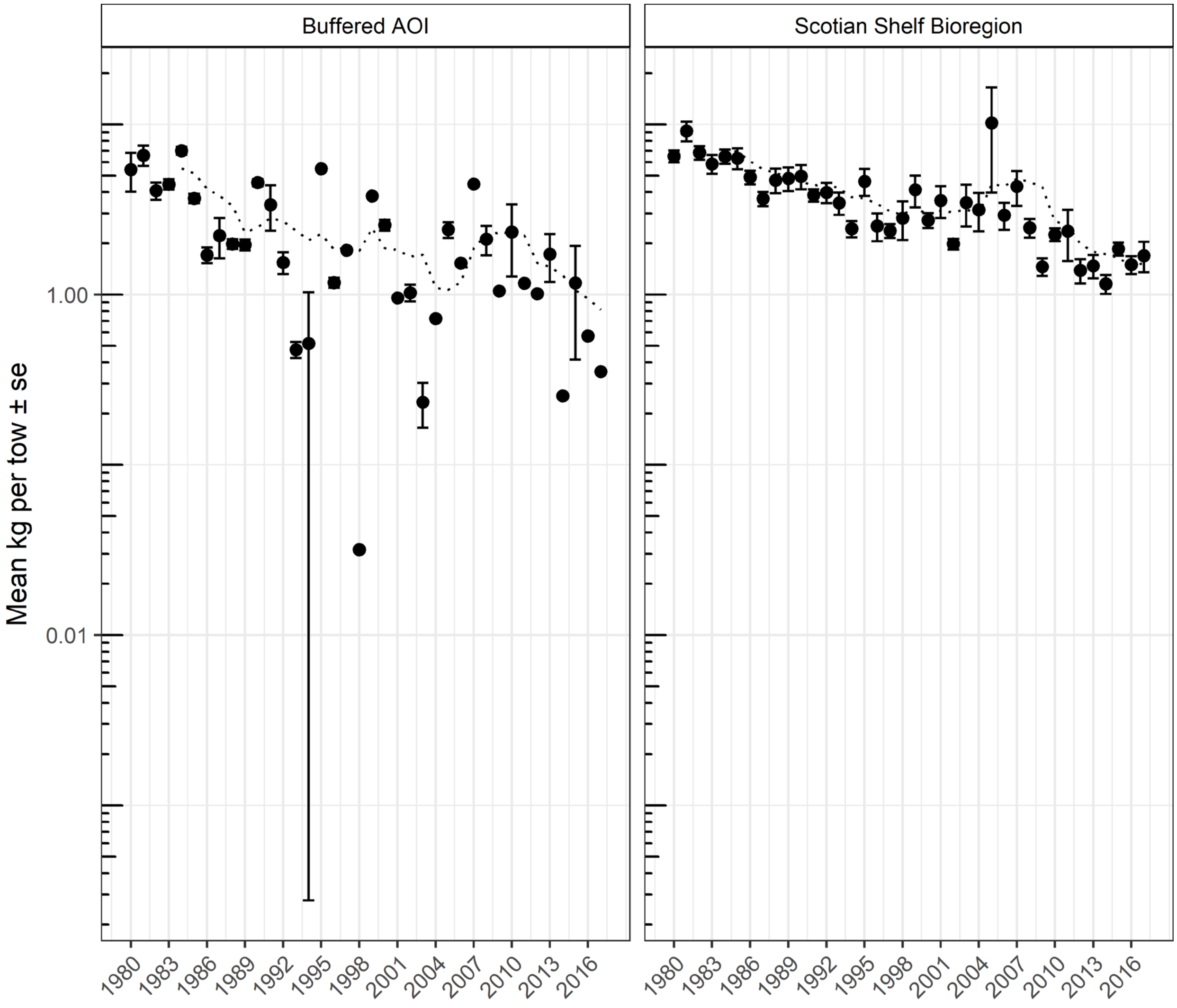

*Figure 70. Mean weight (± se) for Thorny Skate* (Amblyraja radiata*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25km buffer of the AOI boundaries.*

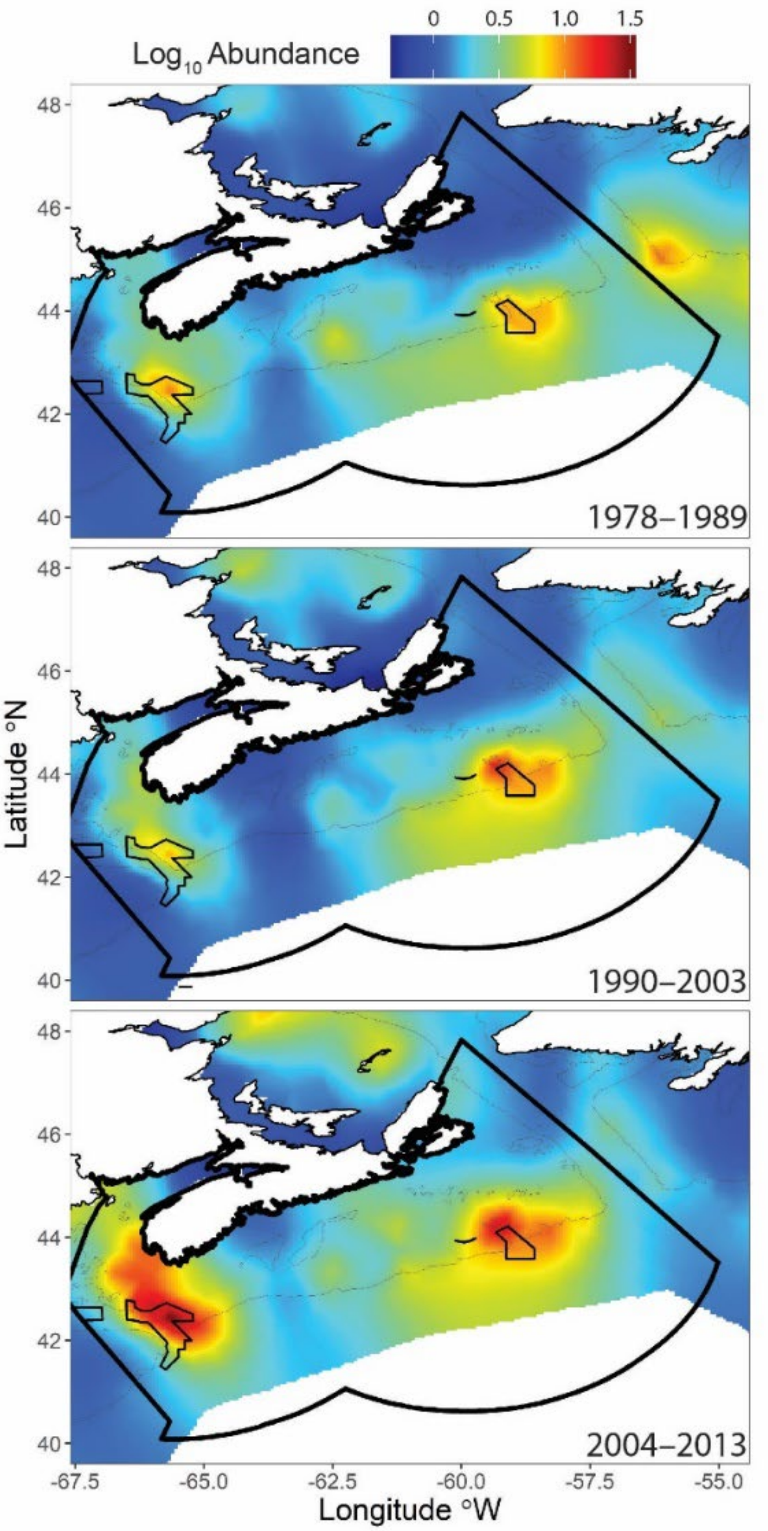

*Figure 71. Distribution of juvenile Atlantic Halibut (*Hippoglossus hippoglossus*) abundance in Atlantic Canada showing two persistent areas of high abundance on the Scotian Shelf — one in Southwest Nova Scotia that overlaps with the AOI and one to the east that overlaps with the Gully Marine Protected Area (modified from Boudreau et al. 2017). The black polygons denote the boundary for the AOI, the Gully MPA, and the Maritimes Region (thicker black line).*

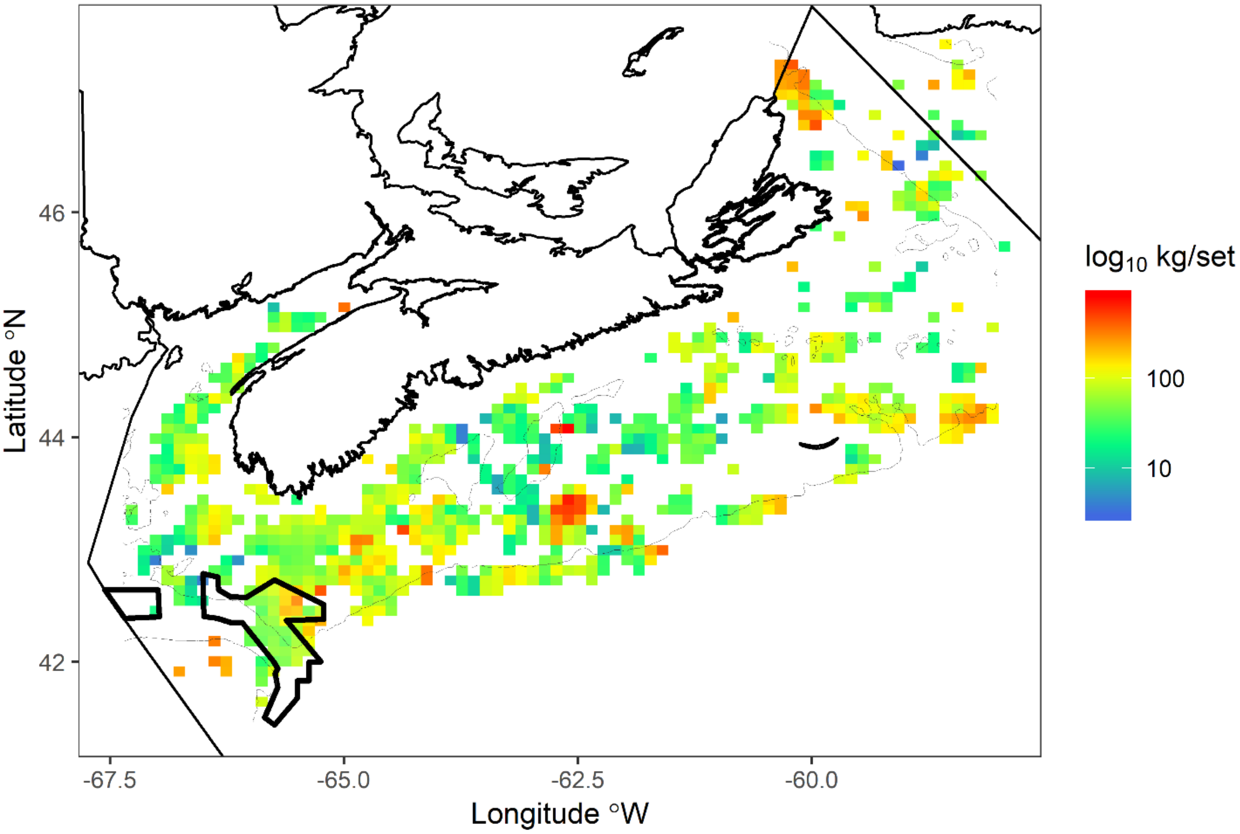

*Figure 72. Distribution of catch for Atlantic Halibut (*Hippoglossus hippoglossus*) captured during the Halibut DFO-Industry Longline Survey between 1998 and 2018. Data was aggregated across all years to a resolution of 10 km$^2$. The black polygon represents the boundaries of the AOI used as a study area.*

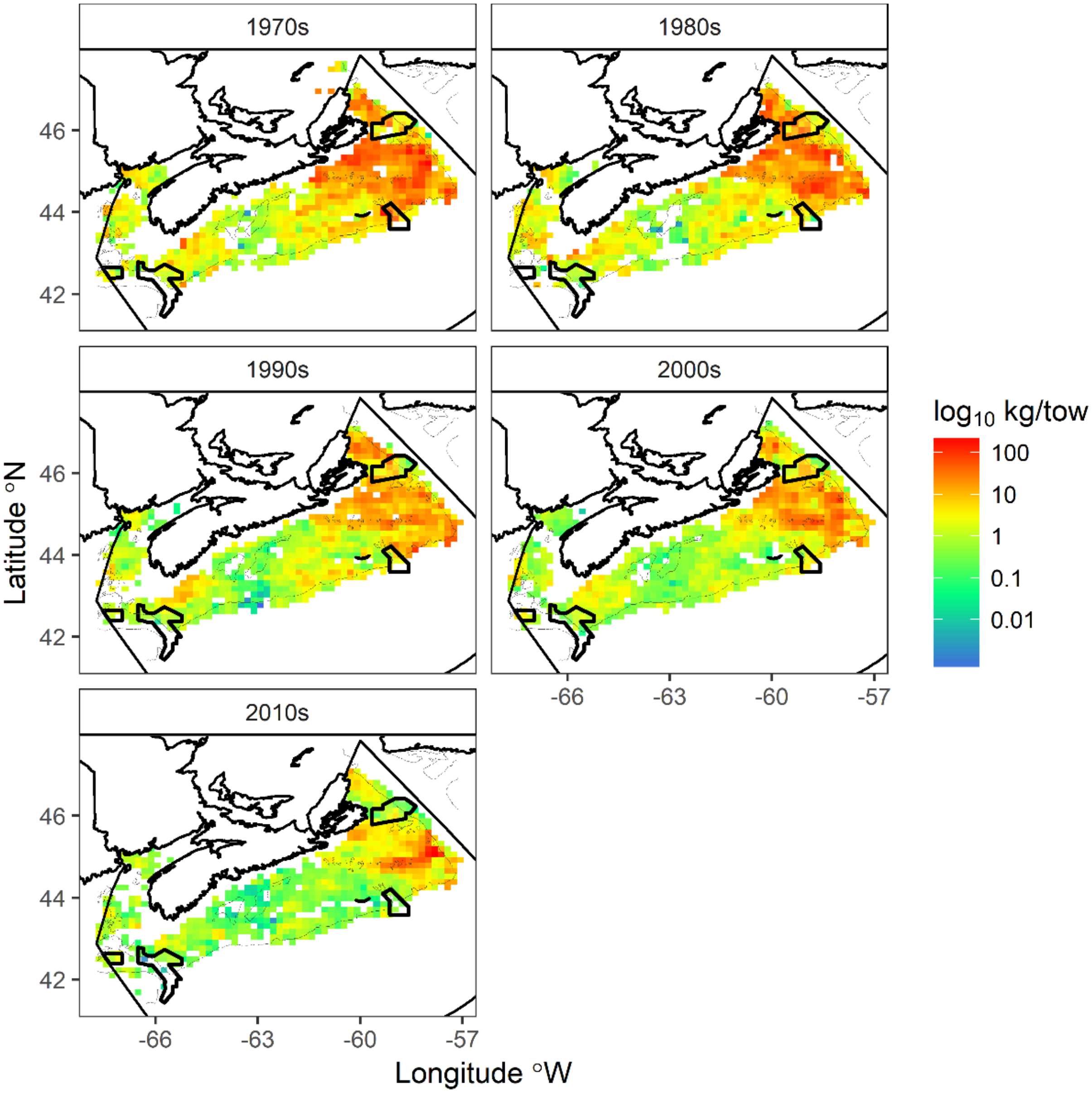

*Figure 73. Distribution of catch for American Plaice (*Hippoglossoides platessoides*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

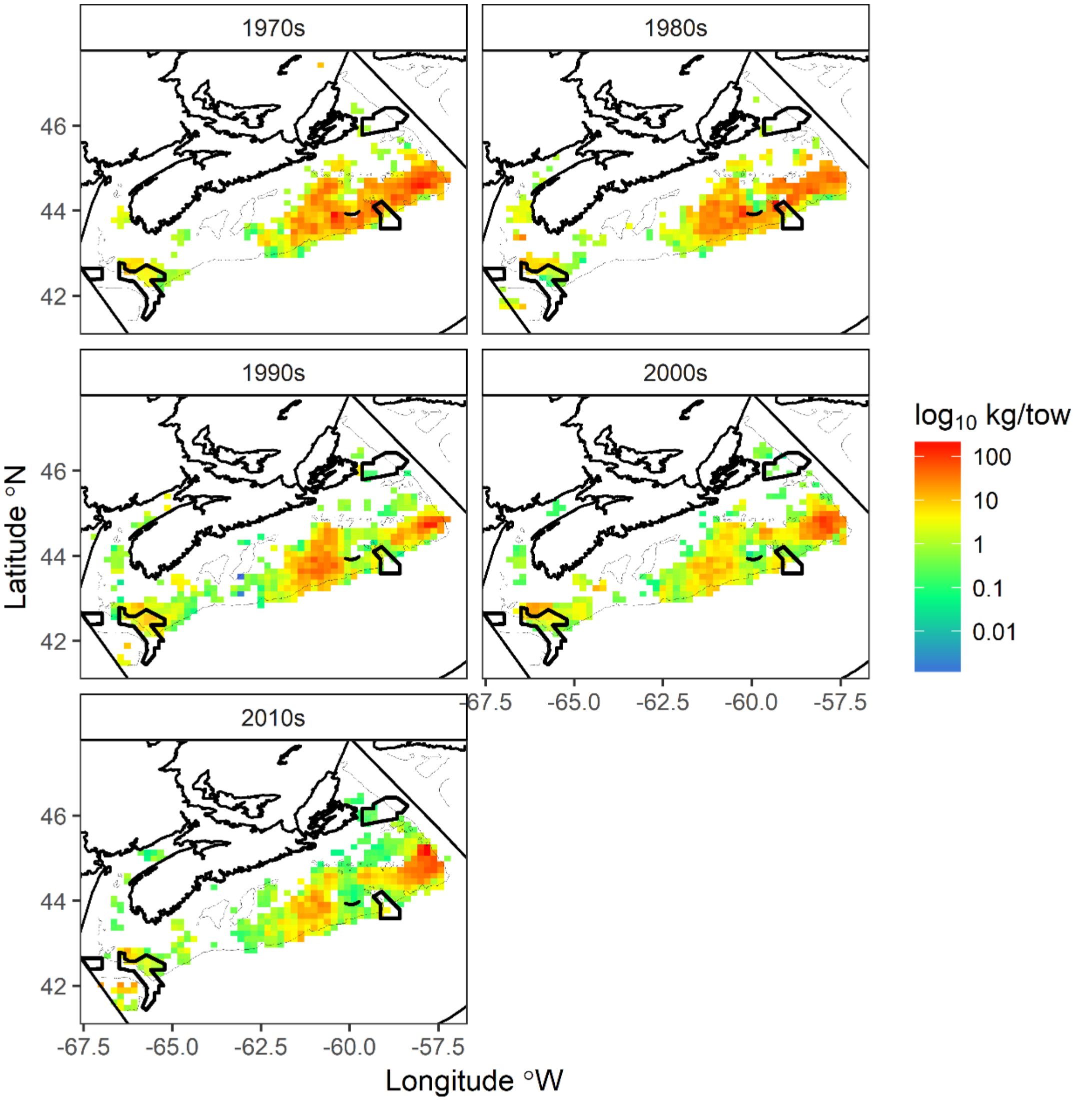

*Figure 74. Distribution of catch for Yellowtail Flounder (*Pleuronectes ferruginea*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

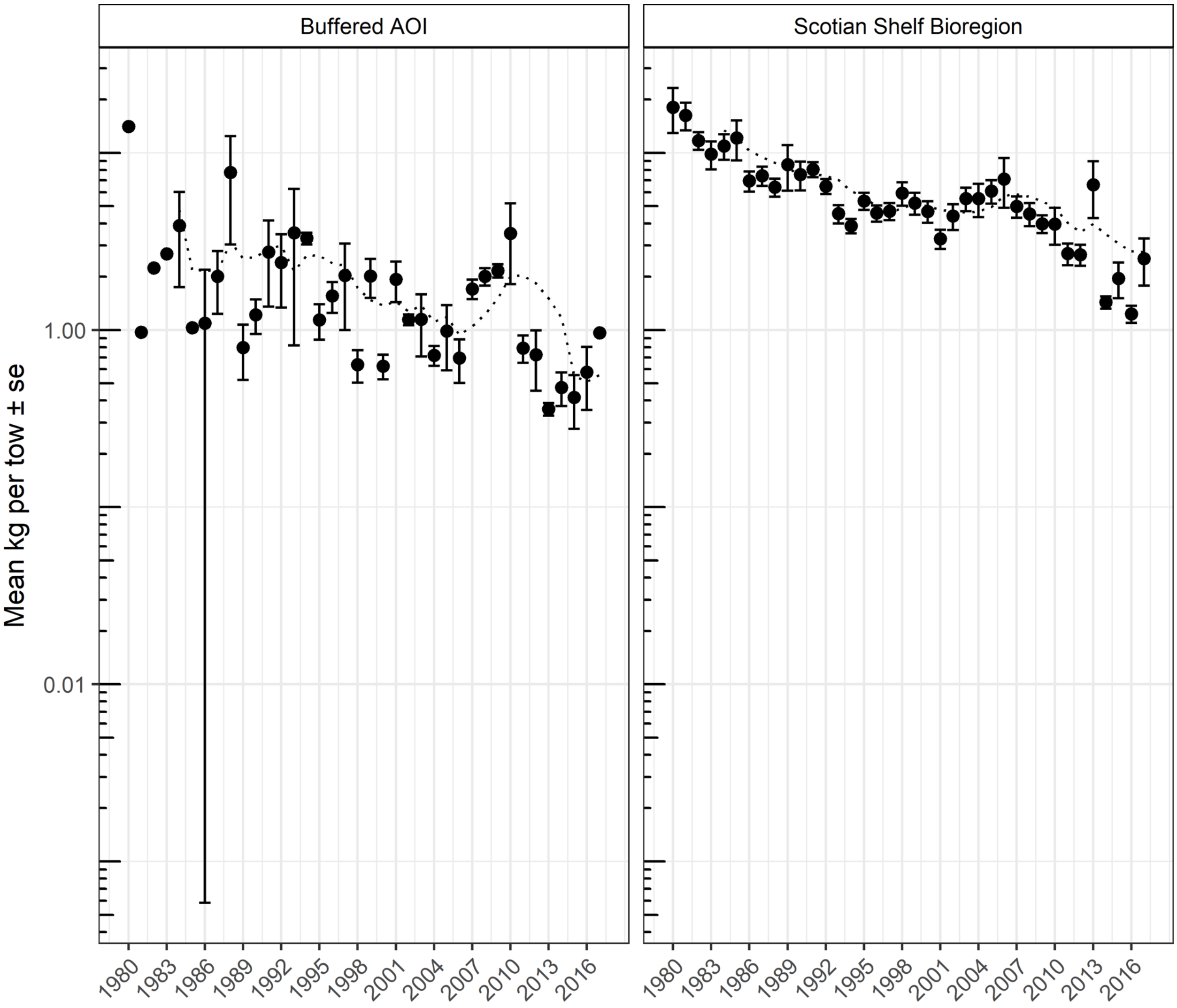

*Figure 75. Mean weight (± se) for American Plaice (*Hippoglossoides platessoides*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25 km buffer of the AOI boundaries.*

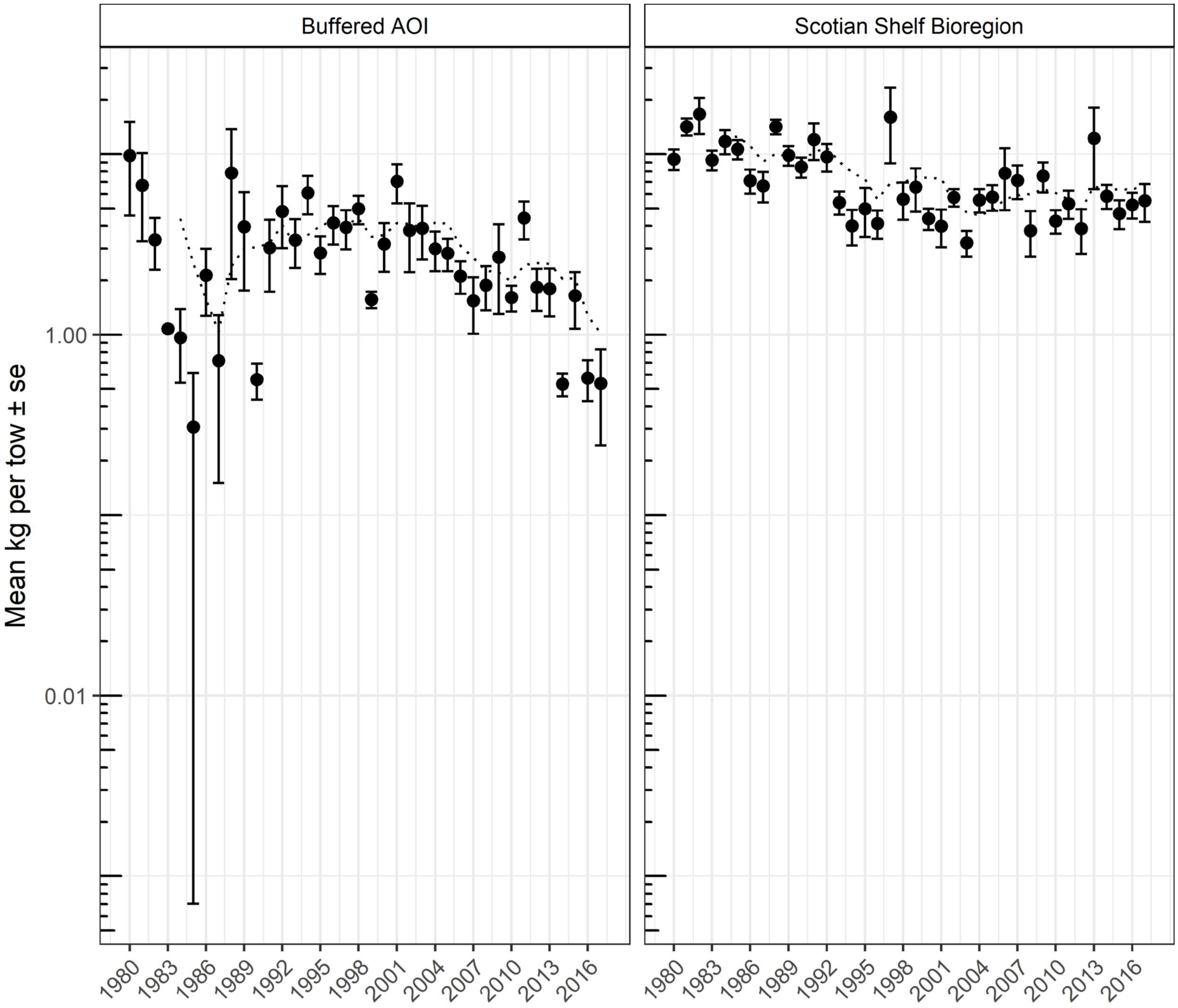

*Figure 76. Mean weight (± se) for Yellowtail Flounder (*Pleuronectes ferruginea*) captured during the summer RV Survey from 1980–2017. Means are calculated based on a random stratified design based on weight (kg) standardized to a 1.75 nautical mile trawl set. Dashed lines represent a 5 year lagged mean. Data considered for the AOI were aggregated within a 25 km buffer of the AOI boundaries.*

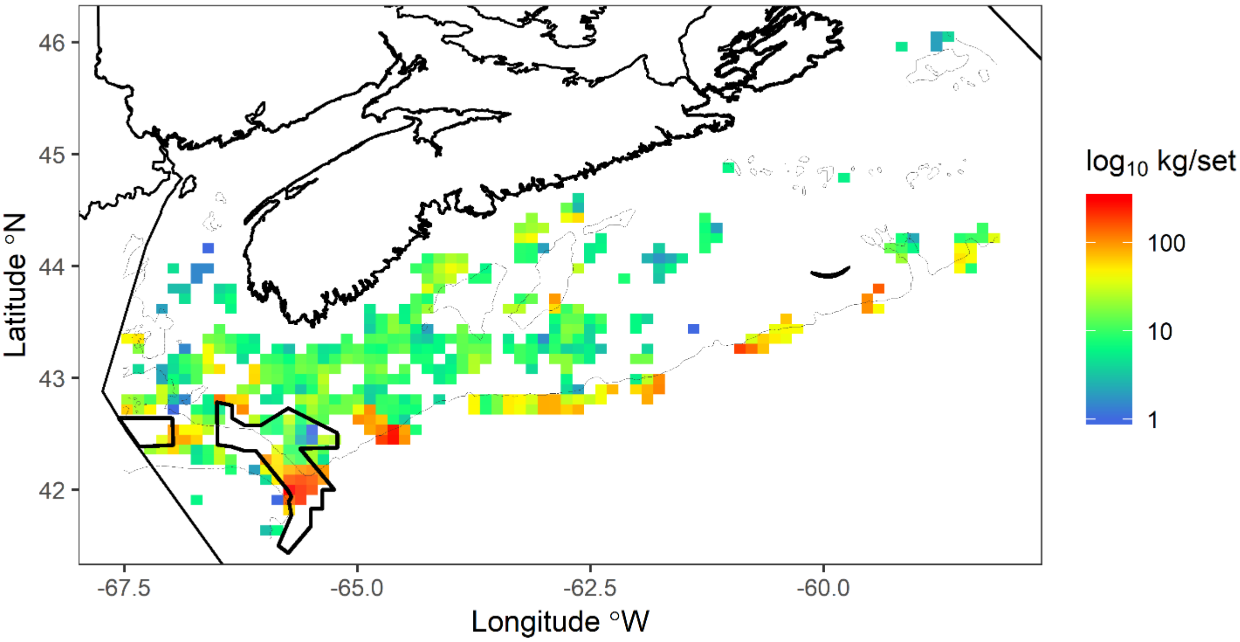

*Figure 77. Cusk (*Brosme brosme*) landings (log kg/set) from the Halibut DFO-Industry Longline Survey from 1998 to 2018 in the Maritimes Bioregion. The longlines used in this survey are thought to more accurately represent the distribution of Cusk relative to the RV trawl survey, which does not adequately capture Cusk.*

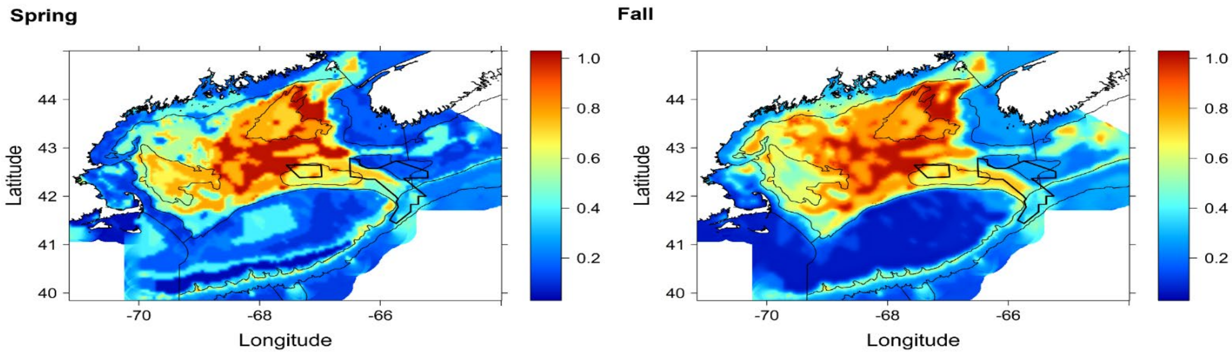

*Figure 78. Habitat suitability models for Cusk (*Brosme brosme*) in the Gulf of Maine based on spring and fall NOAA groundfish survey data. The black polygon represents the boundaries of the AOI. Figures modified with permission from Runnebaum et al. (2017).*

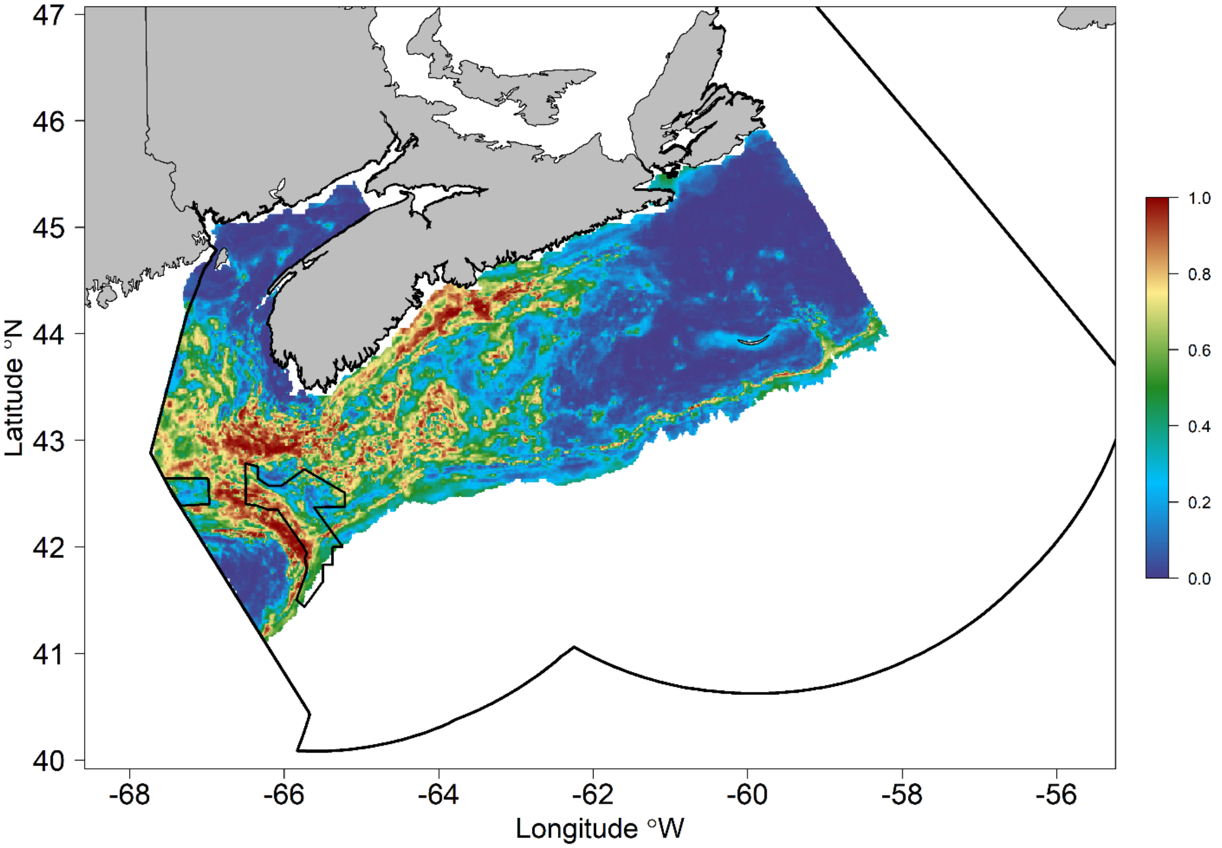

*Figure 79. Habitat suitability model (predicted presence) for Cusk (*Brosme brosme*) for the Maritimes Region predicted using a random forest method. The probability of presence is shown, with red indicating 100% probability of presence, and blue indicating 0% probability of presence (modified with permission from Harris et al. 2018). The black polygons denote the boundary for the AOI and the Maritimes Region.*

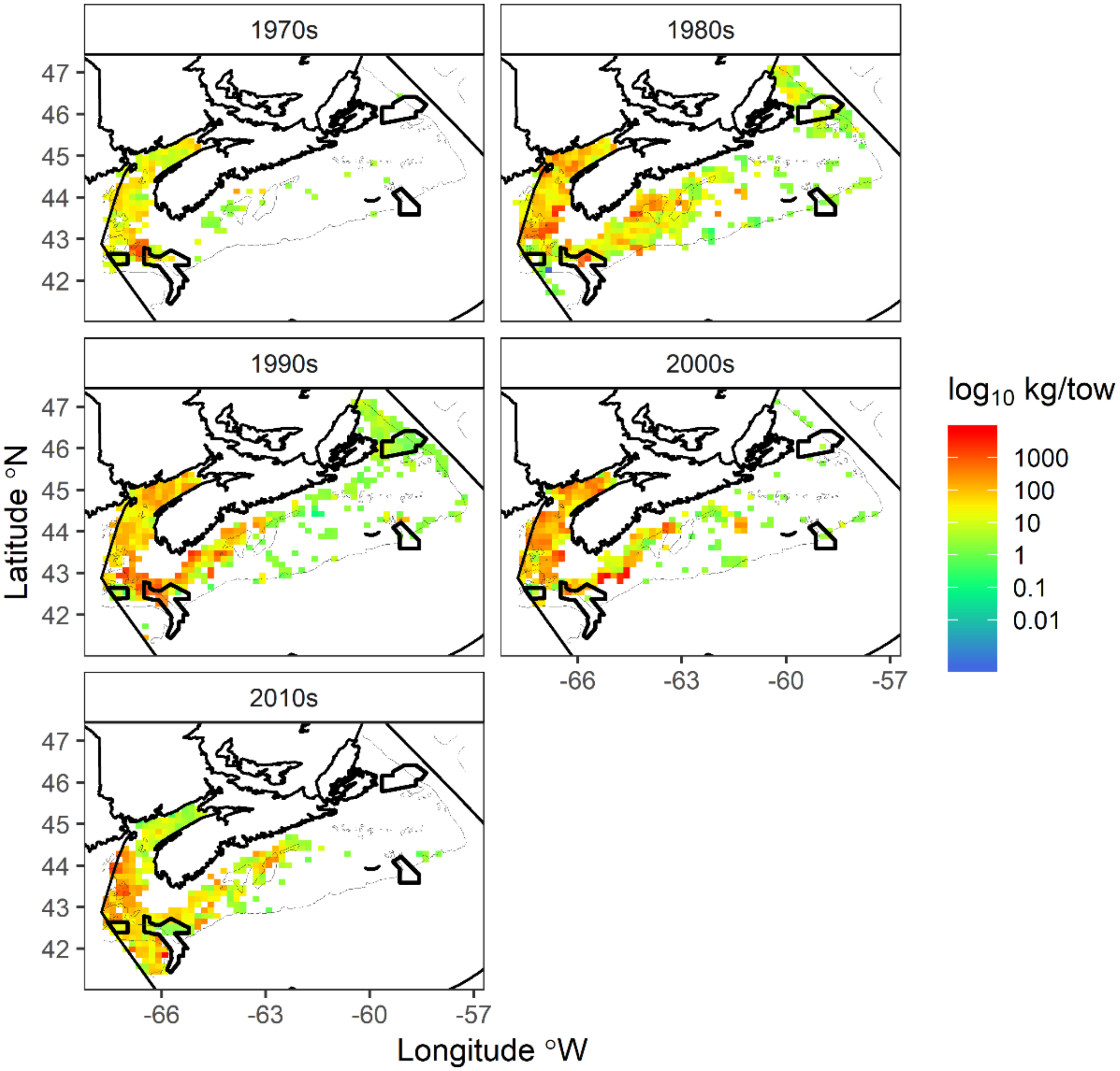

*Figure 80. Distribution of catch for Spiny Dogfish (*Squalus acanthias*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

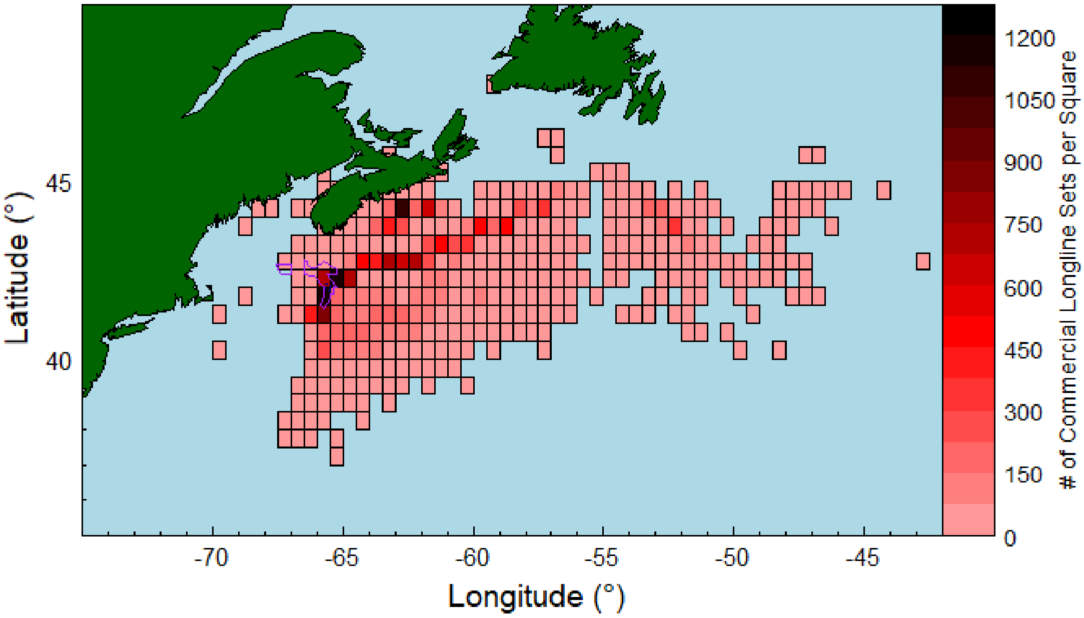

*Figure 81. The distribution of the Canadian Atlantic Swordfish and Other Tunas Pelagic Longline (PLL) fishing sets from 2004 to 2018, using 0.5 by 0.5 degree grid cells. During that time frame there were 23,983 PLL sets with 491 of those sets removed due to a lack of coordinates provided. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. The sets are generally along the shelf break with the most populated grid square having 1,200 sets.*

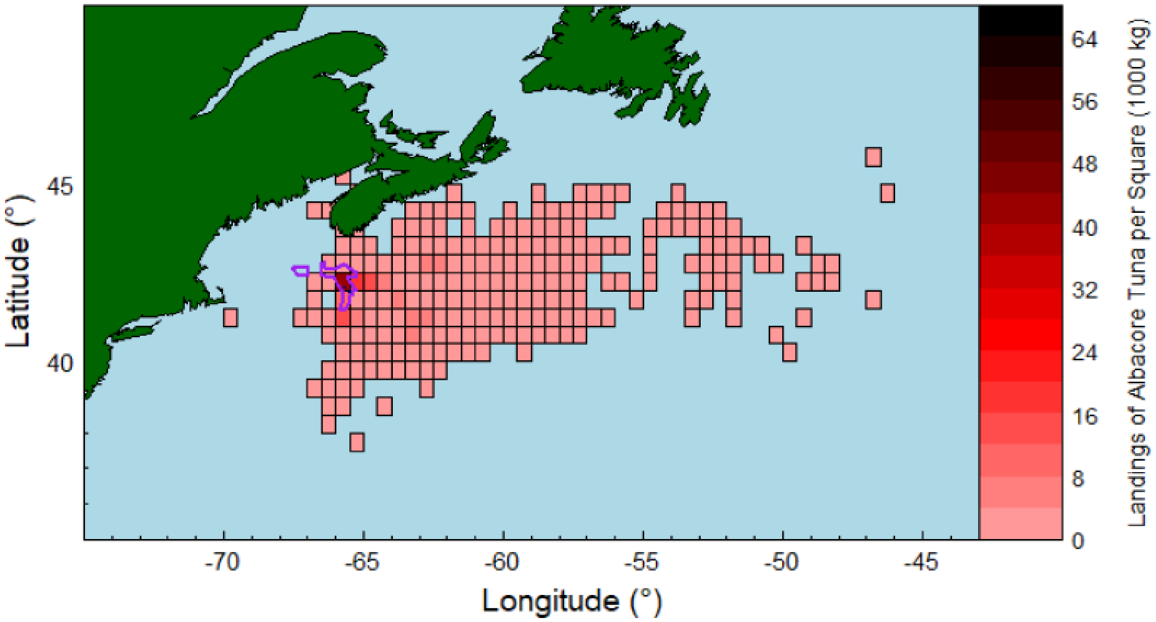

*Figure 82. The distribution of Atlantic Albacore Tuna (*Thunnus alalunga*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.5 by 0.5 degree grid cells. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. During that timeframe there was 314,362 kg of Atlantic Albacore tuna landed by the PLL fishery, this accounts for approximately 74% of all of the Atlantic Albacore tuna landings in the Maritimes Region. 2% of the longline landings (5,161 kg) were removed from the map due to a lack of coordinates for the landing. The greatest volume of landings in a single grid square was 41,298 kg.*

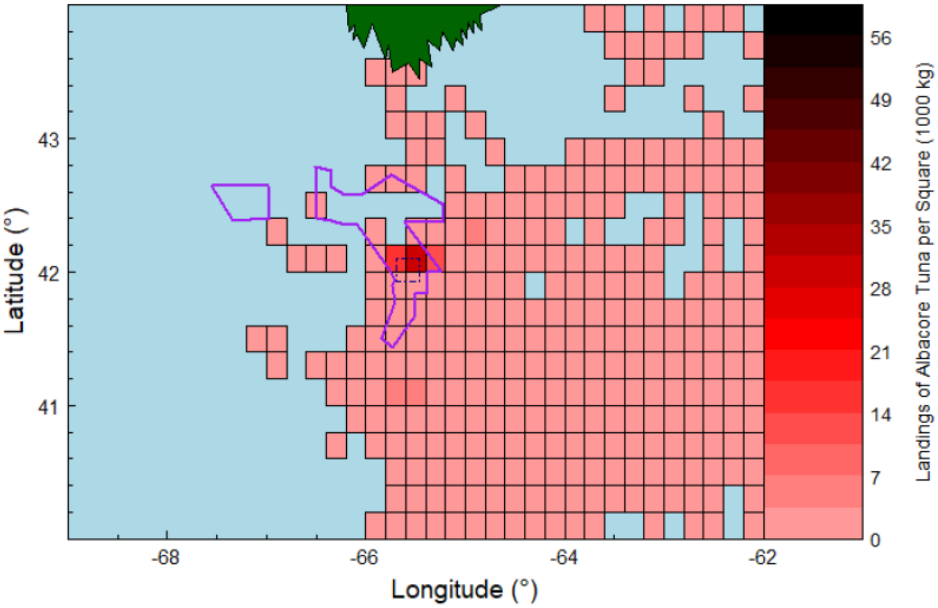

*Figure 83. The distribution of Atlantic Albacore tuna (*Thunnus alalunga*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.2 by 0.2 degree grid cells and focused on the area around the Fundian Channel – Browns Bank Area of Interest (outlined in purple). The greatest volume of landings in a single grid square was 30,623 kg. The map shows a total of 221,433 kg worth of Atlantic Albacore tuna landings, by the PLL fishery, nearly 52% of the total Maritimes landings of Atlantic Albacore tuna from 2004 to 2018 (426,745 kg).*

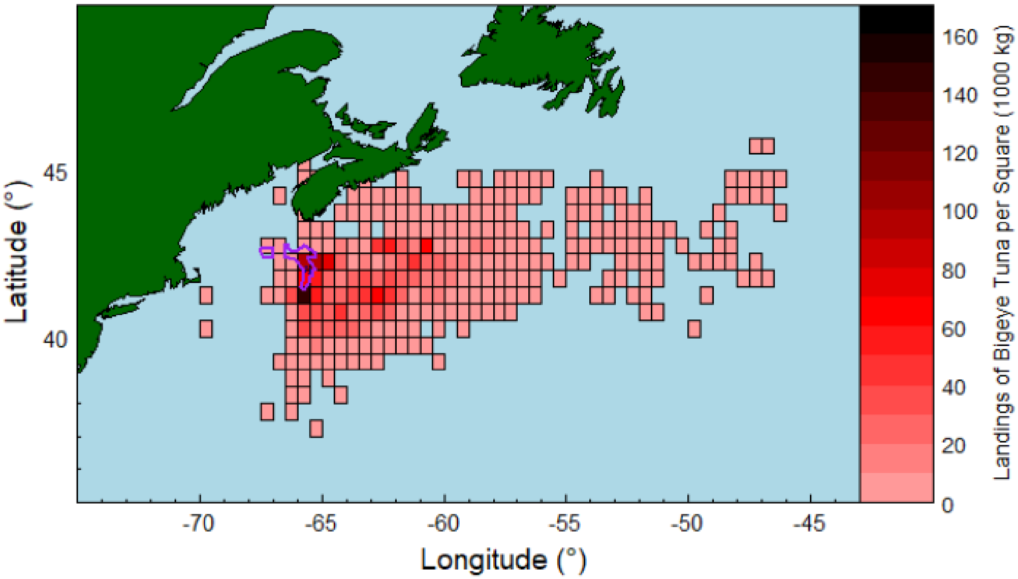

*Figure 84. The distribution of Bigeye Tuna (*Thunnus obesus*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.5 by 0.5 degree grid cells. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. During that time frame there was 2,309,777 kg of Bigeye tuna landed by the PLL fishery, which accounts for nearly 89% of all Bigeye tuna landings in the Maritimes Region. 1% of the longline landings (22,732 kg) were removed from the map due to a lack of coordinates for the landing. The greatest volume of landings in a single grid square was 147,800 kg.*

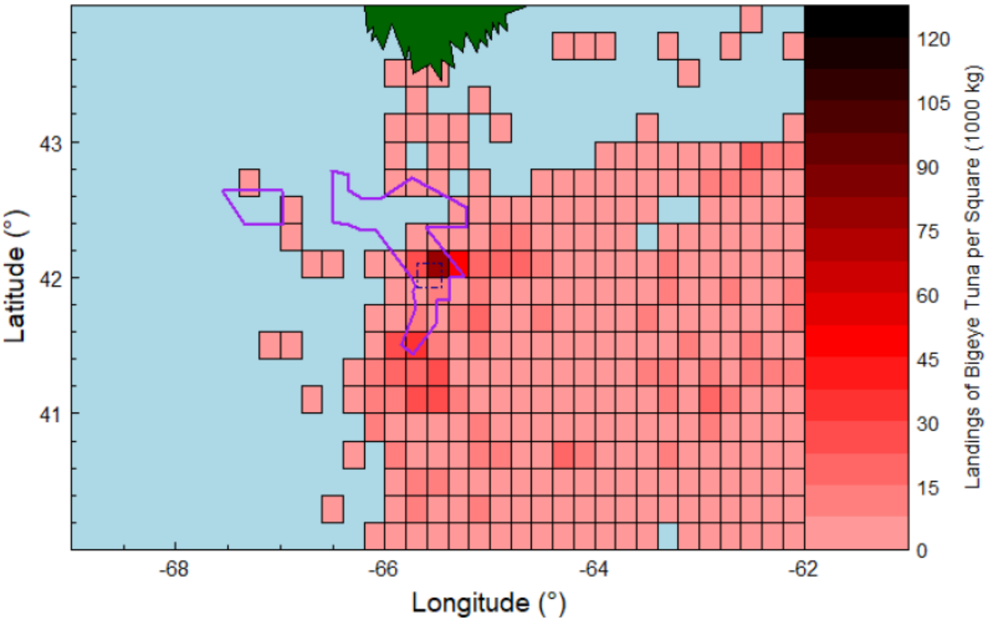

*Figure 85. The distribution of Bigeye Tuna (*Thunnus obesus*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.2 by 0.2 degree grid cells and focused on the area around the Fundian Channel – Browns Bank Area of Interest (outlined in purple). The greatest volume of landings in a single grid square was 77,830 kg. The map shows a total of 1,637,021 kg worth of Bigeye tuna landings, by the PLL fishery, nearly 63% of the total Maritimes landings of Bigeye tuna from 2004 to 2018 (2,599,121 kg).*

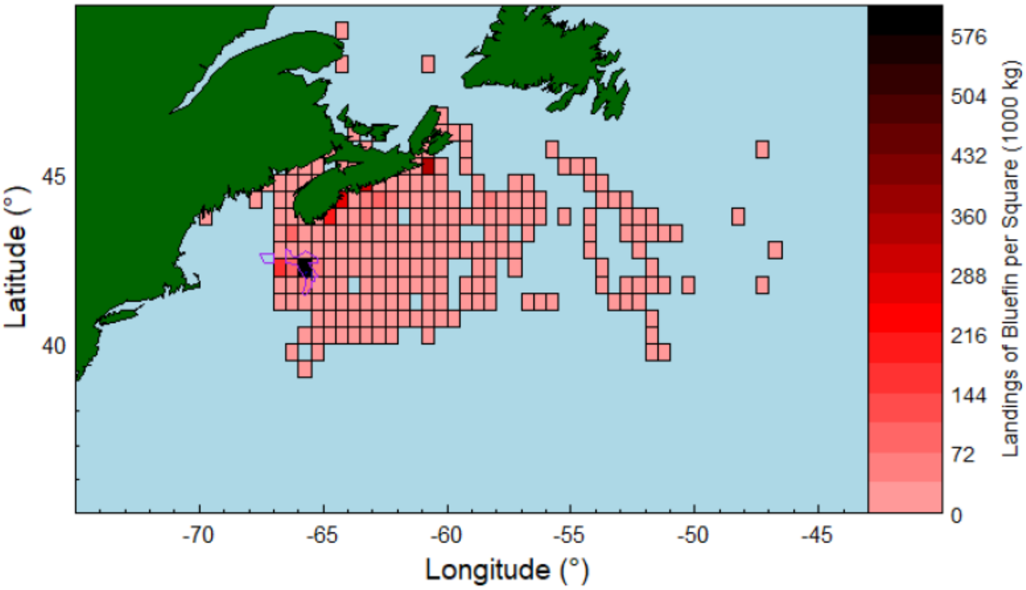

*Figure 86.The distribution of Bluefin Tuna (*Thunnus thynnus*) landings in fisheries other than the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.5 by 0.5 degree grid cells. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. During that timeframe there was 3,825,021 kg of Bluefin tuna landed in these other fisheries, which accounts for roughly 98% of all of the Bluefin Tuna landings in the Maritimes Region. The greatest volume of landings in a single grid square was 605,764 kg.*

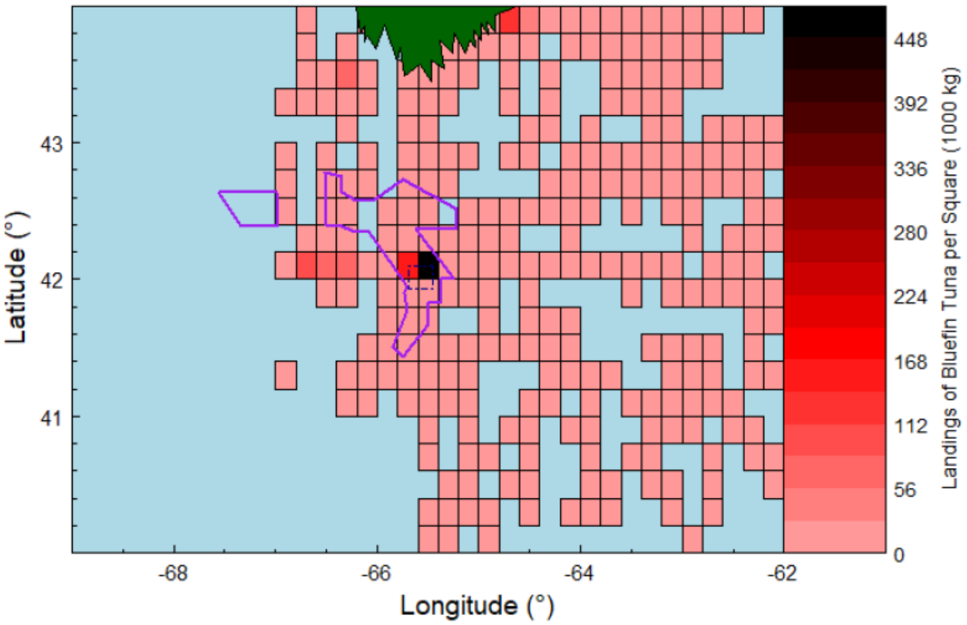

*Figure 87. The distribution of Bluefin Tuna (*Thunnus thynnus*) landings in fisheries other than the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.2 by 0.2 degree grid cells and focused on the area around the Fundian Channel – Browns Bank Area of Interest (outlined in purple). The greatest volume of landings in a single grid square was 463,920 kg. The map shows a total of 2,411,263 kg worth of Bluefin tuna landings, by other fisheries, roughly 62% of the total Maritimes landings of Bluefin tuna from 2004 to 2018 (3,901,173 kg).*

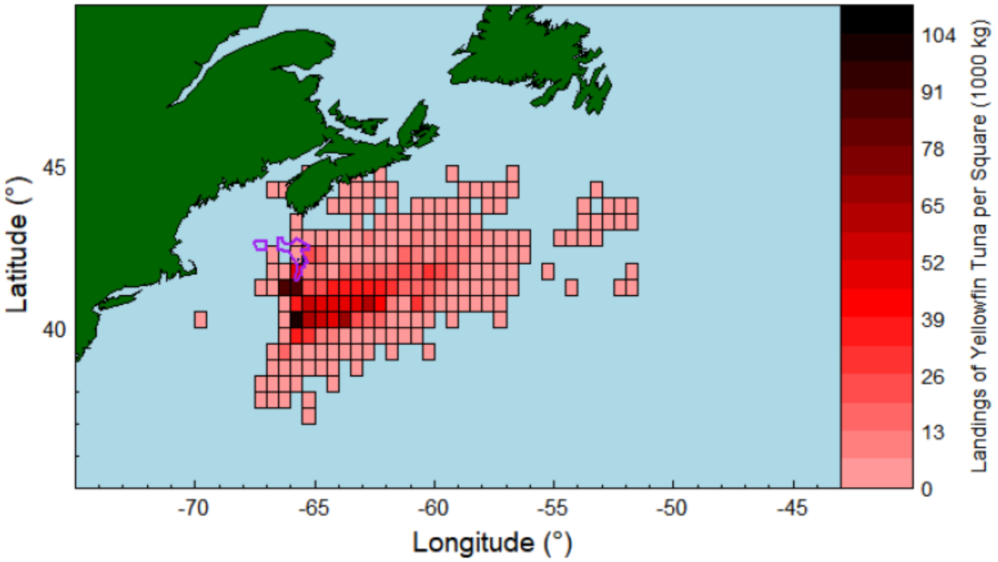

*Figure 88. The distribution of Yellowfin Tuna (*Thunnus albacares*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.5 by 0.5 degree grid cells. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. During that timeframe there was 1,993,003 kg of Yellowfin Tuna landed by the PLL fishery this accounts for approximately 98% of all of the Yellowfin Tuna landings in the Maritimes Region. 2% of the longline landings (42,720 kg) were removed from the map due to a lack of coordinates for the landing. The greatest volume of landings in a single grid square was 103,028 kg.*

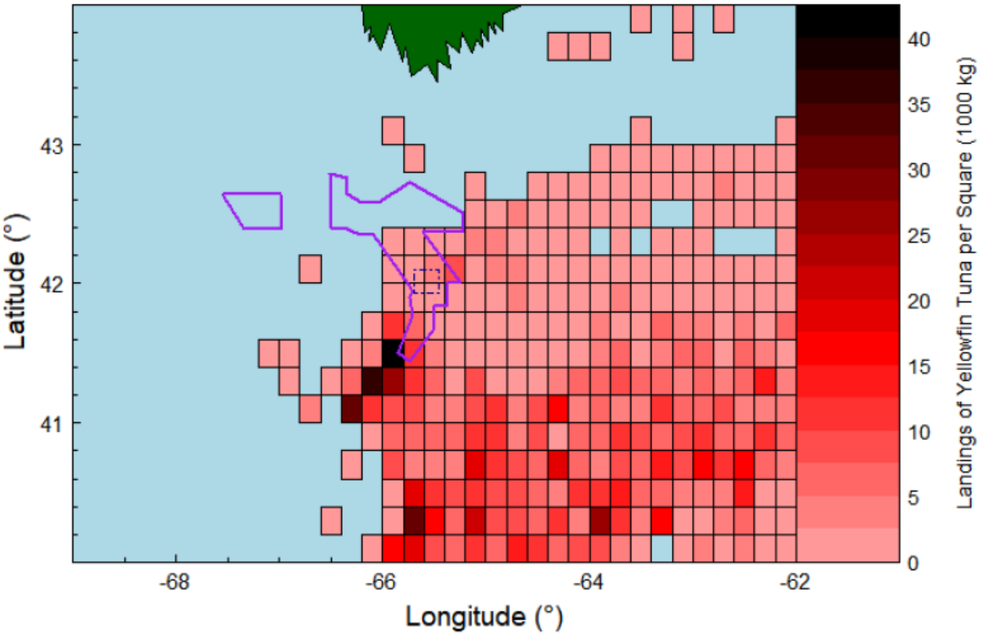

*Figure 89. The distribution of Yellowfin Tuna (*Thunnus albacares*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.2 by 0.2 degree grid cells and focused on the area around the Fundian Channel – Browns Bank Area of Interest (outlined in purple). The greatest volume of landings in a single grid square was 40,054 kg. The map shows a total of 1,526,715 kg worth of Yellowfin Tuna landings, by the PLL fishery, nearly 78% of the total Maritimes landings of Yellowfin tuna from 2004 to 2018 (2,039,664 kg).*

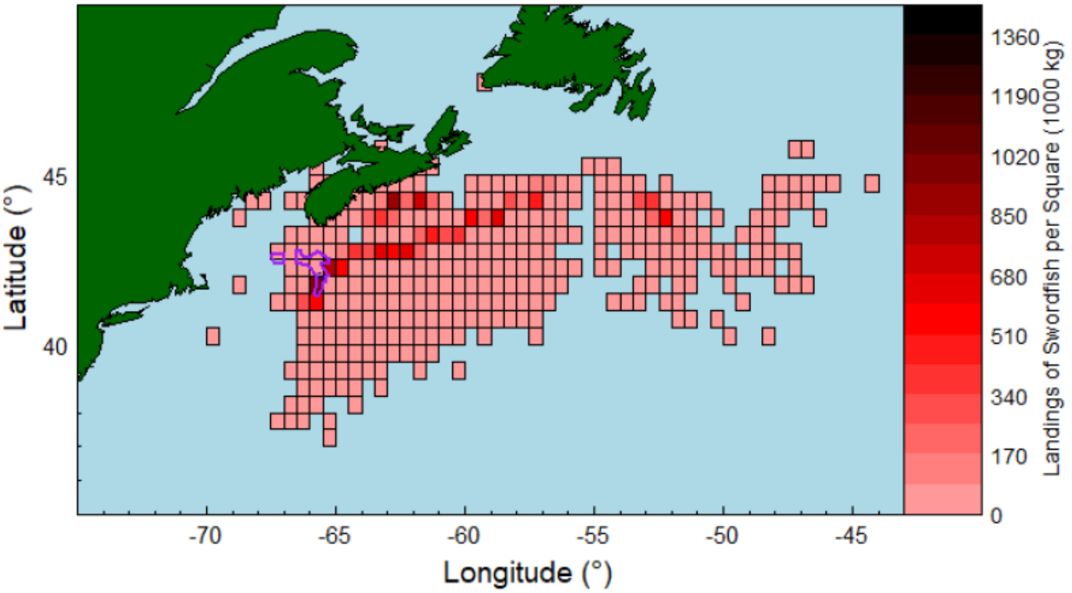

*Figure 90. The distribution of Swordfish (*Xiphias gladius*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.5 by 0.5 degree grid cells. The Fundian Channel – Browns Bank Area of Interest is outlined in purple. During that time frame there was 16,583,017 kg of Swordfish landed by the PLL fishery this accounts for approximately 80% of all of the Swordfish landings in the Maritimes Region. The greatest volume of landings in a single grid square was 984,667 kg.*

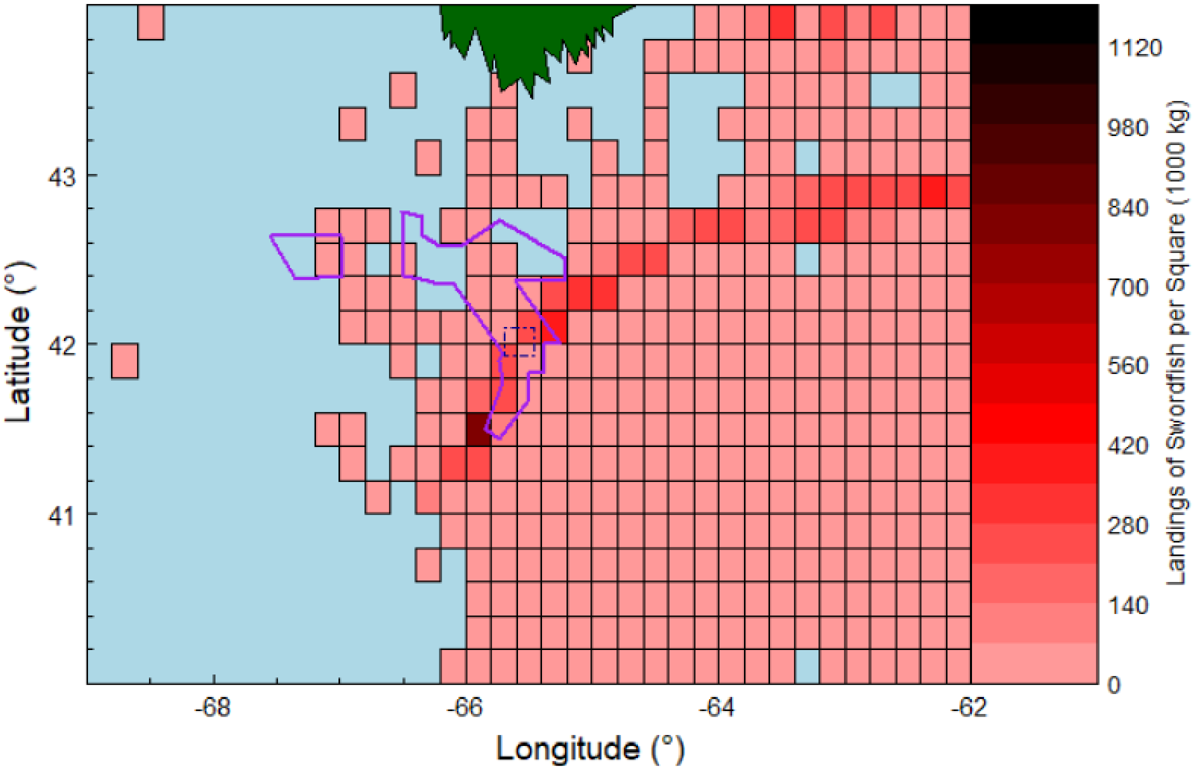

*Figure 91. The distribution of Swordfish (*Xiphias gladius*) landings in the Canadian Atlantic Swordfish and Other Tuna's Pelagic Longline (PLL) fishery from 2004 to 2018, using 0.2 by 0.2 degree grid cells and focused on the area around the Fundian Channel – Browns Bank Area of Interest (outlined in purple). The greatest volume of landings in a single grid square was 797,669 kg. The map shows a total of 8,916,081 kg worth of Swordfish landings, by the PLL fishery, nearly 43% of the total Maritimes landings of Bluefin tuna from 2004 to 2018 (20,637,983 kg).*

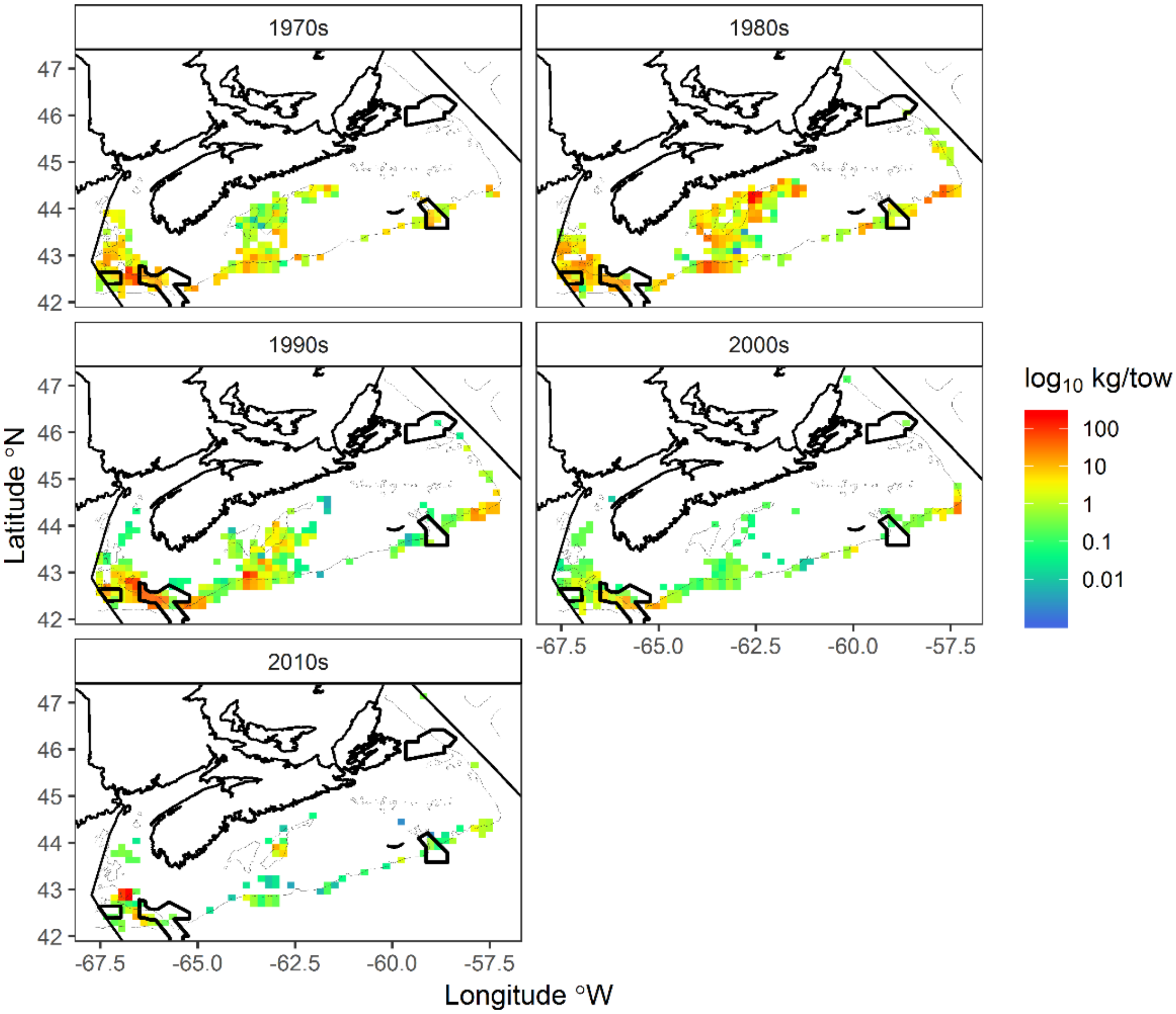

*Figure 92. Distribution of catch for Atlantic Argentine (*Argentina silus*) captured during the summer RV Survey by decade from the 1970s to 2017. Data was aggregated within each decade as the mean weight (kg) standardized to a 1.75 nautical mile trawl set at a resolution of 15 km$^2$. Offshore polygons represent the AOI and current Oceans Act MPAs in the Maritimes Bioregion.*

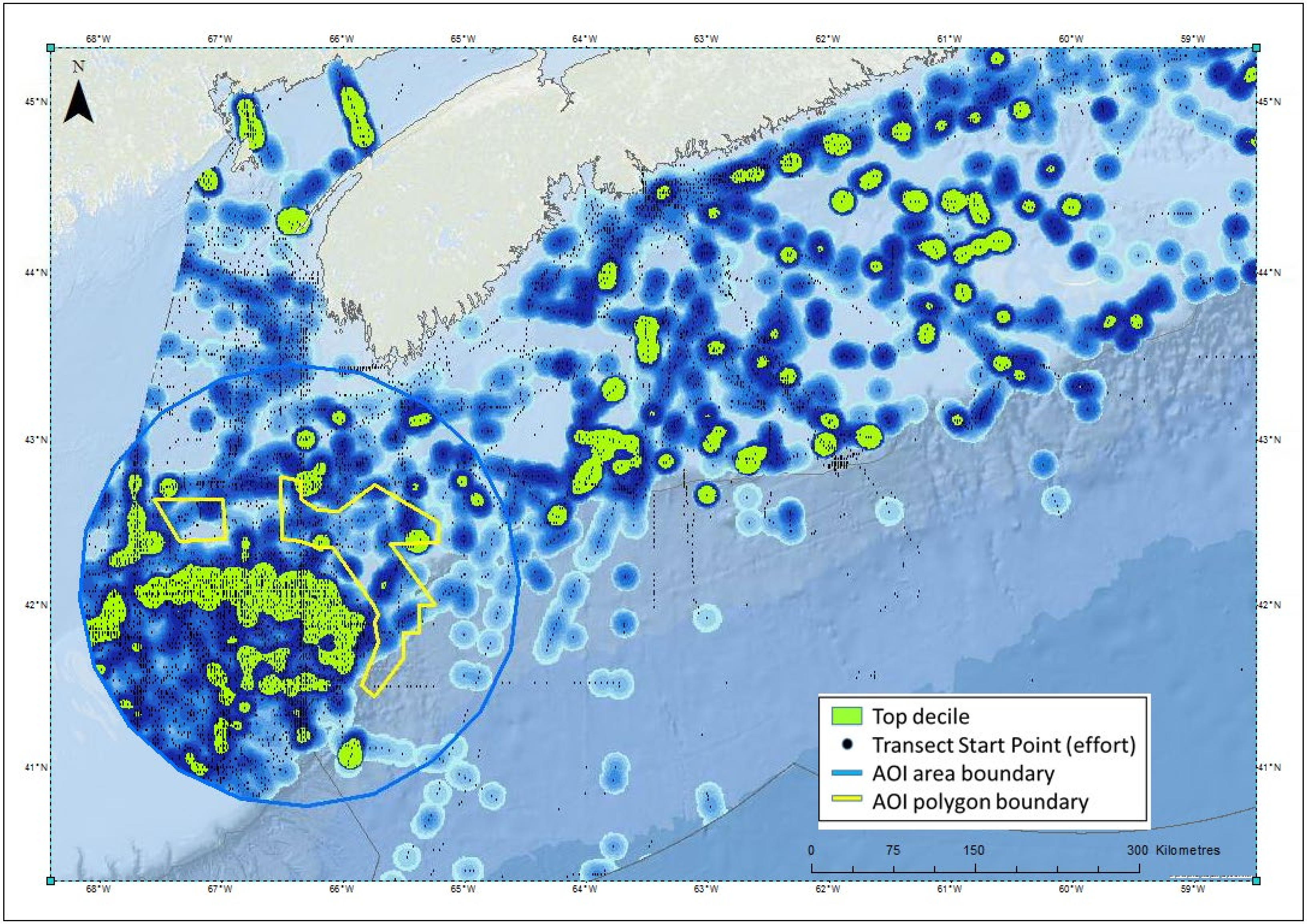

*Figure 93. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for shearwaters. Kernels are based on 10 km search radius, with 1 km cell resolution.*

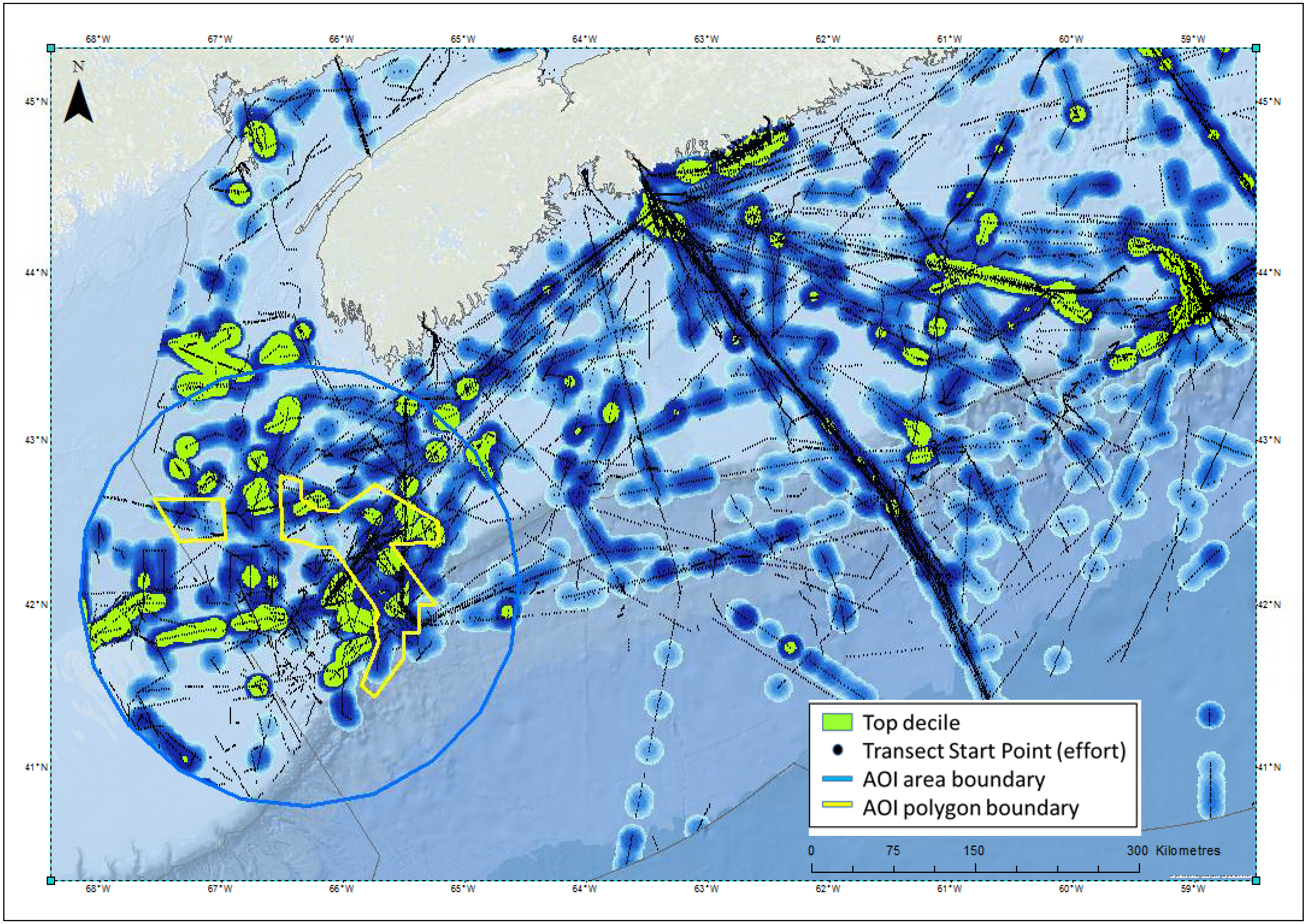

*Figure 94. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for shearwaters. Kernels are based on 10 km search radius, with 1 km cell resolution.*

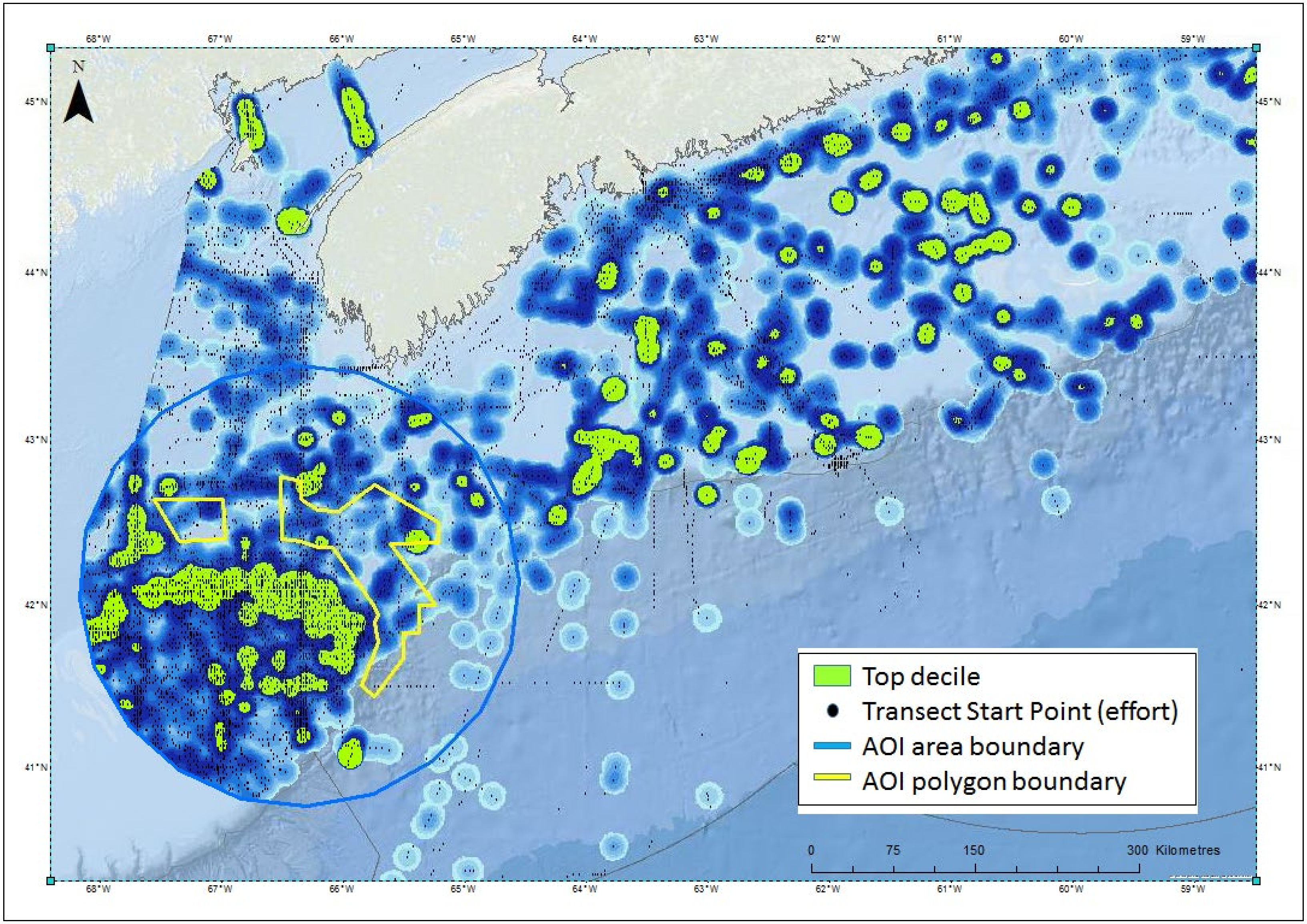

*Figure 95. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Great Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

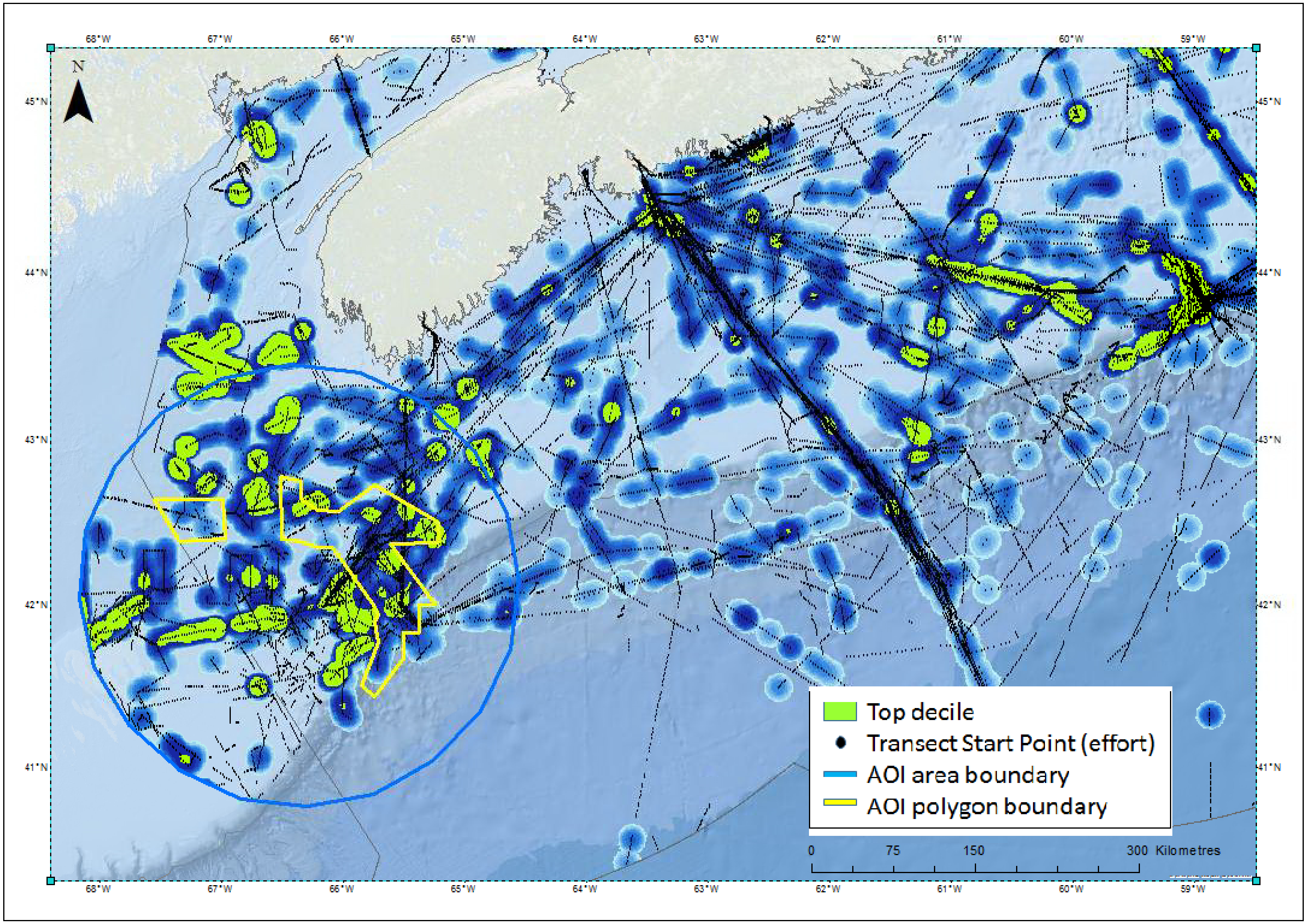

*Figure 96. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Great Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

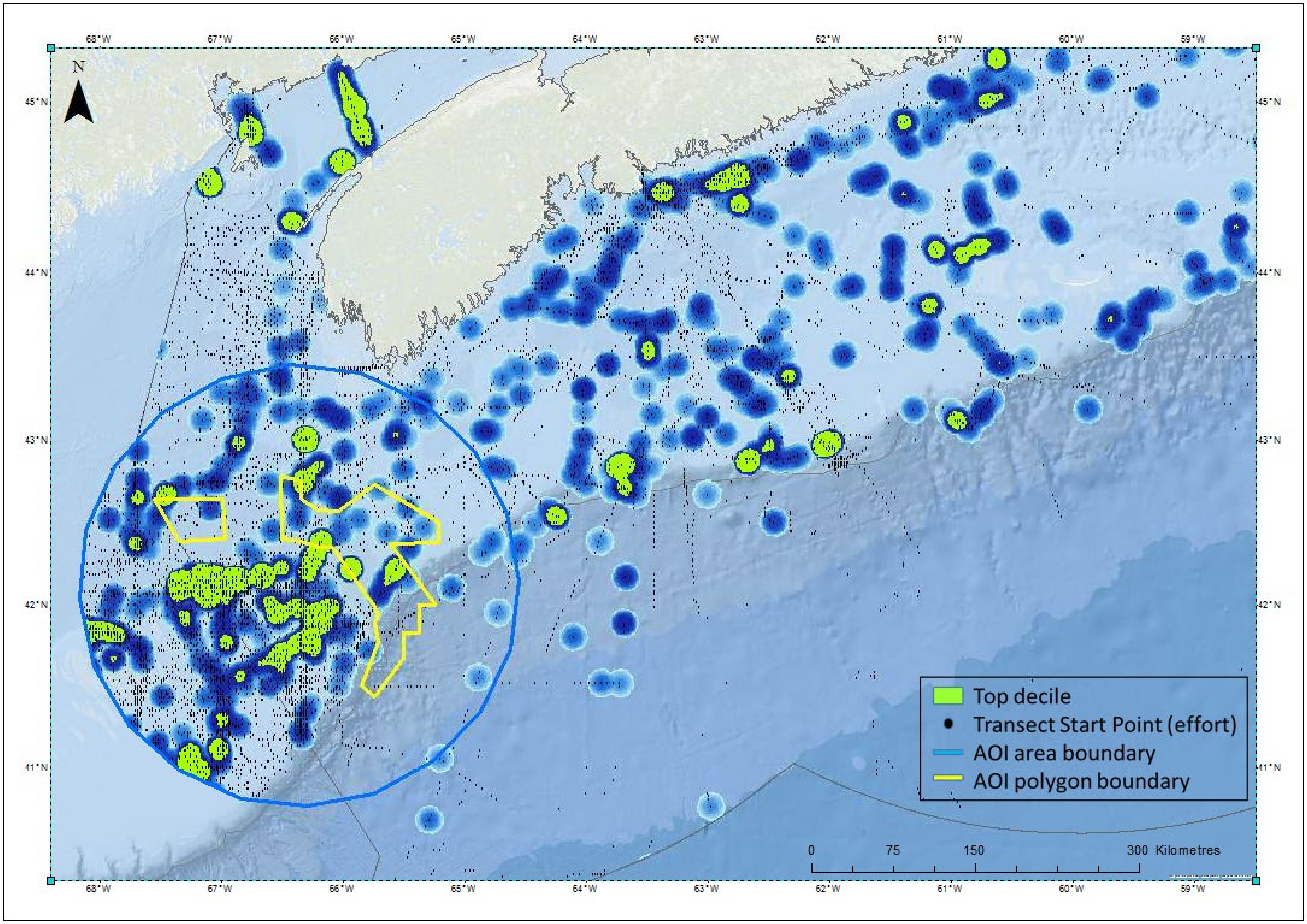

*Figure 97. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Sooty Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

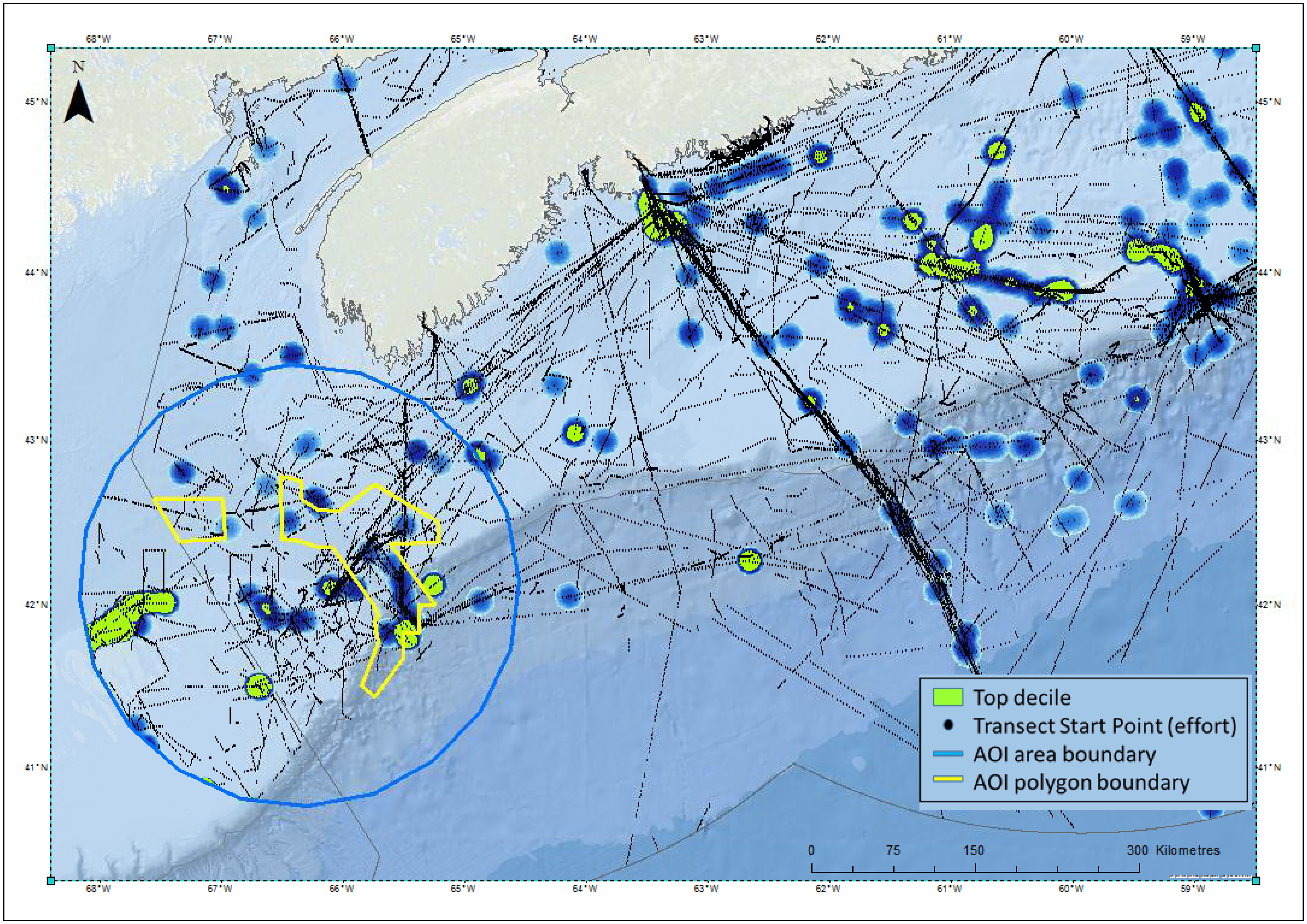

*Figure 98. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Sooty Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

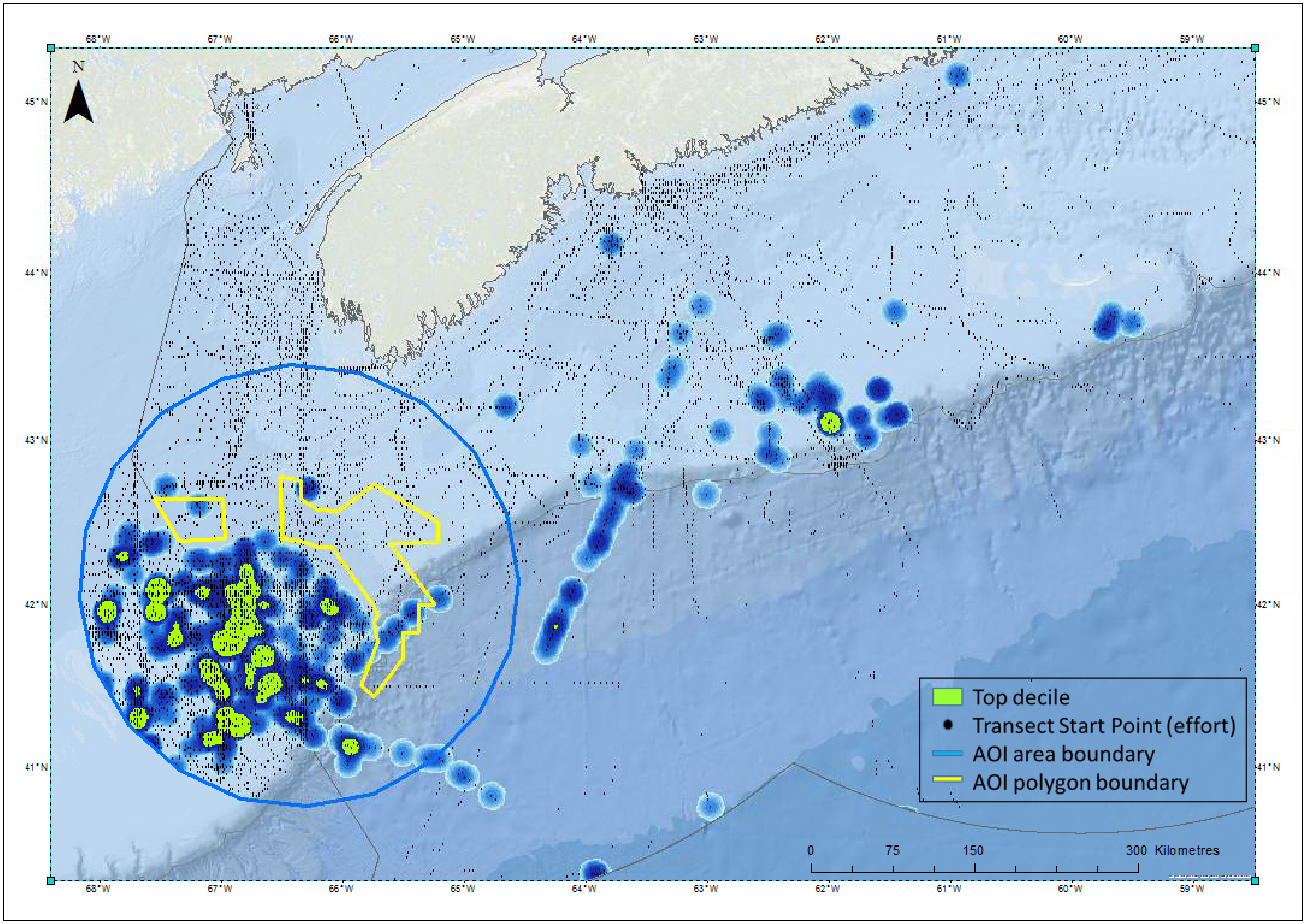

*Figure 99. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Cory's Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

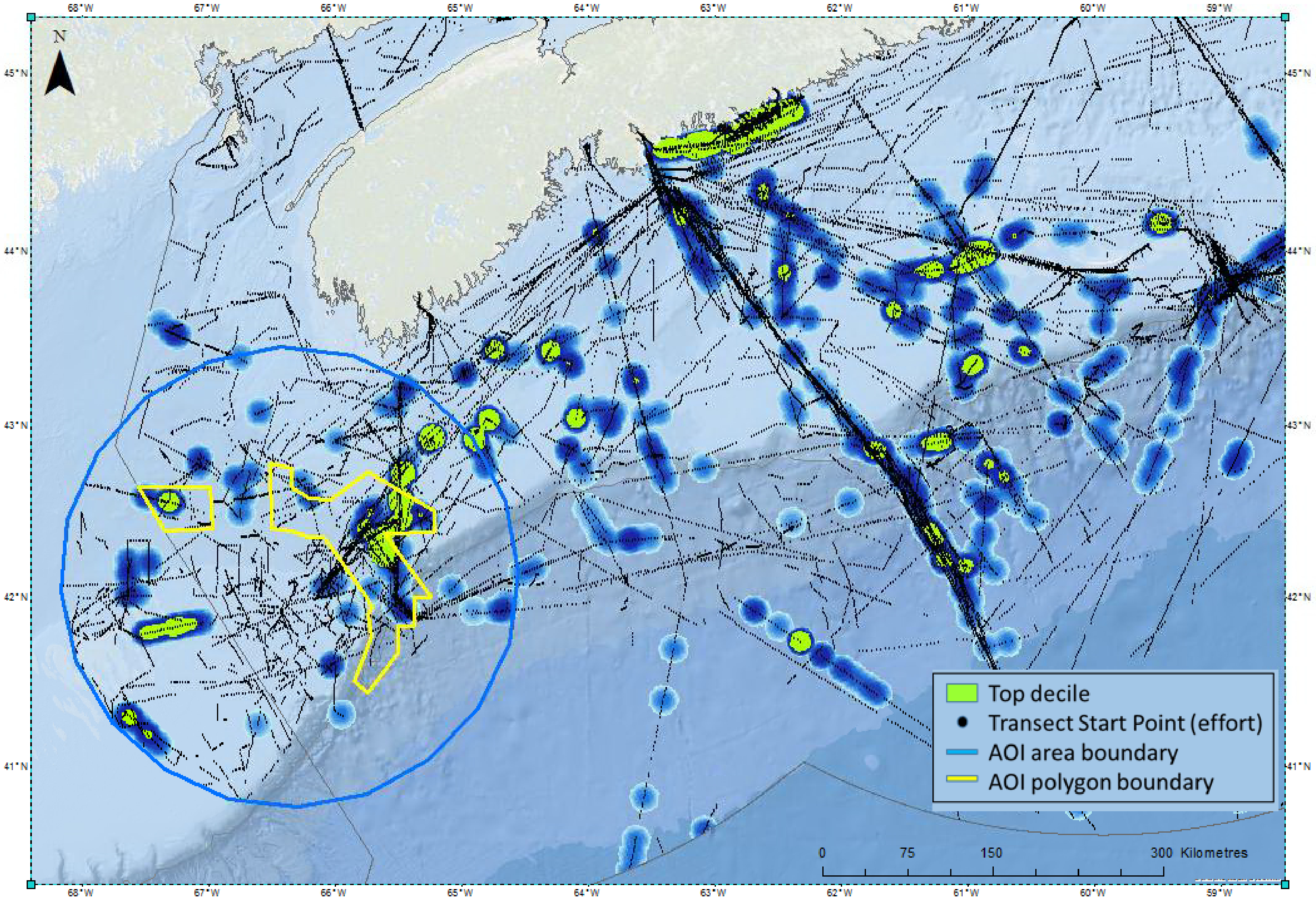

*Figure 100. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Cory's Shearwater. Kernels are based on 10 km search radius, with 1 km cell resolution.*

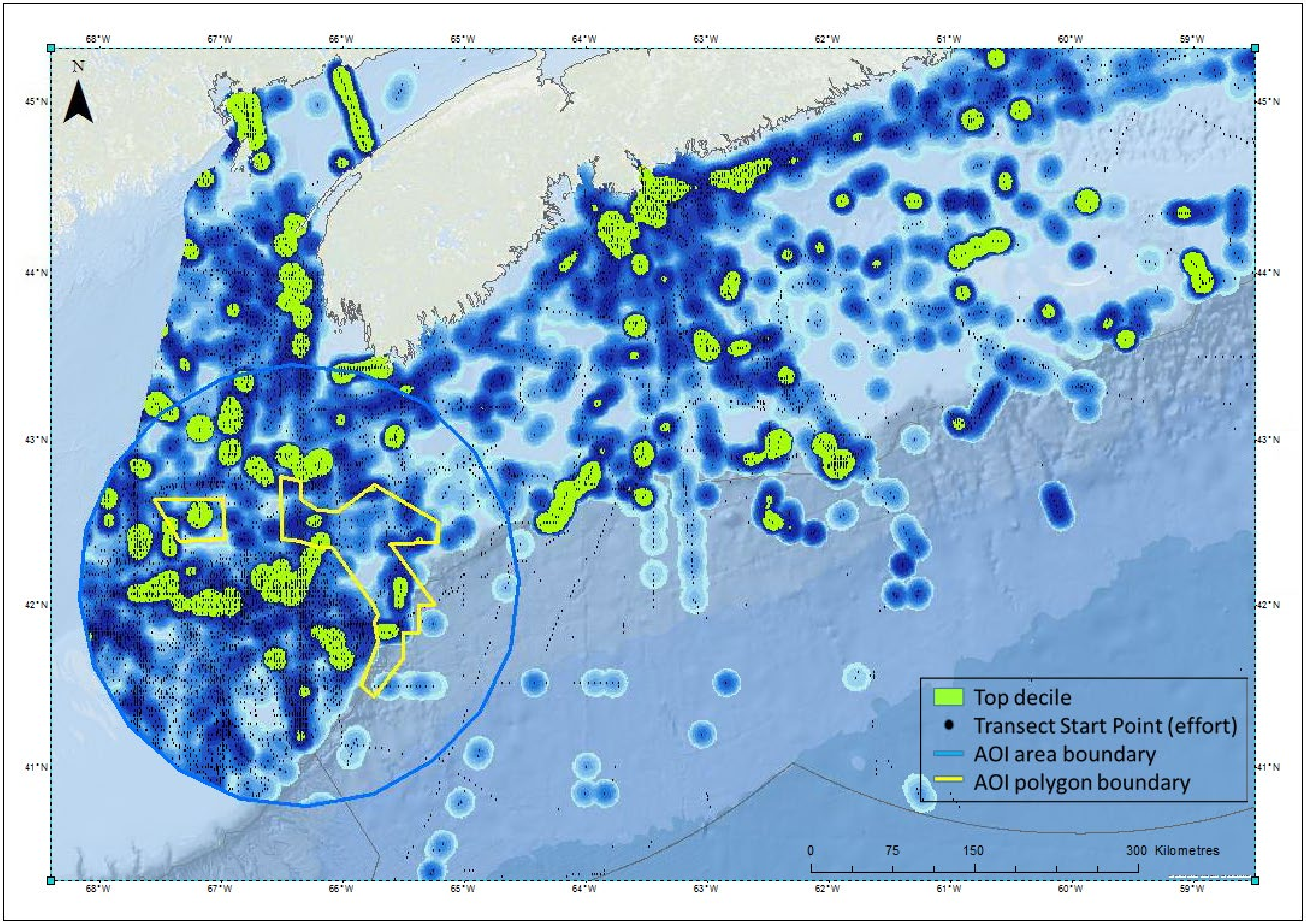

*Figure 101. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for large gulls. Kernels are based on 10 km search radius, with 1 km cell resolution.*

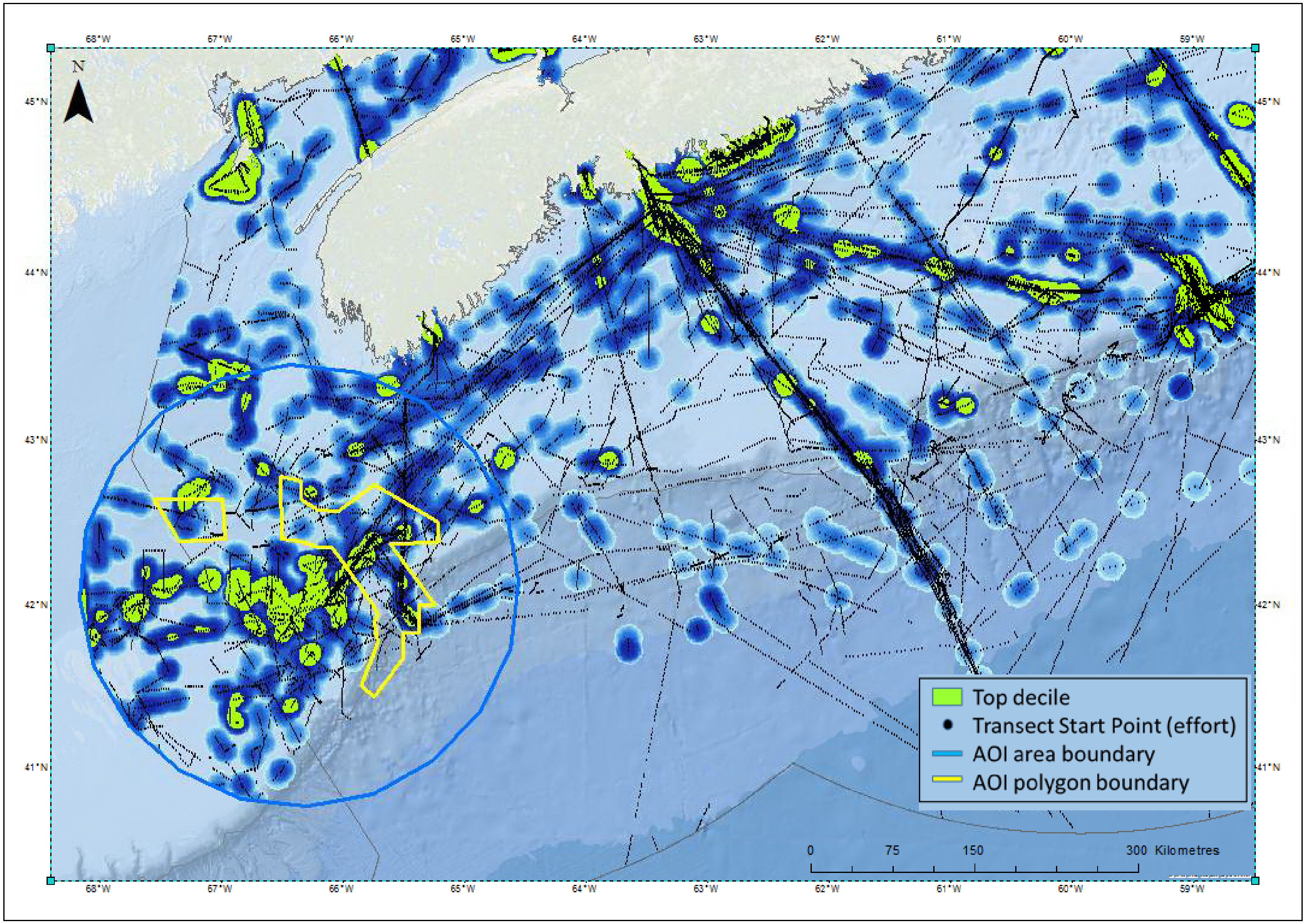

Figure 102. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for large gulls. Kernels are based on 10 km search radius, with 1 km cell resolution.

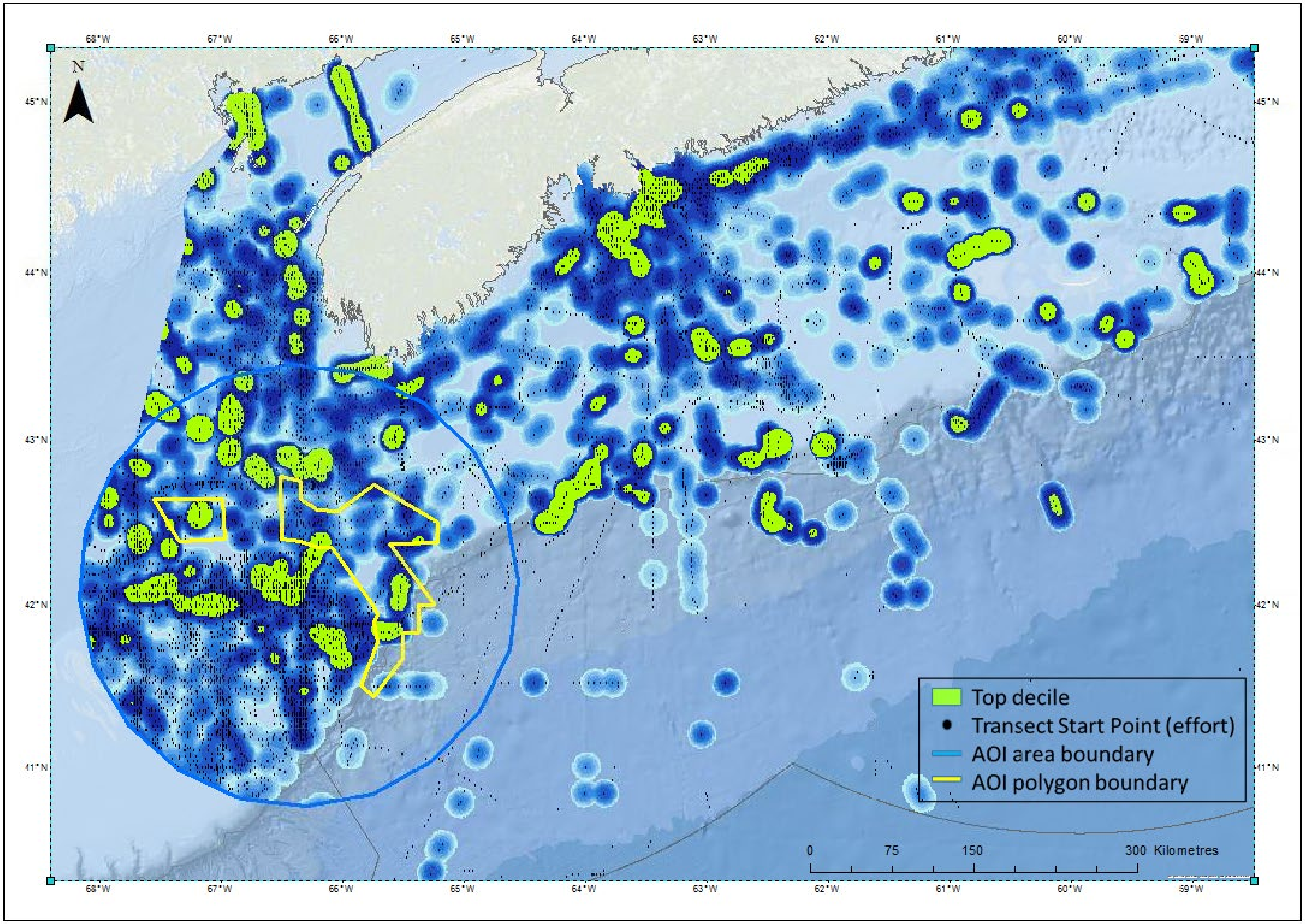

*Figure 103. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Herring Gull. Kernels are based on 10 km search radius, with 1 km cell resolution.*

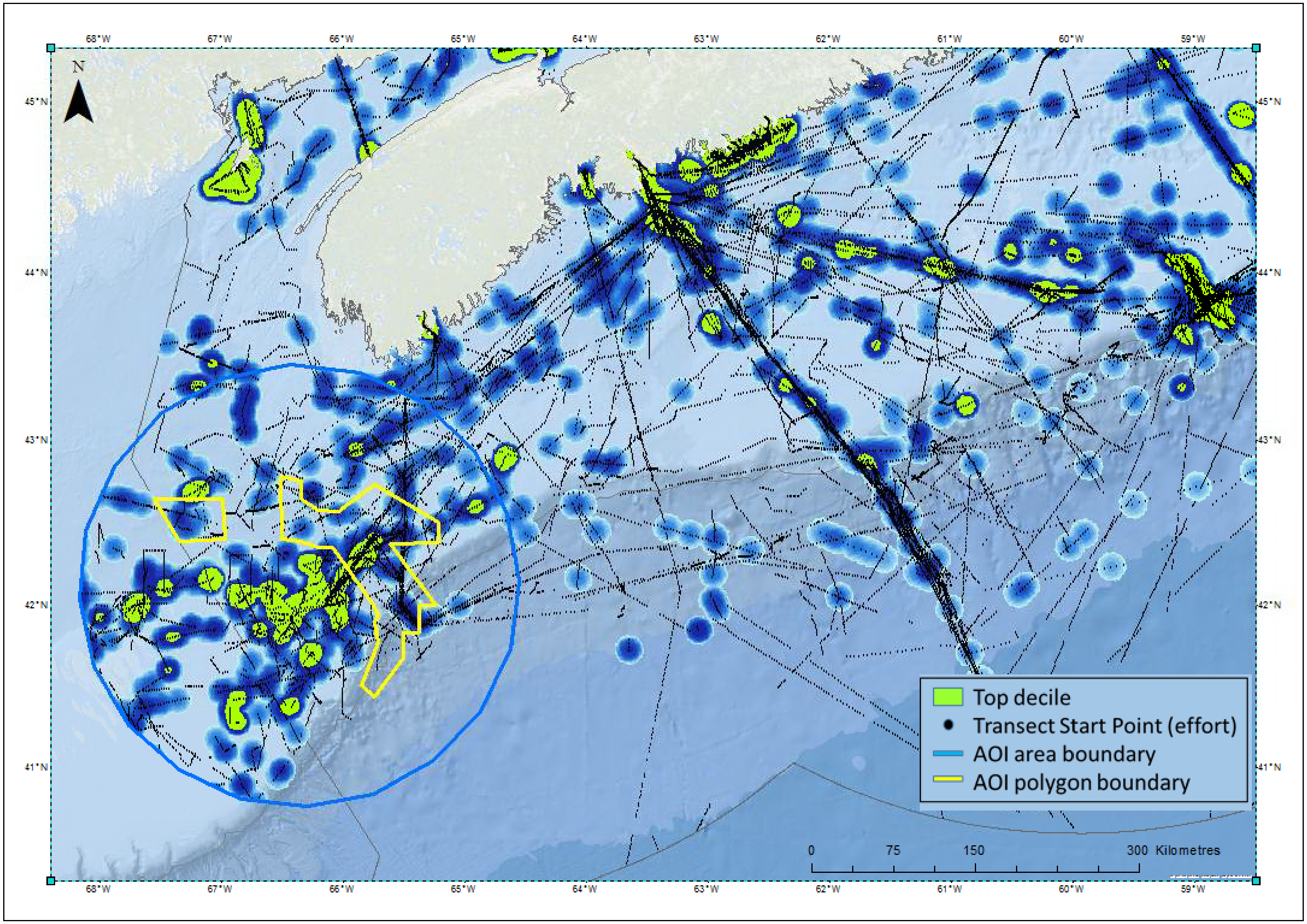

*Figure 104. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Herring Gull. Kernels are based on 10 km search radius, with 1 km cell resolution.*

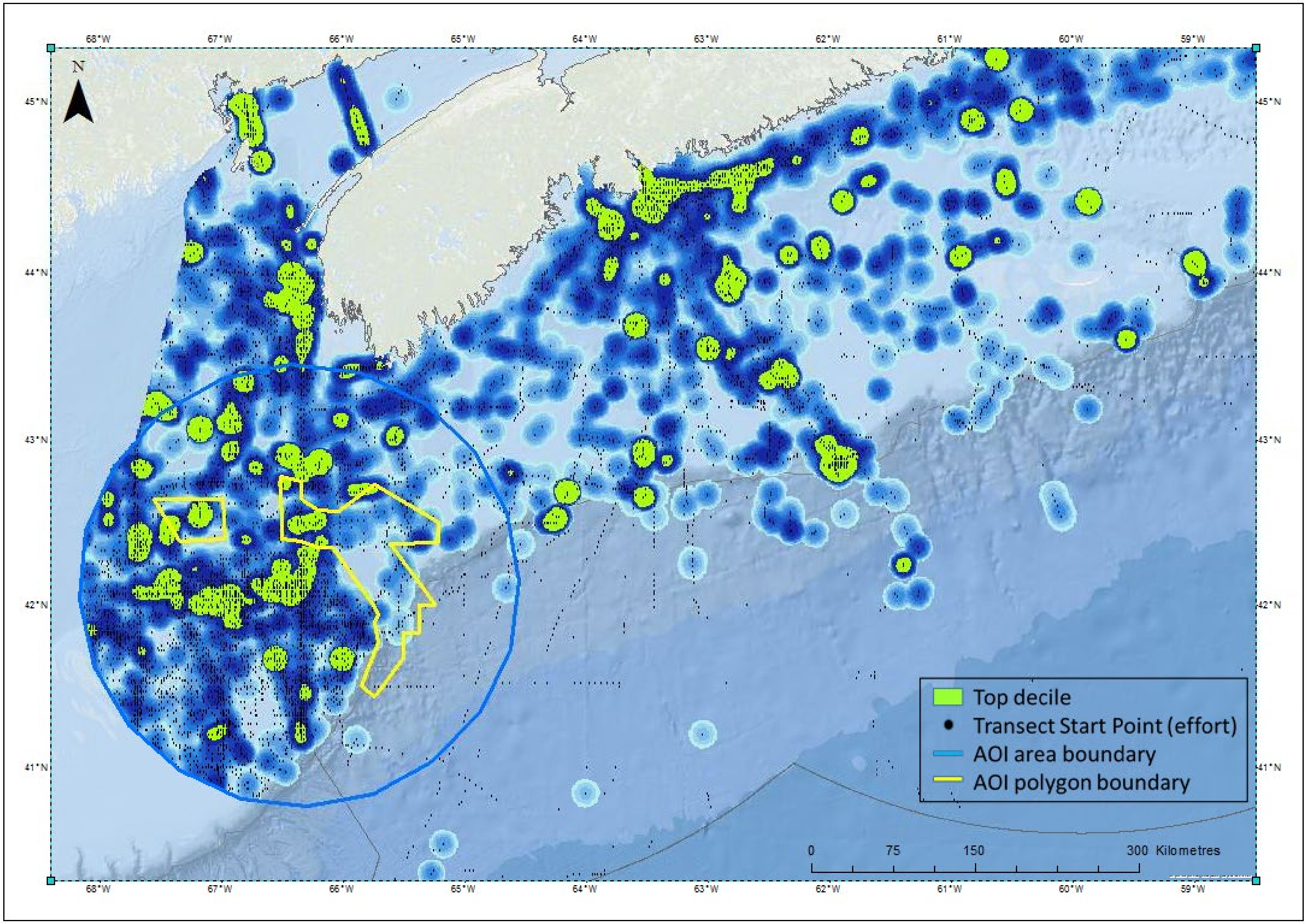

*Figure 105. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Great Black-backed Gull. Kernels are based on 10 km search radius, with 1 km cell resolution.*

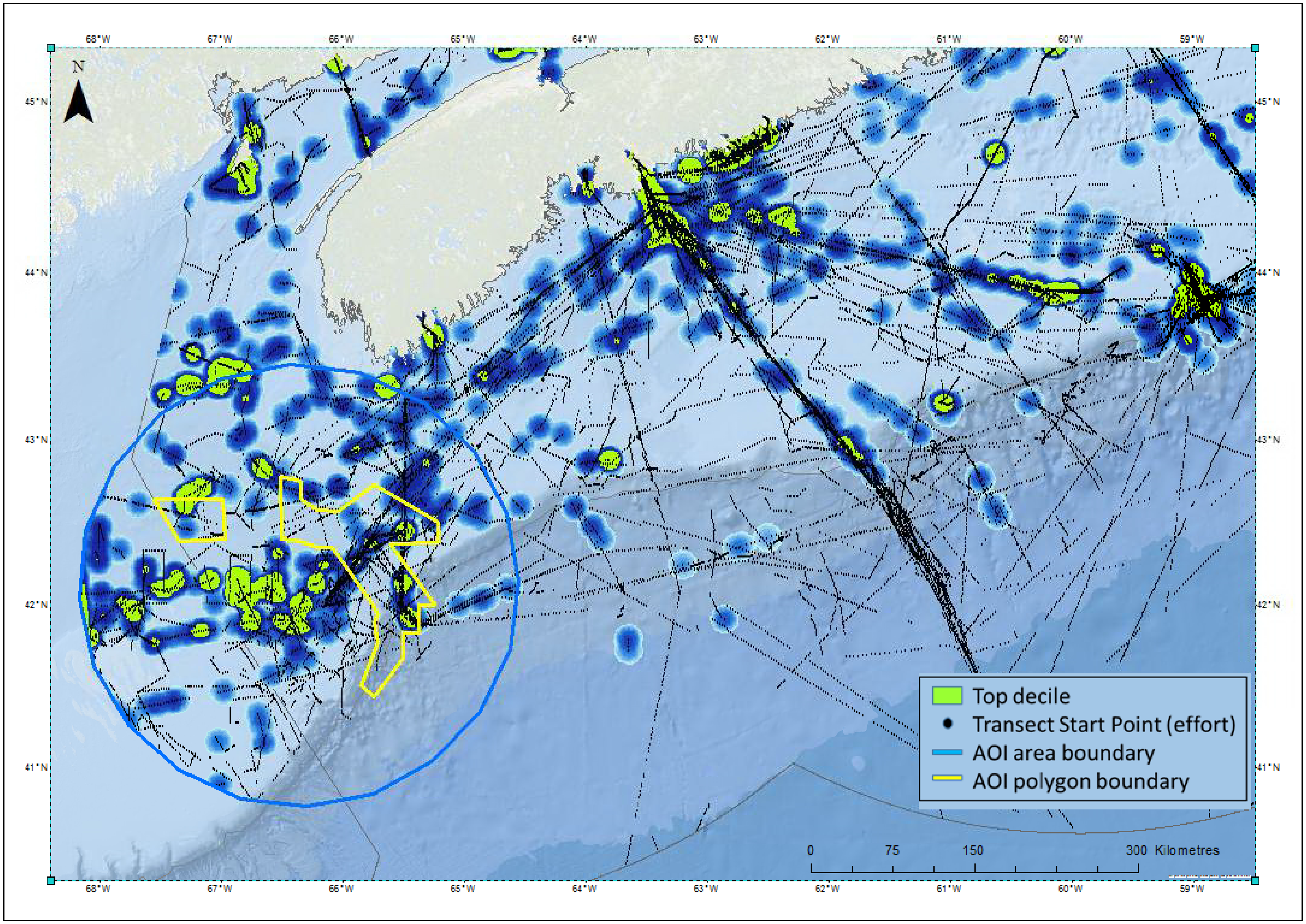

*Figure 106. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Great Black-backed Gull. Kernels are based on 10 km search radius, with 1 km cell resolution.*

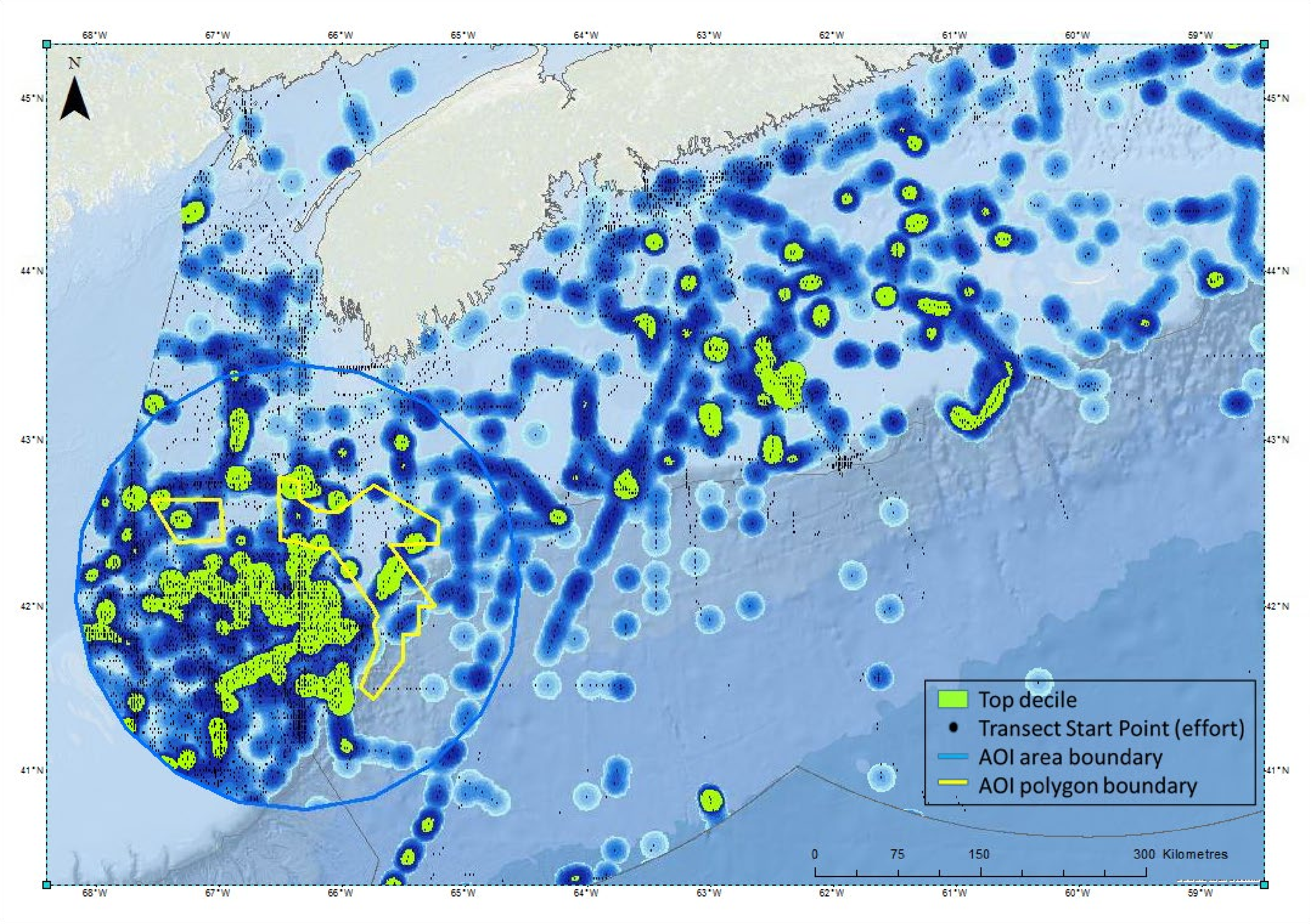

*Figure 107. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for storm-petrels. Kernels are based on 10 km search radius, with 1 km cell resolution.*

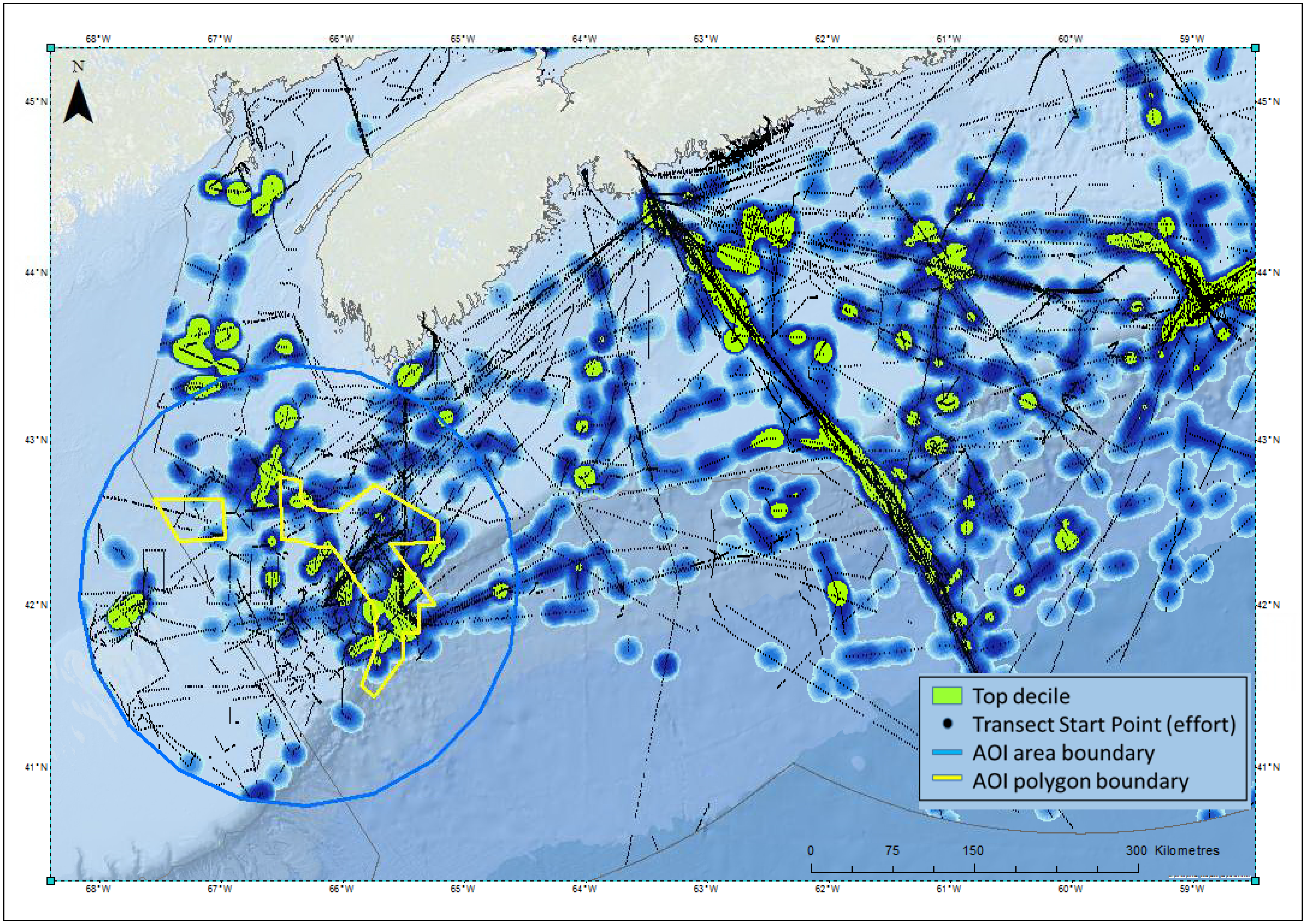

*Figure 108. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for storm-petrels. Kernels are based on 10 km search radius, with 1 km cell resolution.*

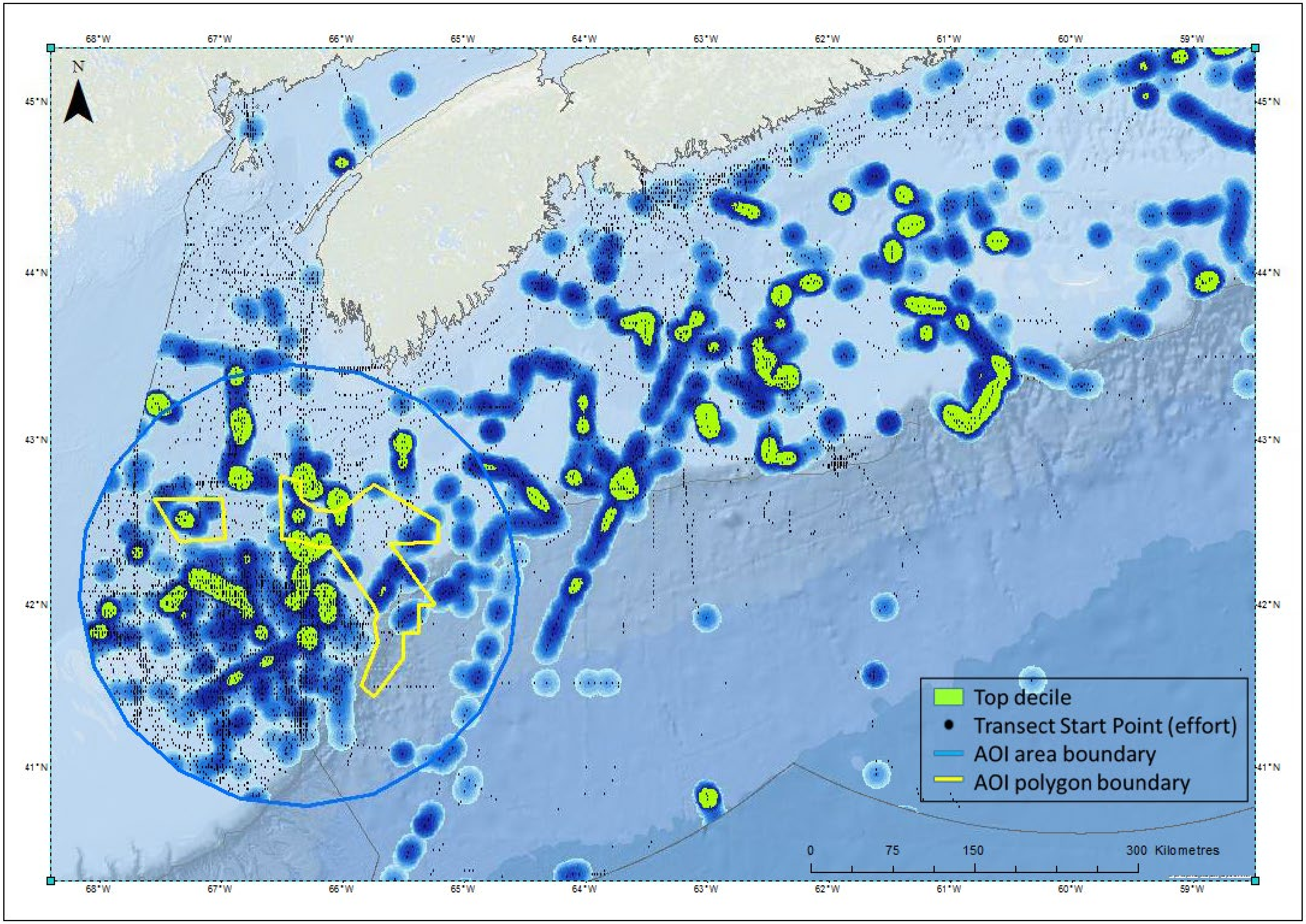

*Figure 109. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Leach's Storm-petrel. Kernels are based on 10 km search radius, with 1 km cell resolution.*

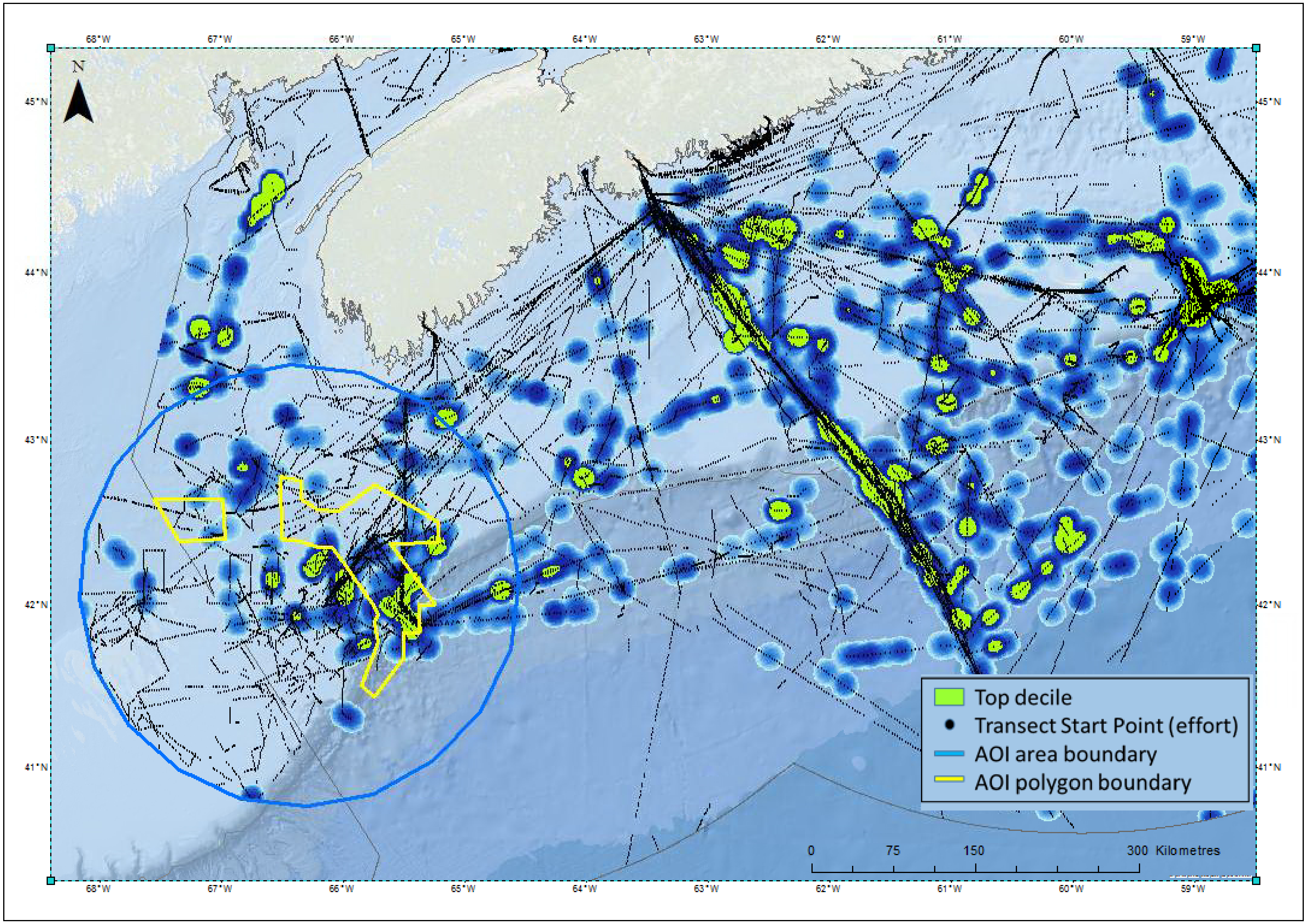

*Figure 110. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Leach's Storm-petrel. Kernels are based on 10 km search radius, with 1 km cell resolution.*

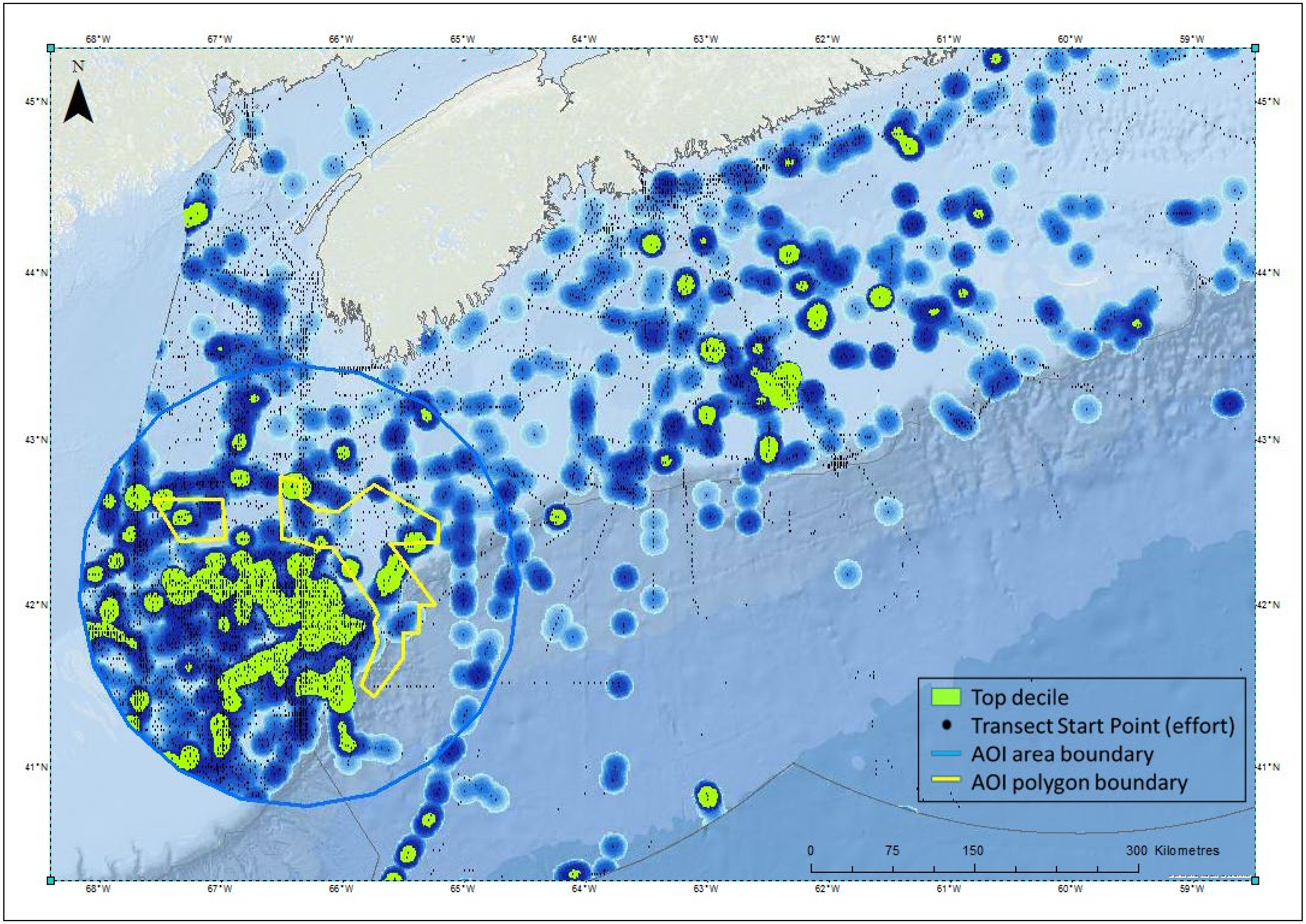

*Figure 111. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Wilson's Storm-petrel. Kernels are based on 10 km search radius, with 1 km cell resolution.*

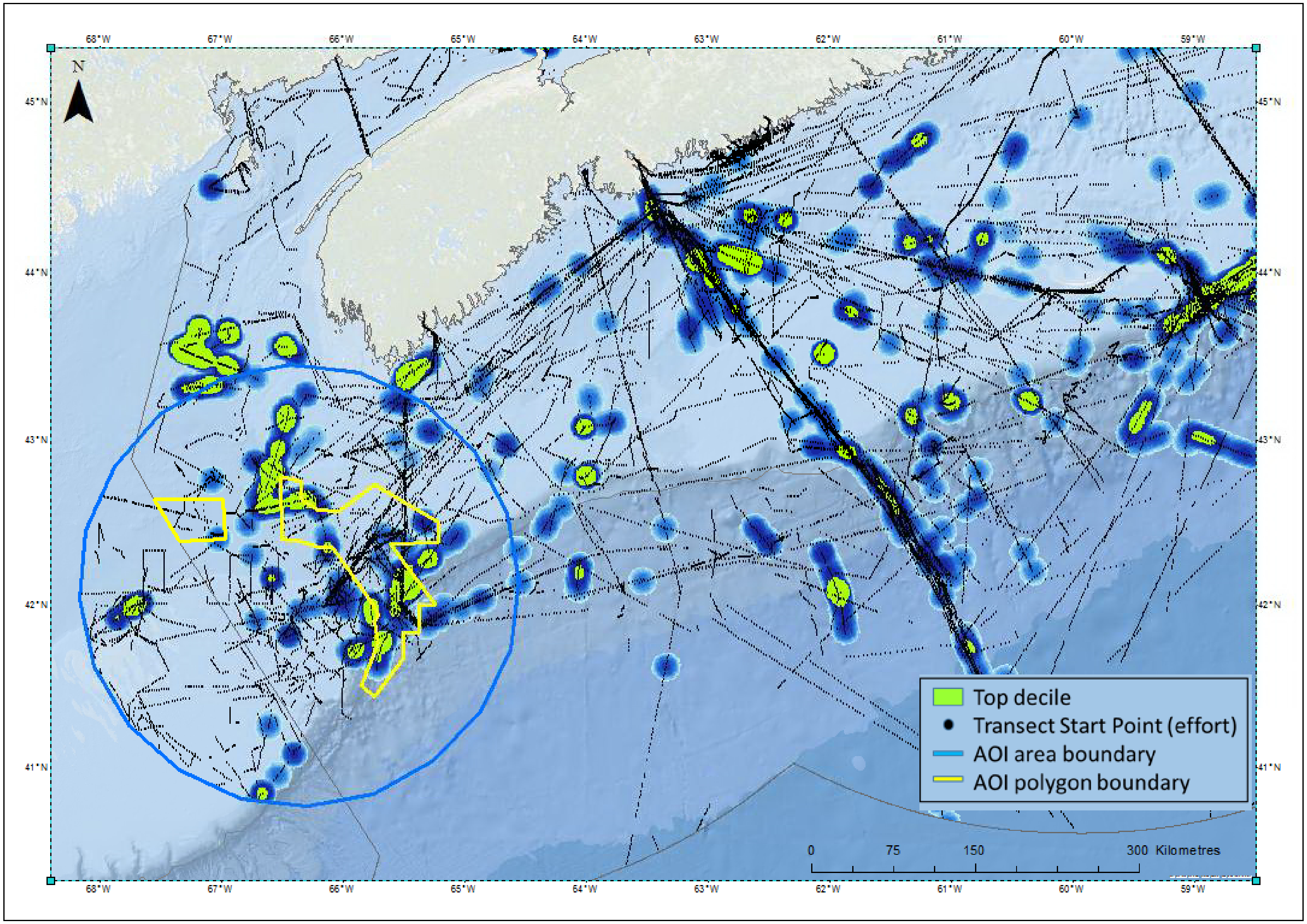

*Figure 112. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Wilson's Storm-petrel. Kernels are based on 10 km search radius, with 1 km cell resolution.*

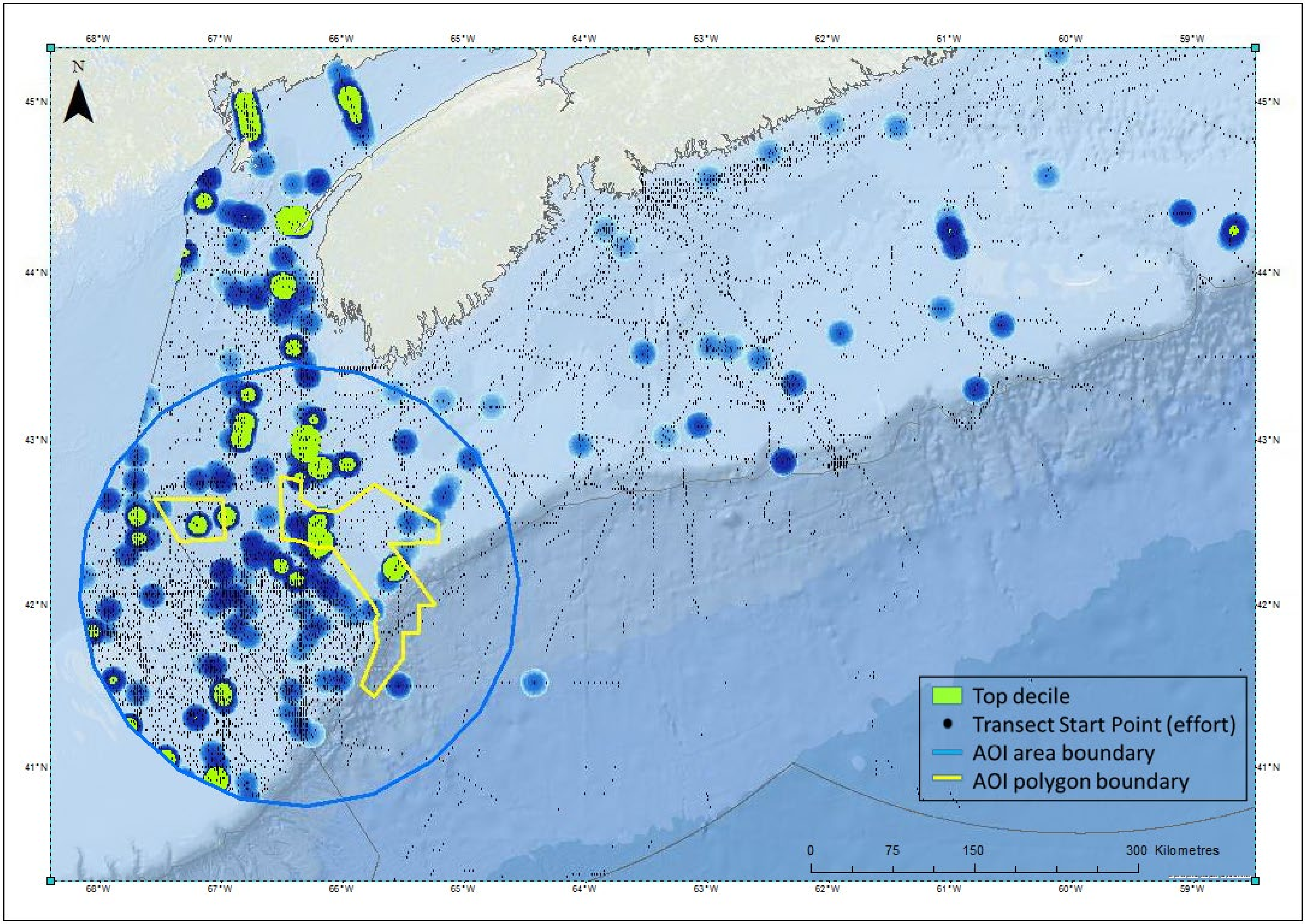

*Figure 113. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for phalaropes. Kernels are based on 10 km search radius, with 1 km cell resolution.*

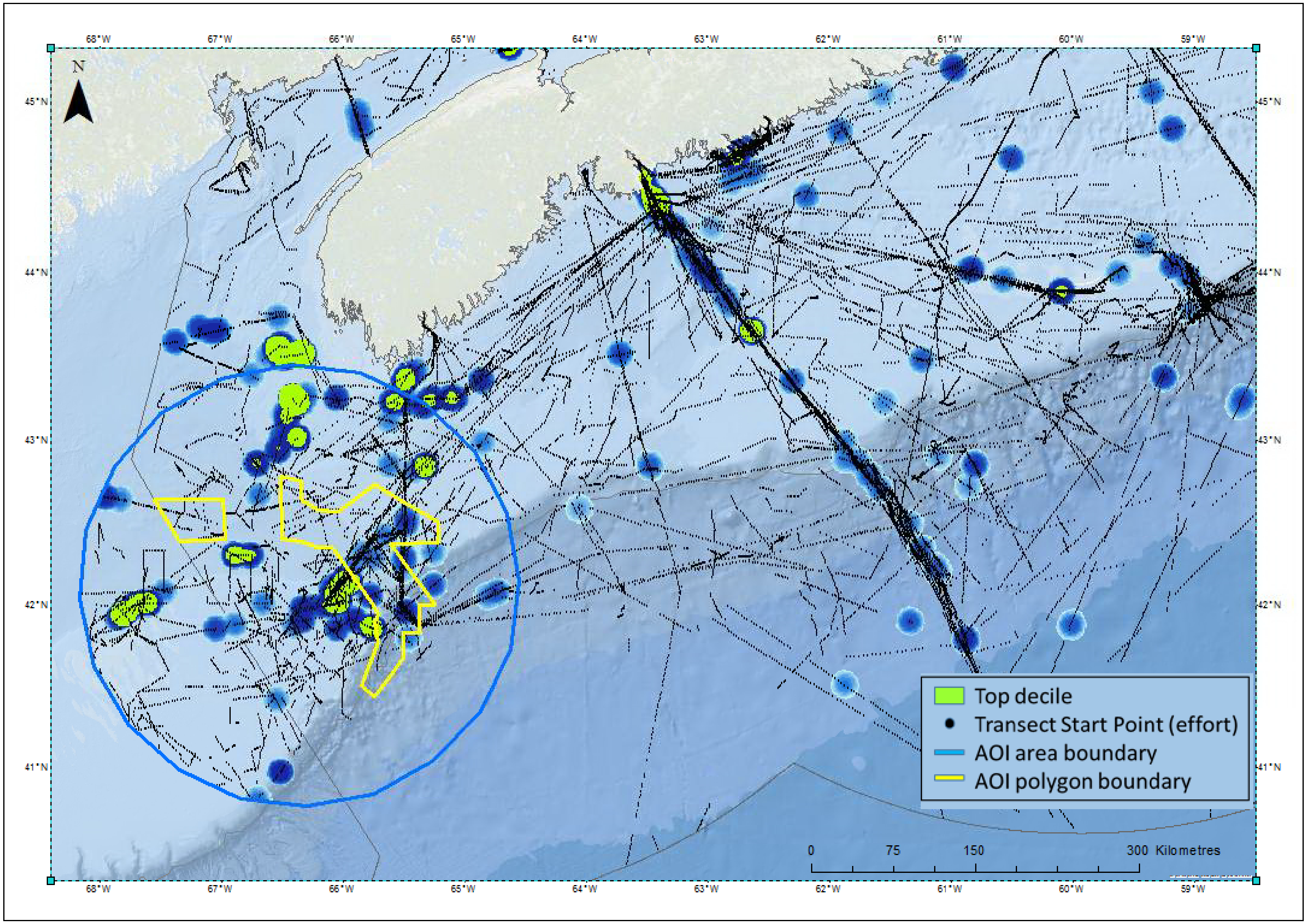

*Figure 114. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for phalaropes. Kernels are based on 10 km search radius, with 1 km cell resolution.*

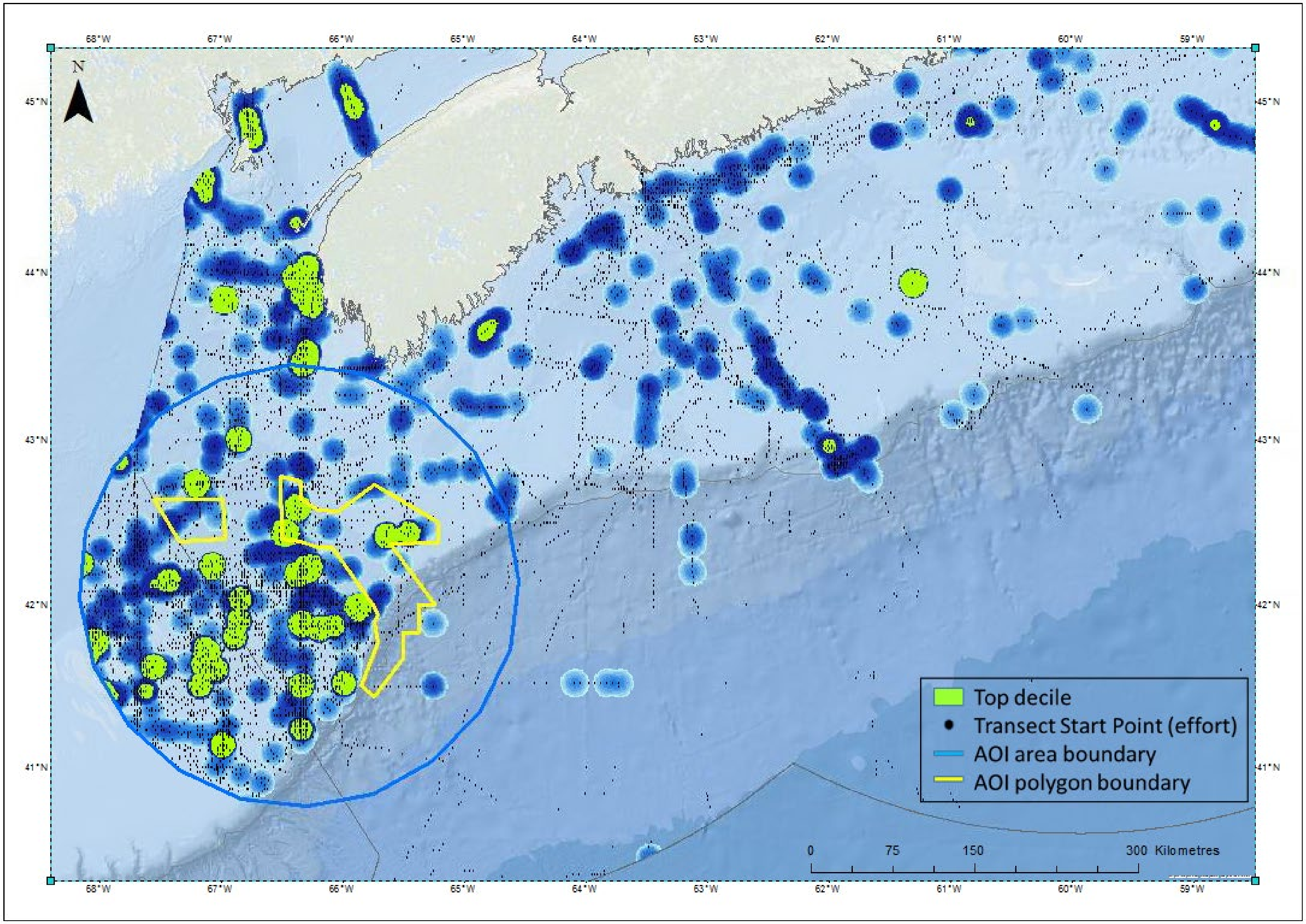

*Figure 115. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for large alcids. Kernels are based on 10 km search radius, with 1 km cell resolution.*

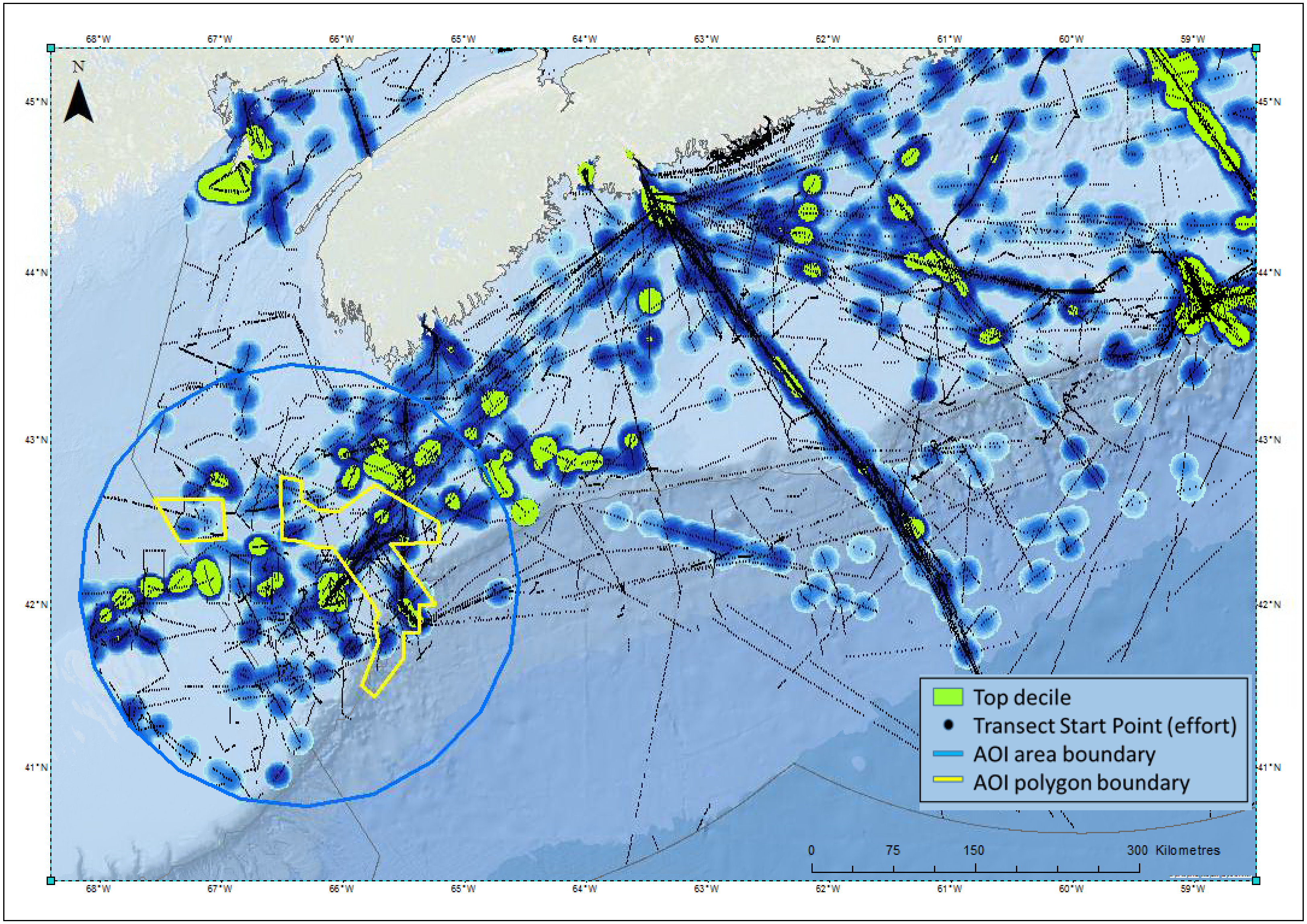

*Figure 116. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for large alcids. Kernels are based on 10 km search radius, with 1 km cell resolution.*

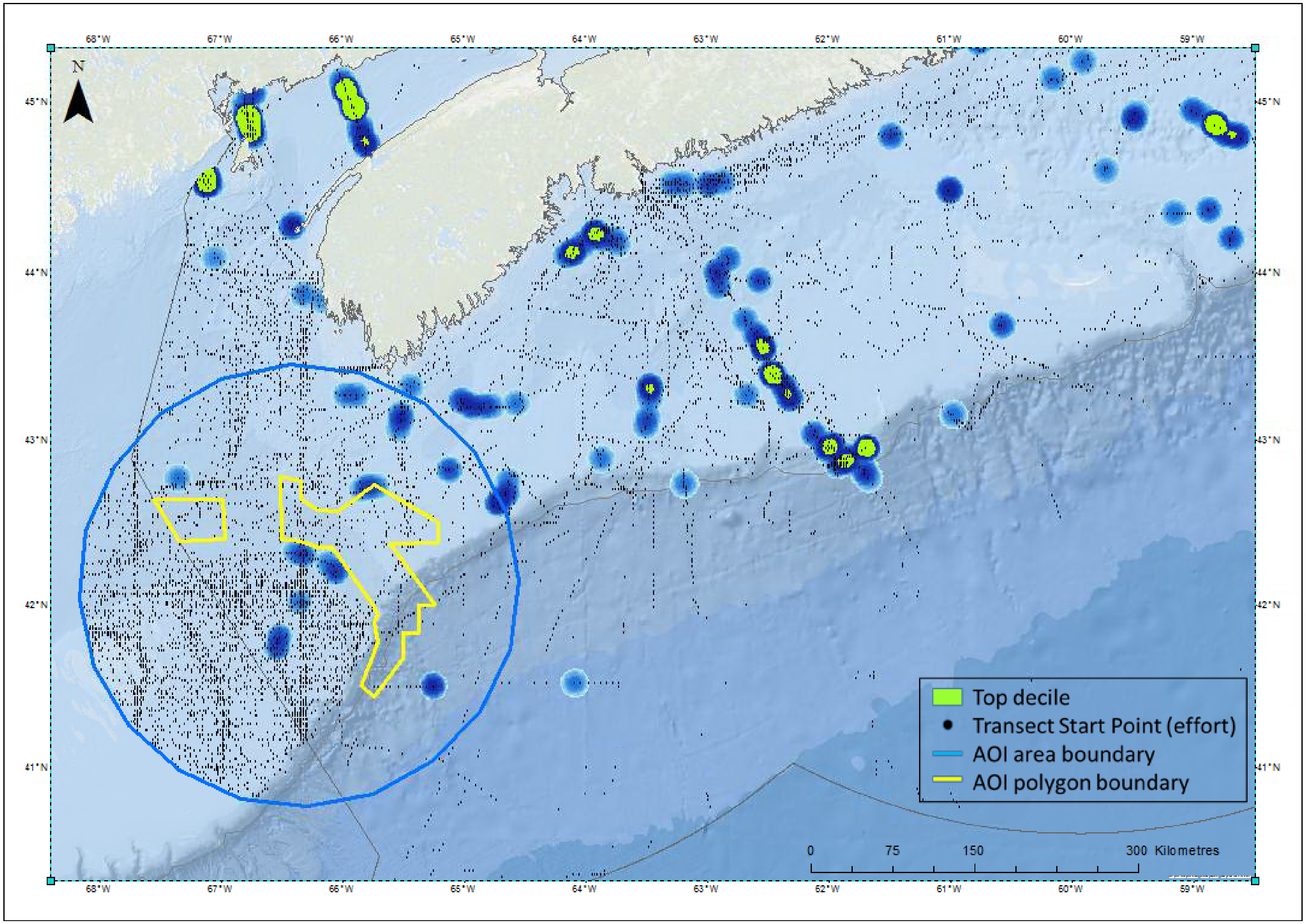

*Figure 117. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for large alcids (on-water detections only). Kernels are based on 10 km search radius, with 1 km cell resolution.*

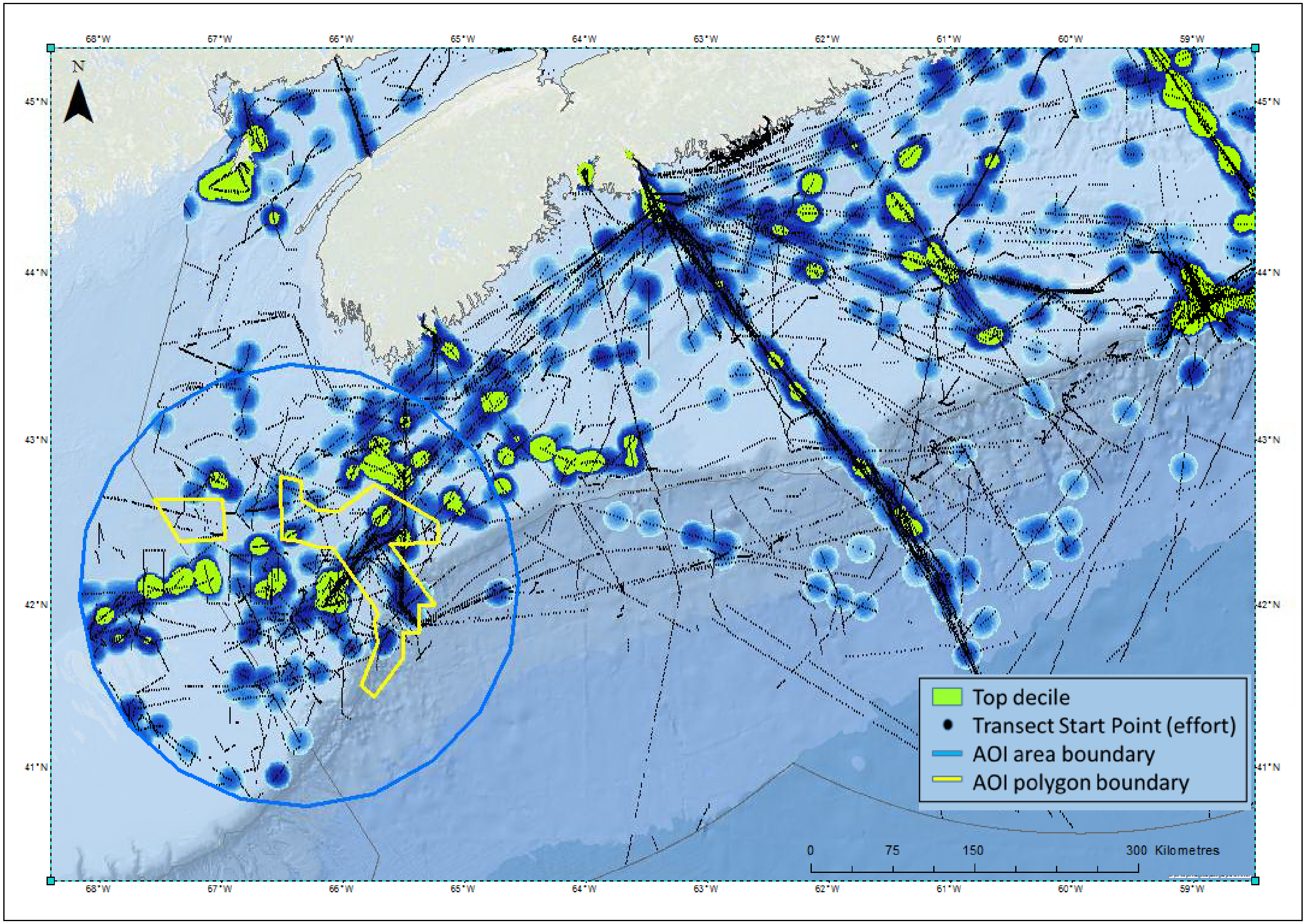

*Figure 118. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for large alcids (on-water detections only). Kernels are based on 10 km search radius, with 1 km cell resolution.*

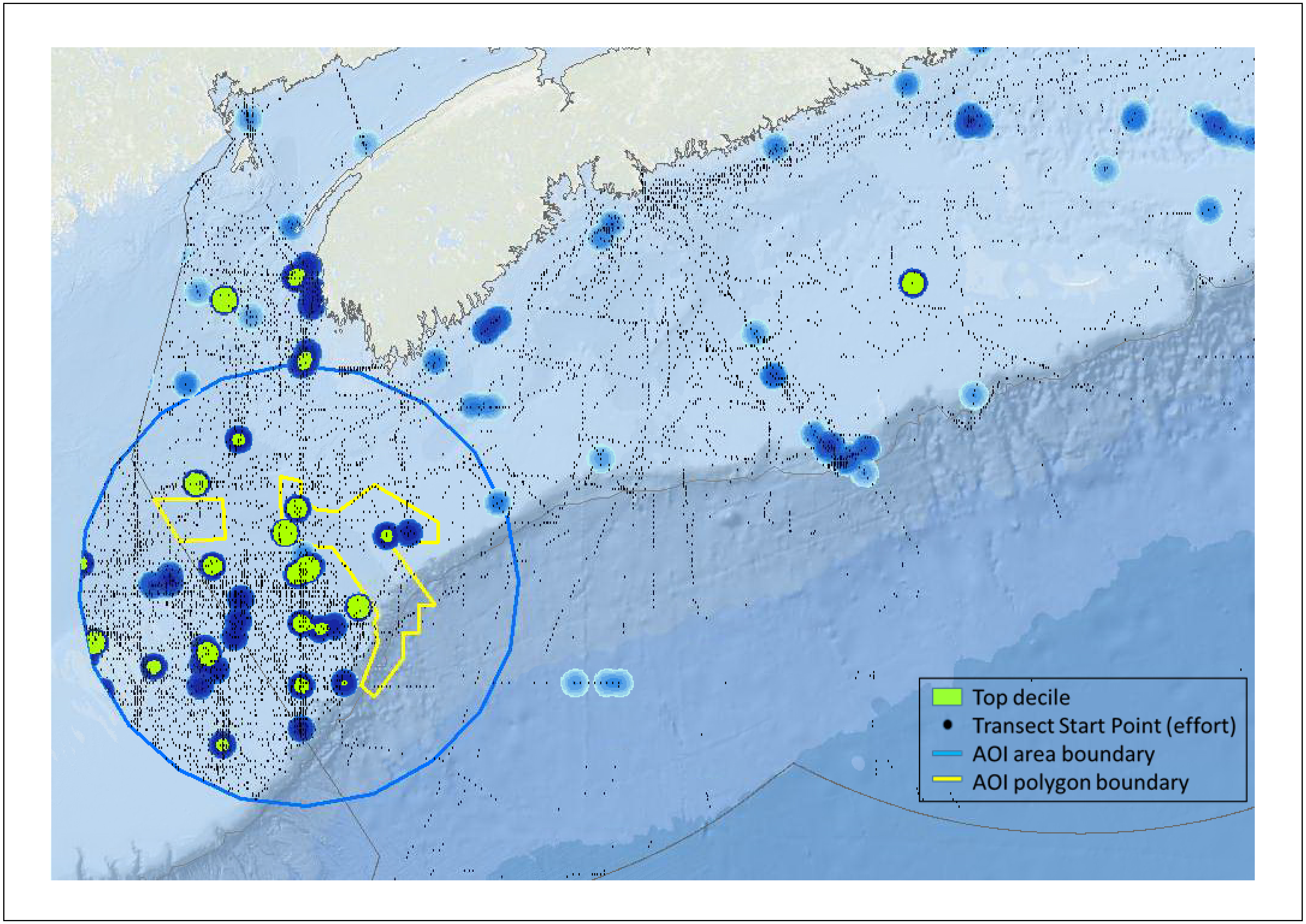

*Figure 119. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Thick-billed Murre. Kernels are based on 10 km search radius, with 1 km cell resolution.*

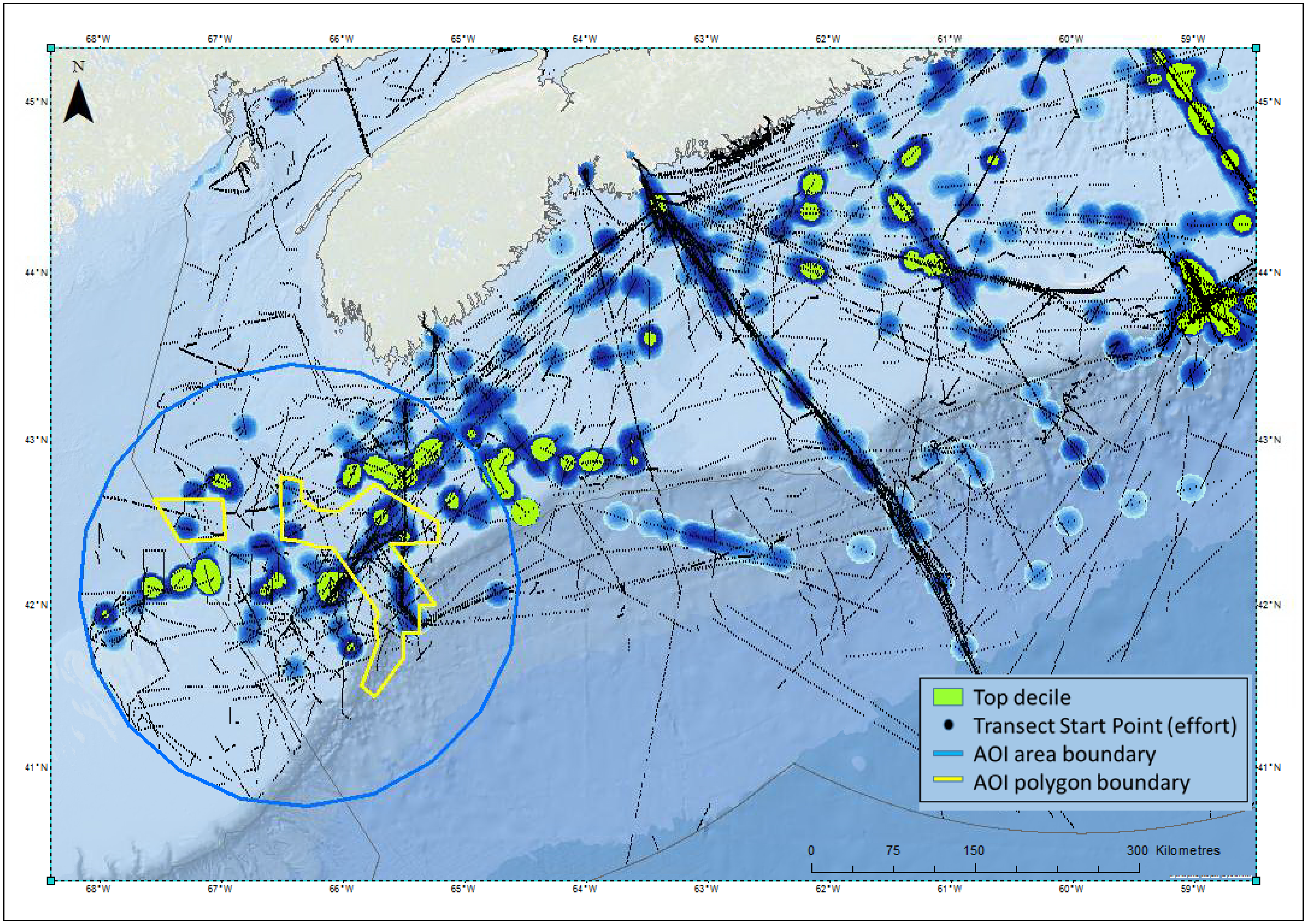

*Figure 120. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Thick-billed Murre. Kernels are based on 10 km search radius, with 1 km cell resolution.*

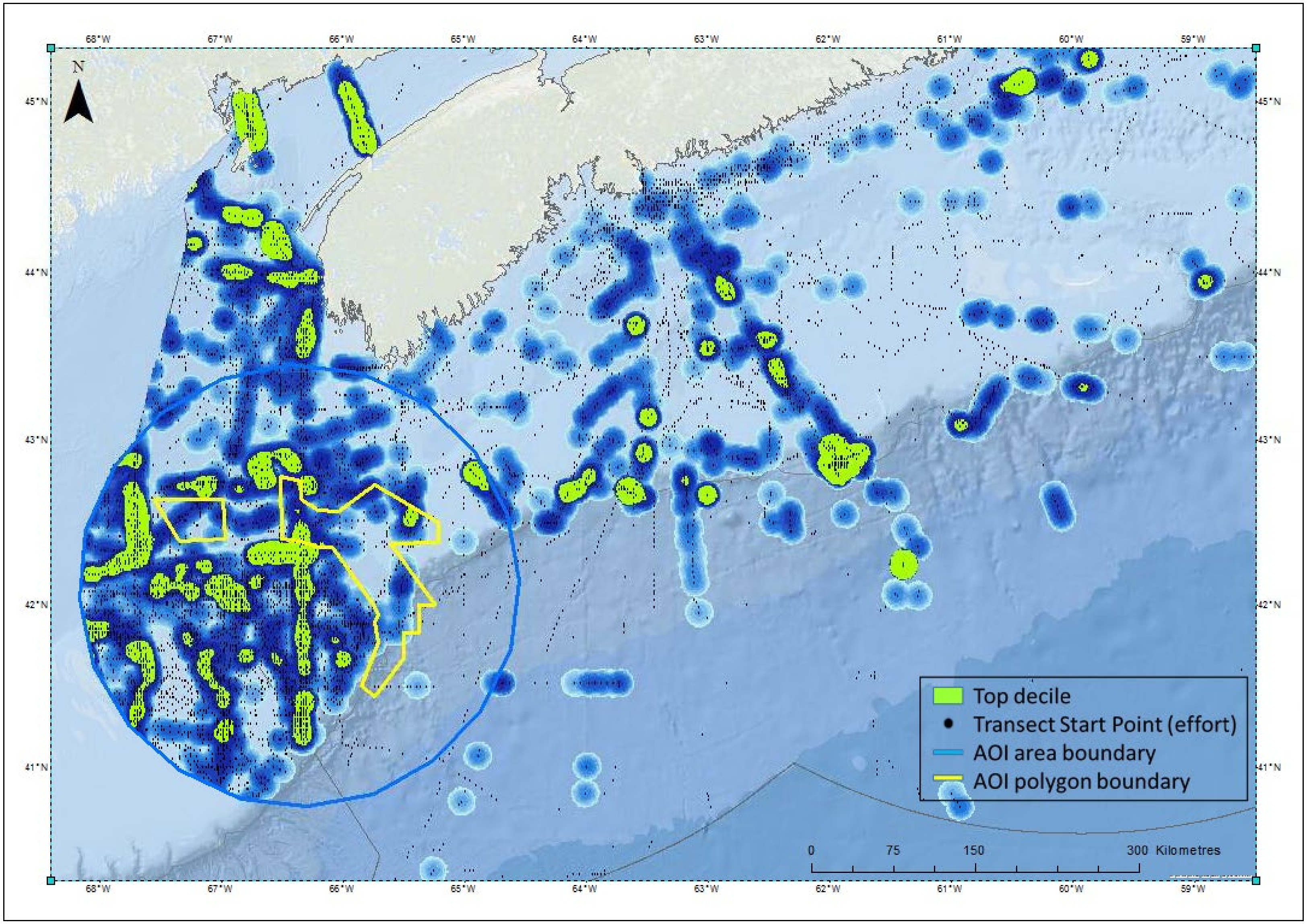

*Figure 121. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Black-legged Kittiwake. Kernels are based on 10 km search radius, with 1 km cell resolution.*

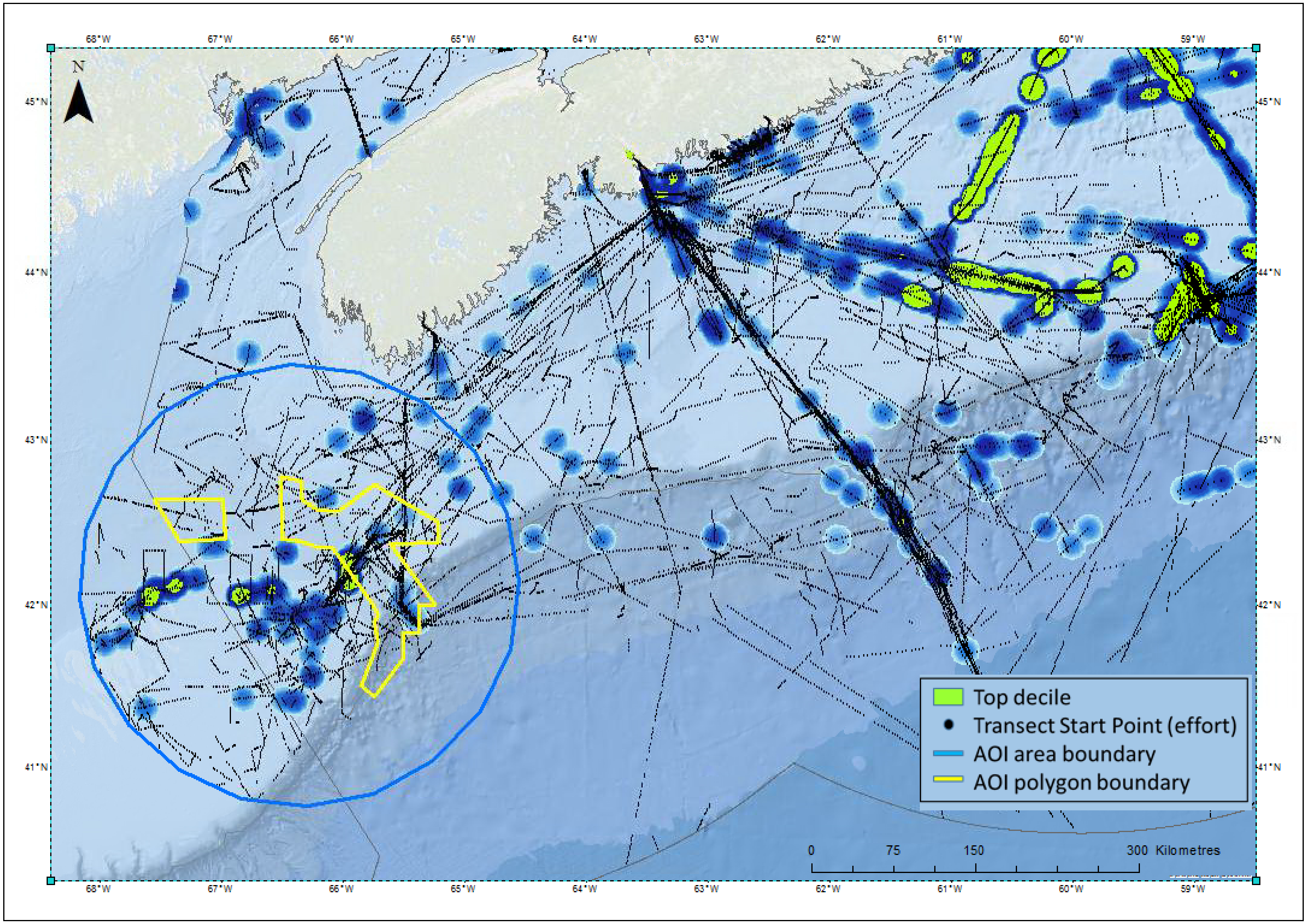

*Figure 122. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Black-legged Kittiwake. Kernels are based on 10 km search radius, with 1 km cell resolution.*

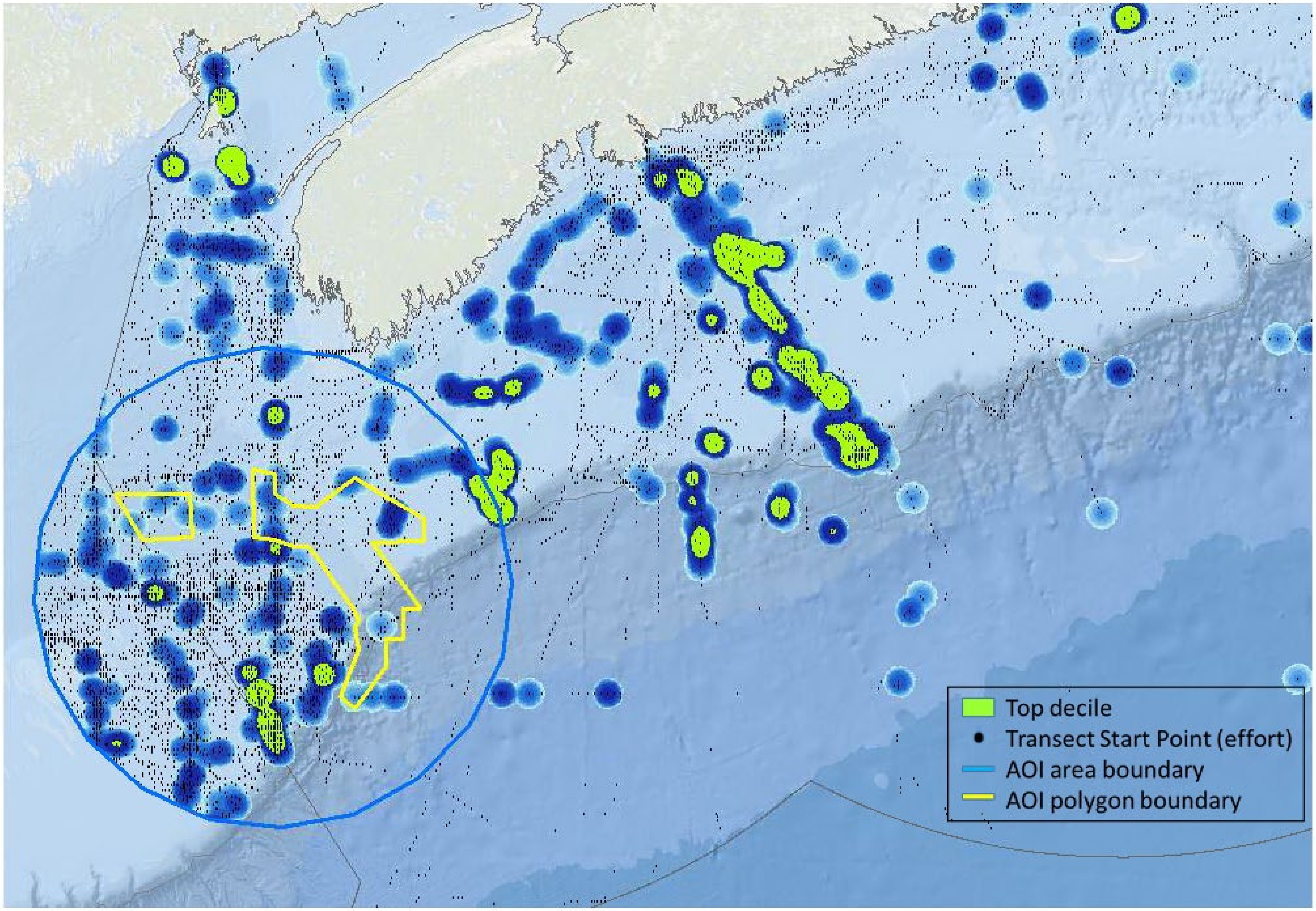

*Figure 123. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Dovekie. Kernels are based on 10 km search radius, with 1 km cell resolution.*

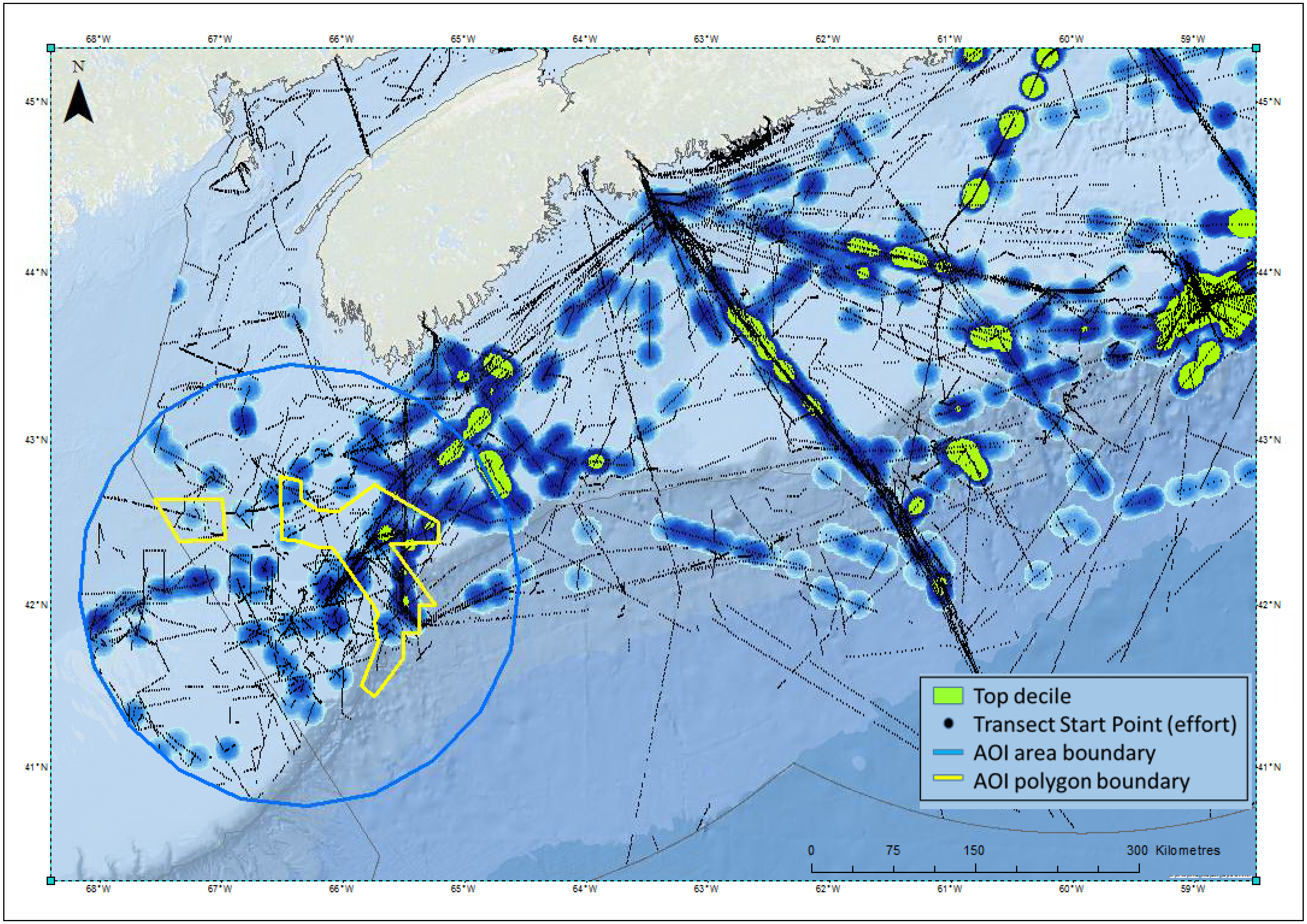

*Figure 124. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Dovekie. Kernels are based on 10 km search radius, with 1 km cell resolution.*

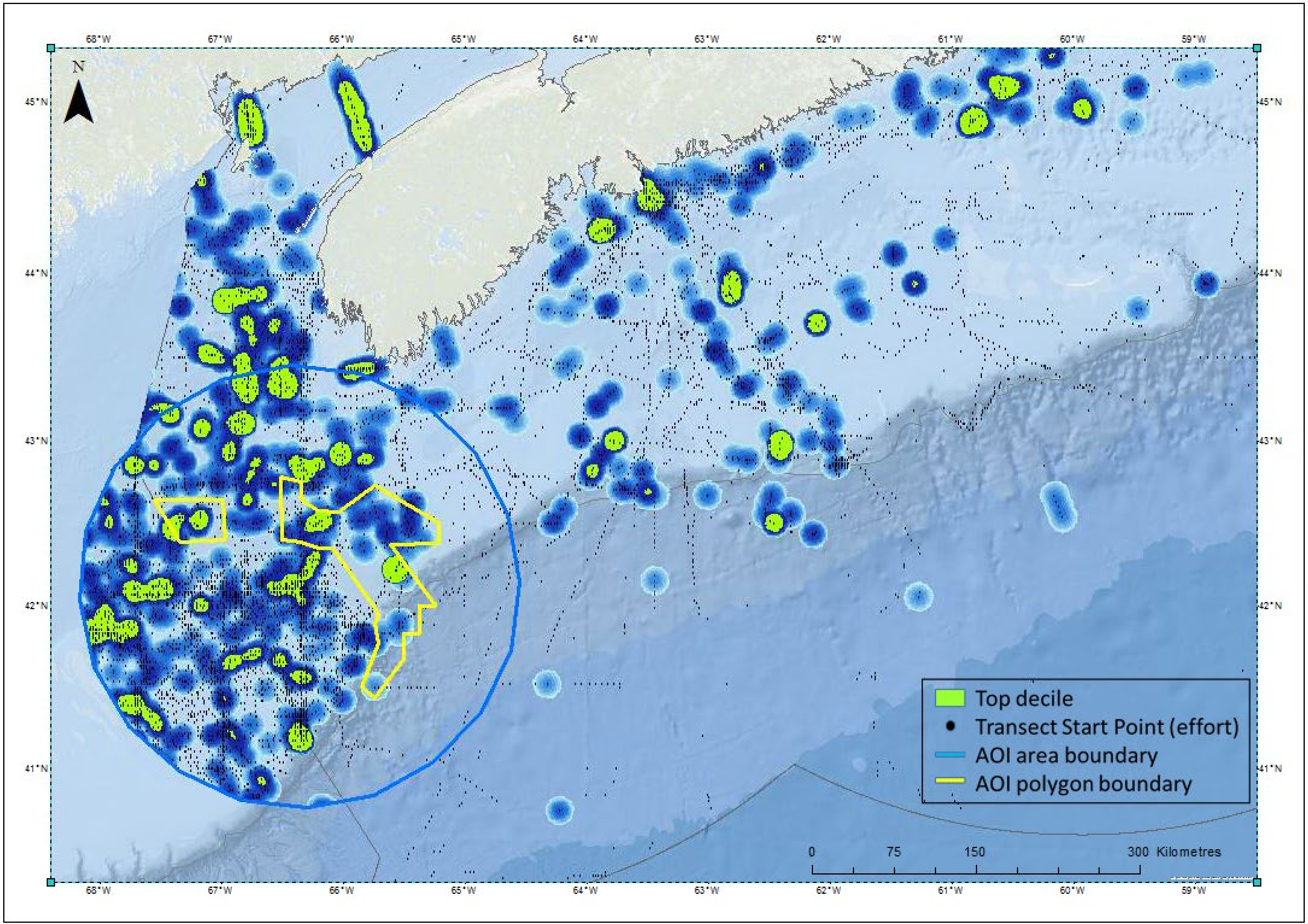

*Figure 125. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for Northern Gannet. Kernels are based on 10 km search radius, with 1 km cell resolution.*

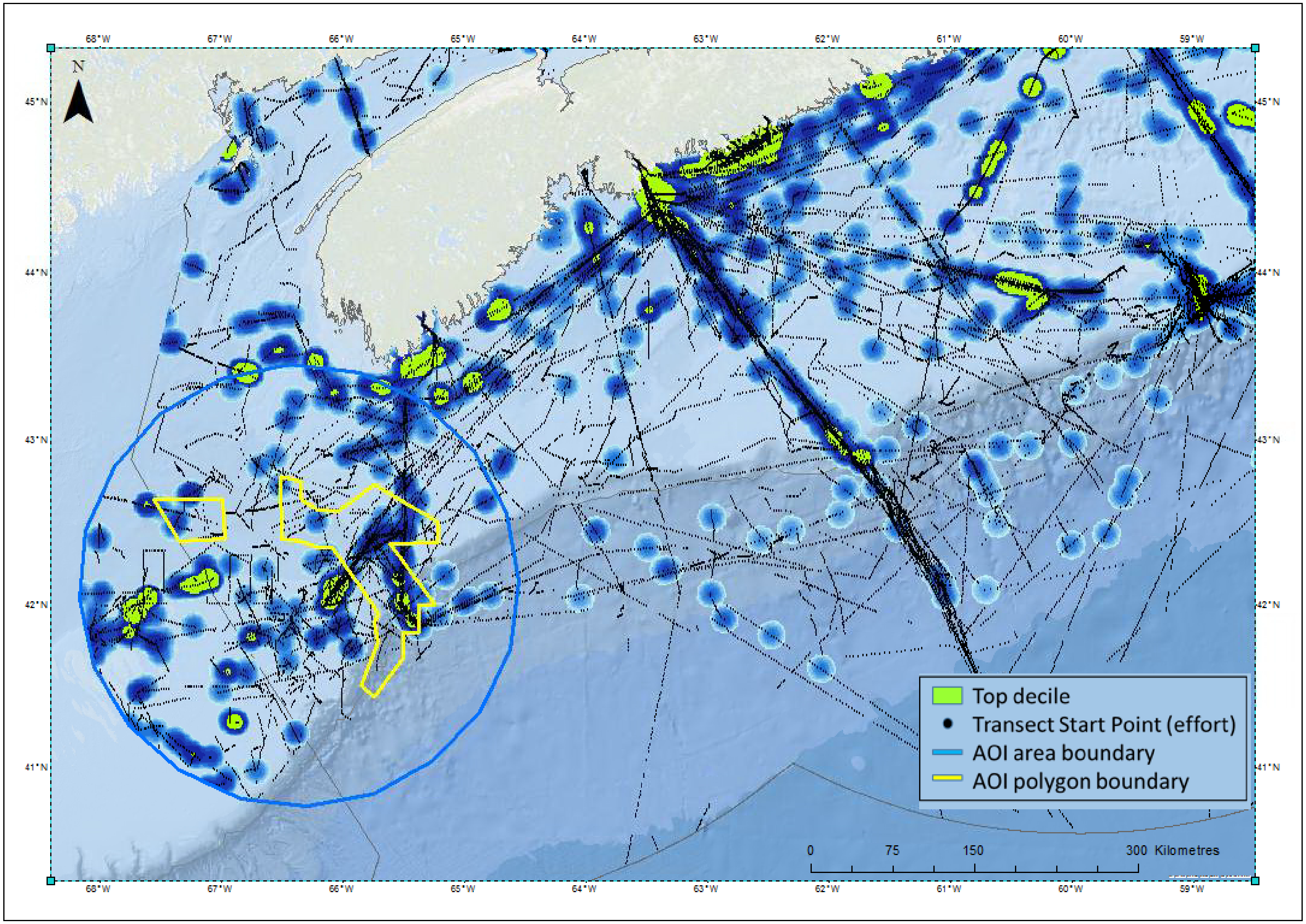

*Figure 126. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for Northern Gannet. Kernels are based on 10 km search radius, with 1 km cell resolution.*

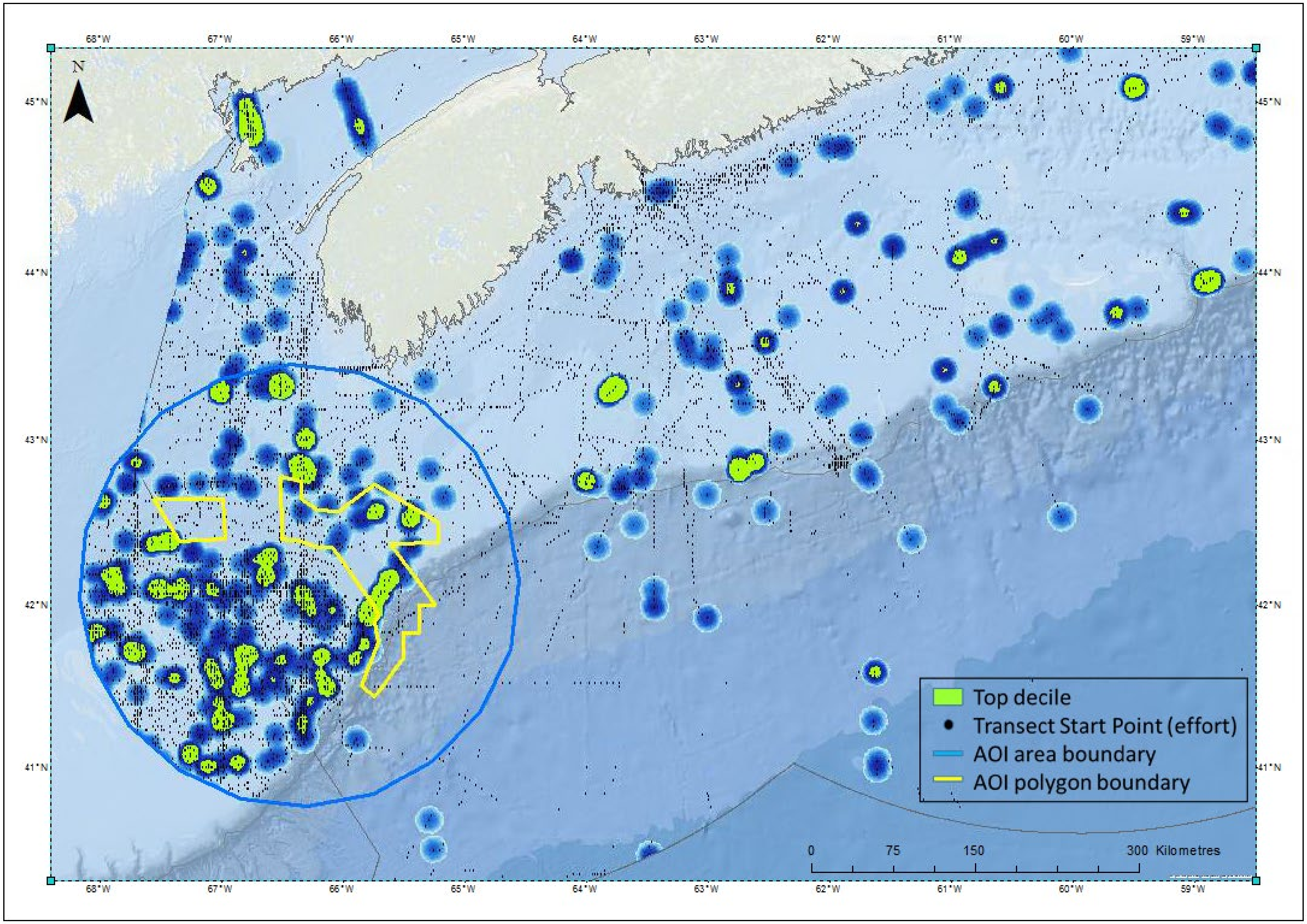

*Figure 127. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for skuas and jaegers. Kernels are based on 10 km search radius, with 1 km cell resolution.*

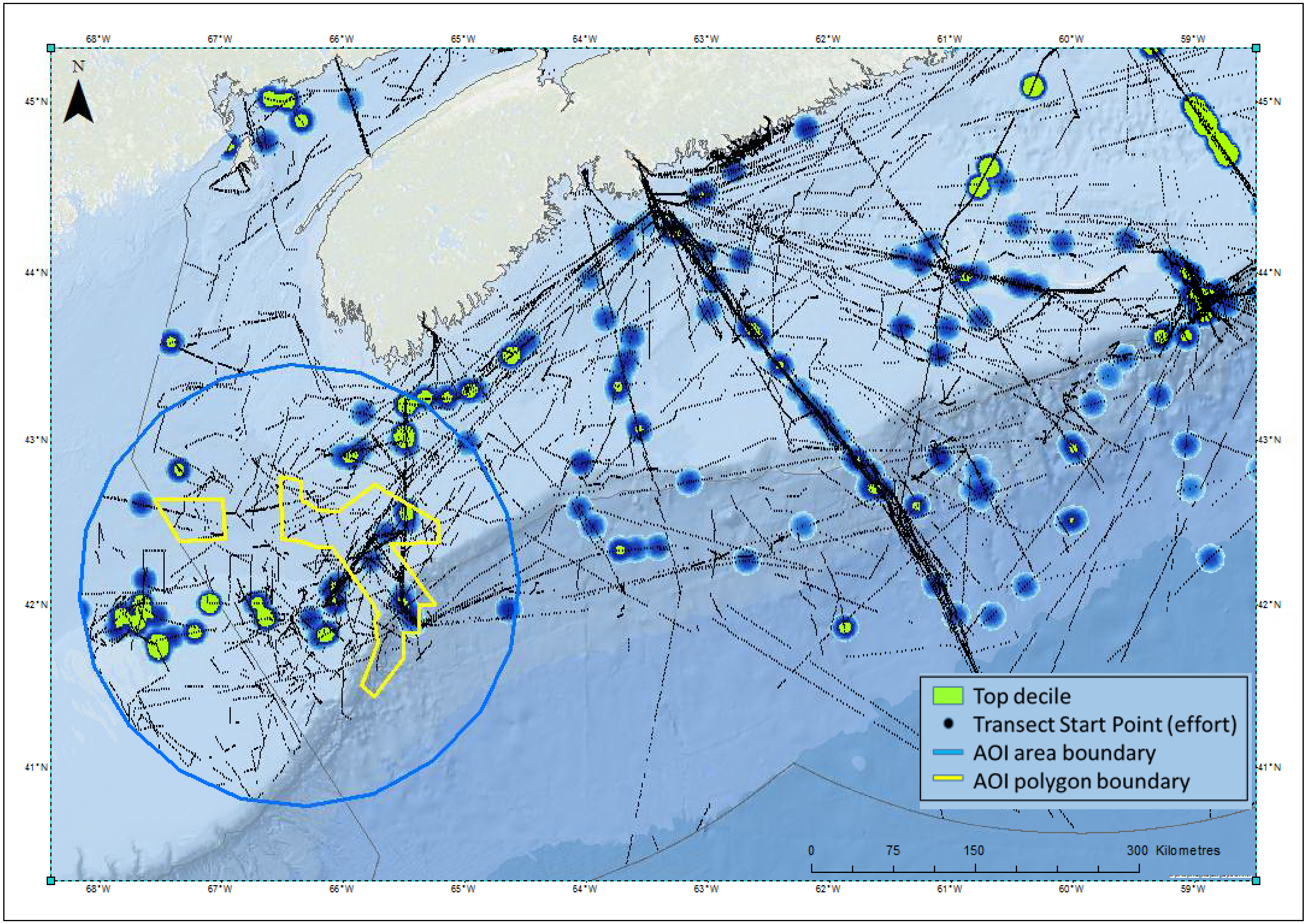

*Figure 128. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for skuas and jaegers. Kernels are based on 10 km search radius, with 1 km cell resolution.*

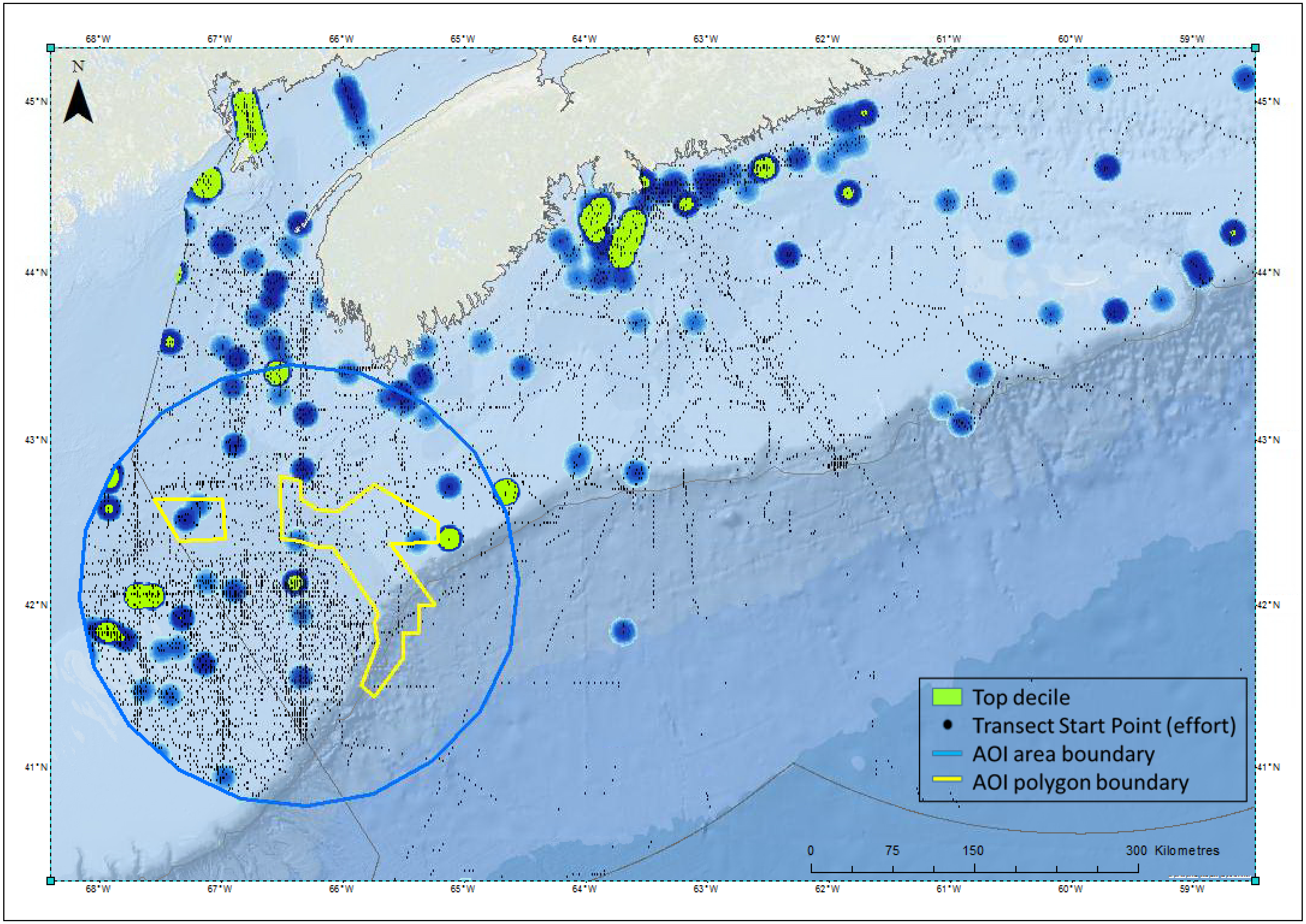

*Figure 129. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from Programme intégré de recherche sur les oiseaux pélagiques (PIROP) for terns (Laridae). Kernels are based on 10 km search radius, with 1 km cell resolution.*

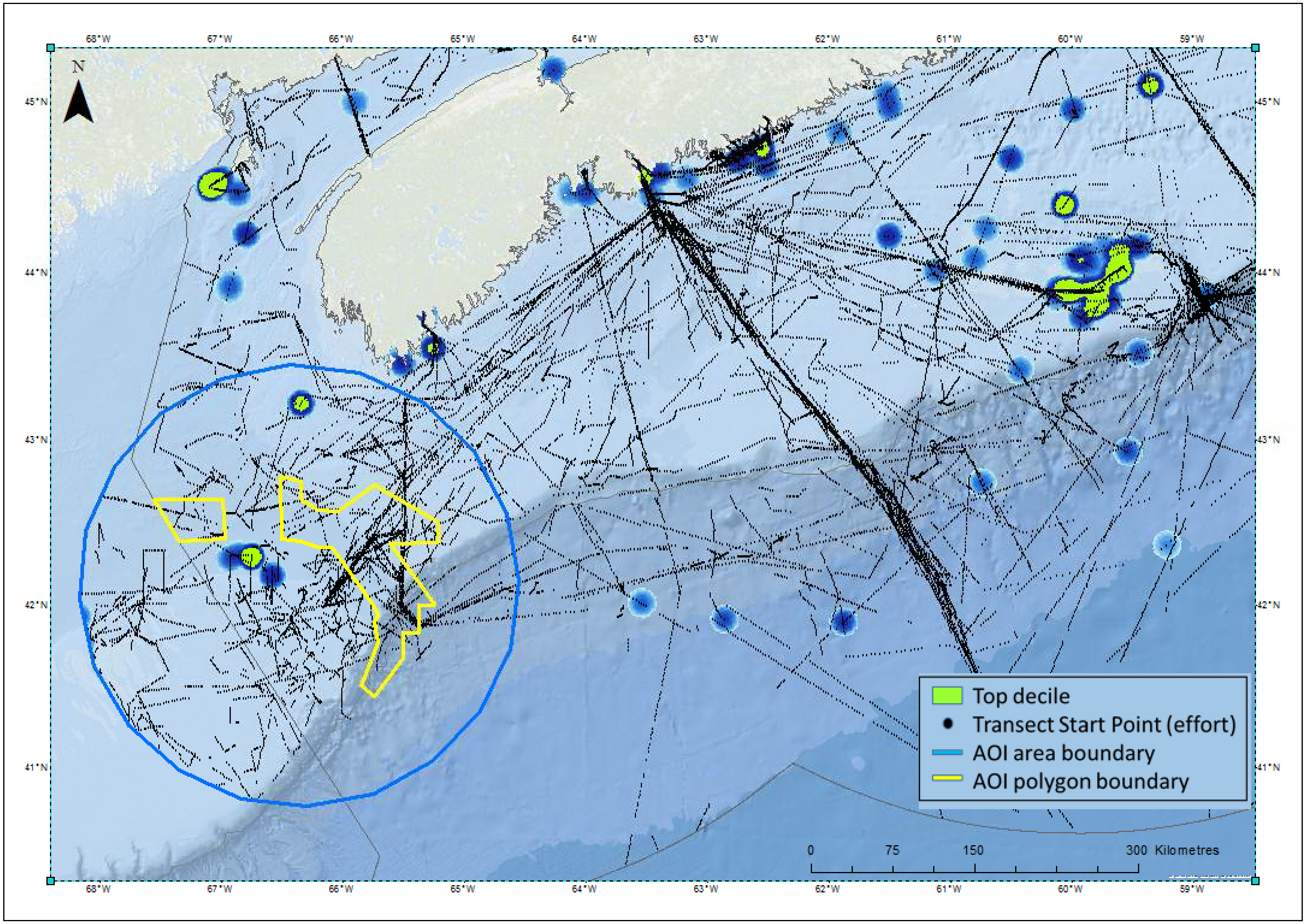

*Figure 130. Kernel densities of total counts of individuals per km travelled, excluding counts of zero, derived from ECSAS for terns (Laridae). Kernels are based on 10 km search radius, with 1 km cell resolution.*

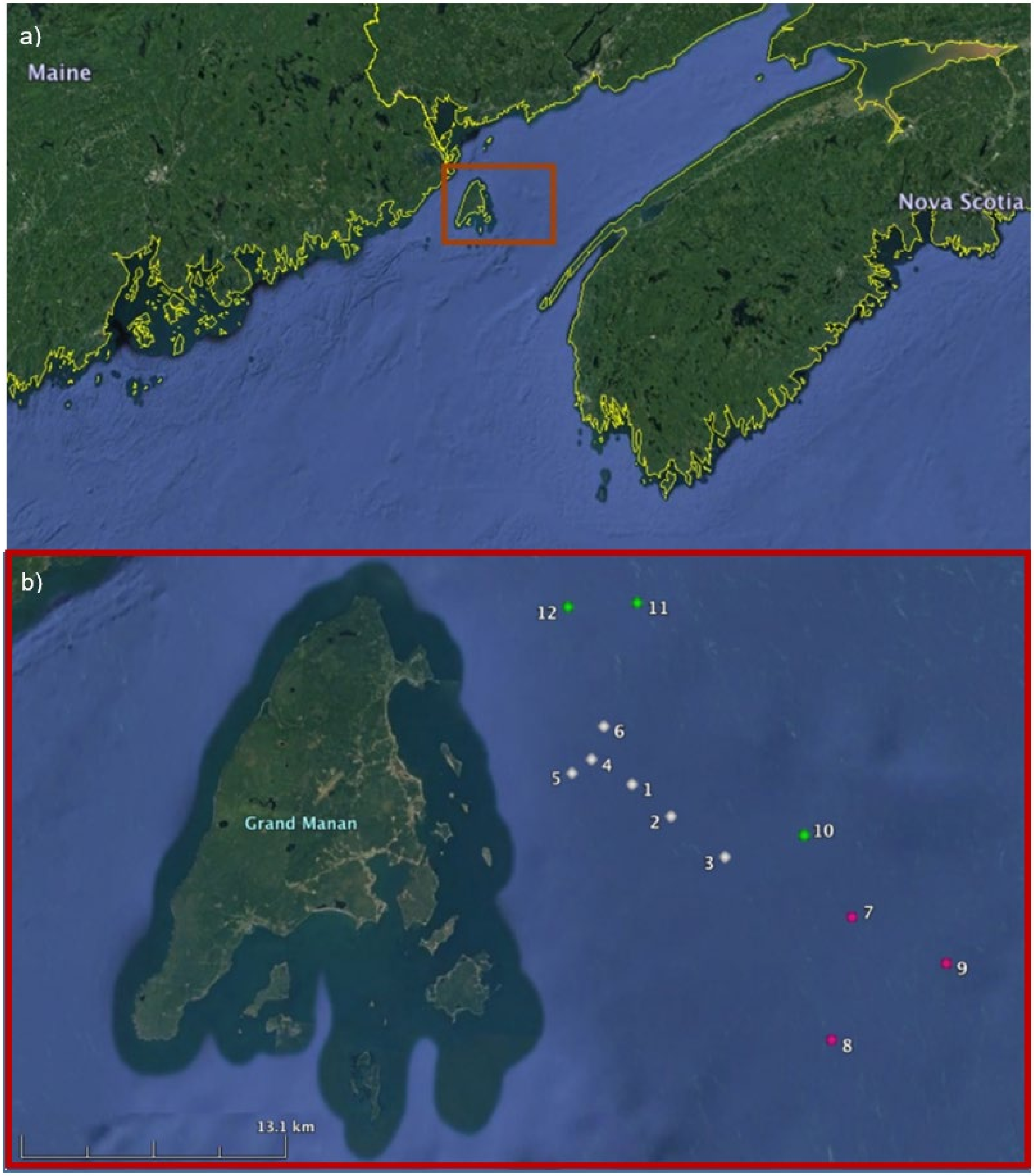

*Figure 131. a) Map of study area of the outer Bay of Fundy and southwest Nova Scotia, with Grand Manan island in the red box. b) Zoomed in area depicted by red box. Colored dots represent tag-on locations, each number corresponding to an individual Basking Shark ID. Each year of deployment is shown as a different color: 2011 = white (n = 6), 2012 = pink (n = 3), 2015 = green (n = 3).*

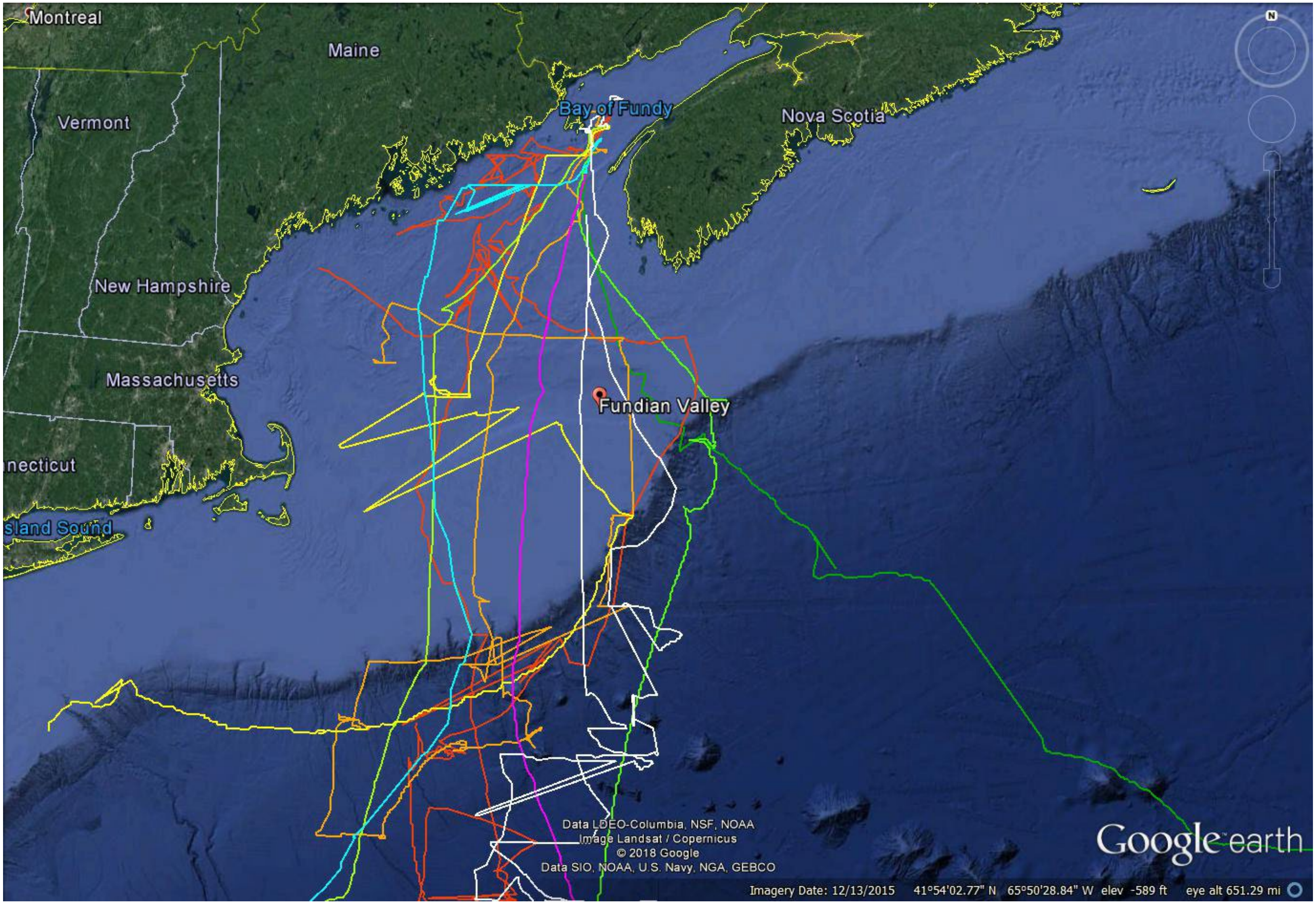

*Figure 132. Tracks from nine Basking Sharks that were tagged in the Bay of Fundy in 2011, 2012, and 2015.*

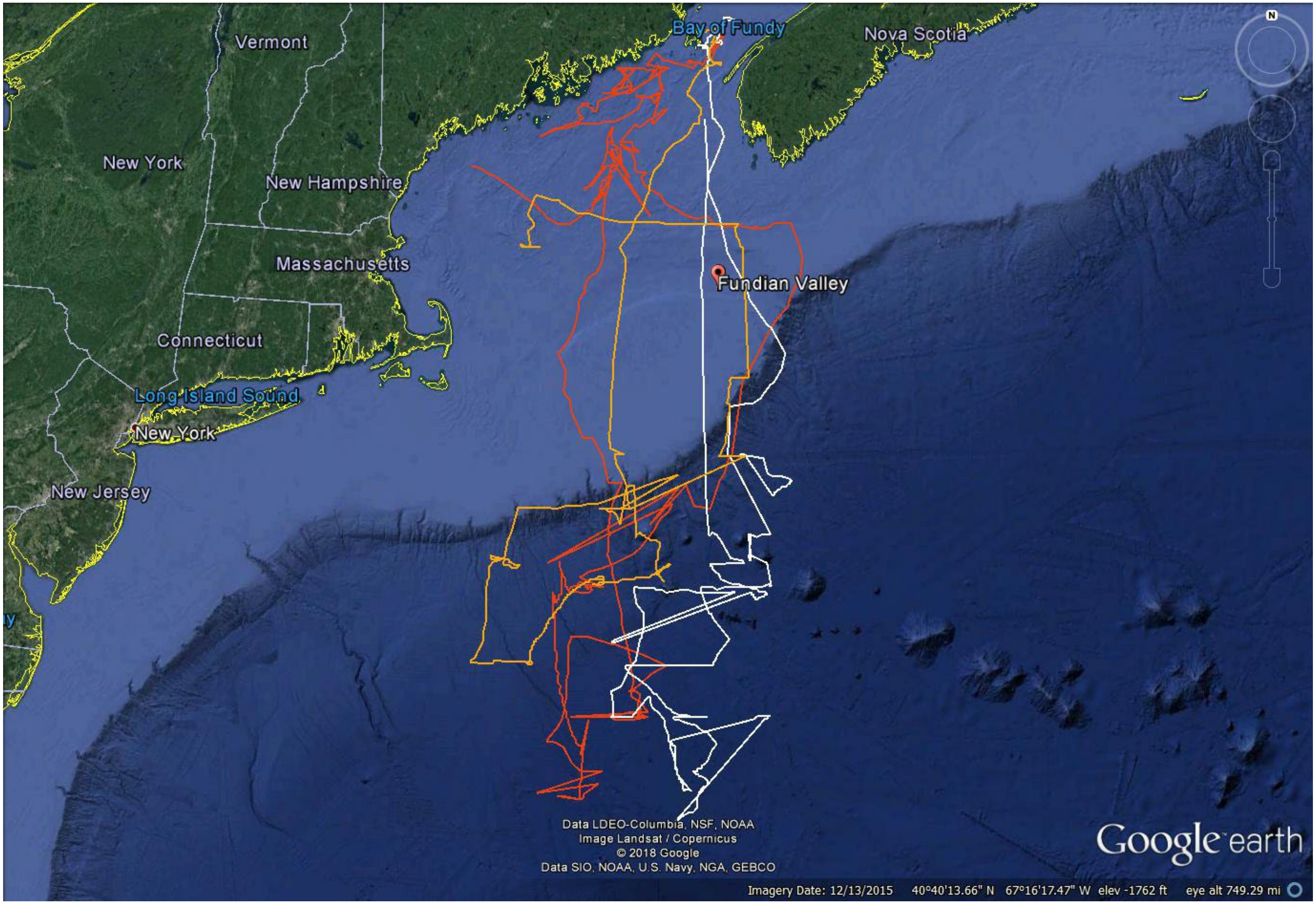

*Figure 133. Close-up of tracks from three Basking Sharks that include return migration pathways to the Bay of Fundy.*