STATE OF THE ATLANTIC OCEAN SYNTHESIS REPORT

R.Y. Bernier, R.E. Jamieson, and A.M. Moore (Eds.)

Fisheries and Oceans Canada
Gulf Region
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SUMMARY

Fisheries and Oceans Canada (DFO) has committed to informing Canadians on the state of Canada’s oceans and aquatic ecosystems. In 2017/18, DFO committed to producing a scientific synthesis report on the State of the Atlantic Ocean from which a plain language public report would be prepared. DFO scientists and external collaborators (i.e., Environment and Climate Change Canada) prepared summary reports on the current status and trends for seven theme groups: oceanography (physical and lower trophic levels), habitat/coastal and significant areas, fish and invertebrate communities, marine mammals, sea turtles, and seabirds. Summaries were based on published or peer-reviewed data and integrated over three Atlantic bioregions: Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves. Complementary case studies were also developed to illustrate concepts, processes, stressors, or comparisons among bioregions. A synthesis workshop brought together collaborators to present and discuss the draft summaries and case studies. Participants agreed on key messages for each theme, including the nature, connectivity, and causes of both natural and anthropogenic changes that are occurring in the Atlantic Ocean.

RÉSUMÉ

Pêches et Océans Canada (MPO) s'est engagé à informer les Canadiens sur l'état des océans et des écosystèmes aquatiques du Canada dans le cadre des rapports sur l'écosystème. En 2017–2018, le MPO avait pour objectif de produire un rapport de synthèse scientifique sur l'état de l'océan Atlantique, à partir duquel un rapport public serait préparé en langage clair. Des scientifiques du MPO et des collaborateurs externes (c.-à-d., Environnement et Changement climatique Canada) ont rédigé des rapports sommaires sur l'état actuel et les tendances selon sept groupes de thèmes : océanographie (physique et niveaux trophiques inférieurs), zones côtières et habitats importants, communautés de poissons et d'invertébrés, mammifères marins, tortues de mer et oiseaux marins. Les sommaires ont été tirés des données publiées ou examinées par des pairs et intégrés pour trois biorégions de l’Atlantique : le plateau néo-écossais, le golfe du Saint-Laurent et les plateaux de Terre-Neuve et du Labrador. Des études de cas complémentaires ont également été élaborées pour illustrer les concepts, les processus, les agents de stress ou les comparaisons entre les biorégions. Un atelier de synthèse a été organisé afin de réunir les scientifiques chargés des différents groupes de thèmes en vue de présenter et d’examiner l’ébauche des sommaires sur l’état et les tendances et les études de cas. Les participants se sont mis d’accord sur les messages clés pour chaque groupe de thèmes portant sur la nature, la connectivité et les causes des changements naturels et anthropiques qui se produisent dans l'océan Atlantique.

1.0 BACKGROUND

As part of Fisheries and Oceans Canada's (DFO) commitment to report on the state of Canada's oceans and aquatic ecosystems, the Department has been tasked with Ecosystem Reporting. The goal of this new Ecosystem Reporting initiative is to inform Canadians about the current status of Canada's oceans. An initial DFO National Ecosystem Reporting Workshop was held in Montreal, QC, on January 31–February 2, 2017 to discuss reporting requirements, develop shared understanding of existing regional reporting, and to develop a national framework for reporting on the State of Canada's Oceans. DFO Ecosystem Reporting is to follow a four-year cycle with a Pacific Ocean report produced by the end of fiscal year 2016/17, an Atlantic Ocean report in 2017/18, an Arctic Ocean report in 2018/19, and a national report on the three oceans in 2019/20. The aim is to produce a plain language public report based on a scientific synthesis report. The DFO National Ecosystem Reporting Steering Committee held a second Ecosystem Reporting Workshop in Dartmouth, NS, on May 24–25, 2017 to determine the overall structure of the State of the Atlantic Ocean report, develop a timeline, and plan for a synthesis workshop in fall 2017.

The reporting structure of the present State of the Atlantic Ocean reporting initiative differs from the previously published national DFO Canadian State of the Oceans reports in that current status and trends summaries of the Atlantic Ocean are provided by theme group rather than a review of ecosystem stressors and human impacts. A reporting structure including seven theme groups: oceanography (physical and lower trophic levels), habitat/coastal and significant areas, fish and invertebrate communities, marine mammals, sea turtles, and seabirds was developed and integrated across three bioregions within the Atlantic zone: Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves (Figure 1-1). This integrated approach is based on published or peer-reviewed data. Although the report is representative of the state of Atlantic ecosystems, it is not comprehensive. Important gaps will be considered in future state of the Atlantic Ocean synthesis reports following the four-year publication cycle of Ecosystem Reporting.

DFO scientific experts were appointed by their regional managers to participate in theme groups that developed status and trend summaries for this report. Scientific expertise from outside of DFO was sought as needed, including from Environment and Climate Change Canada (ECCC) for seabirds which are not within DFO's mandate.

Theme group members and other DFO scientific experts working on particular ecosystem stressors were also invited to contribute case studies in their field of expertise. Case studies complement theme group summaries by explaining concepts or processes, describing ecosystem stressors, or highlighting similarities across the three Atlantic bioregions in more detail. A draft list of 28 case studies was refined to a list of twelve studies to illustrate cases of particular interest to Canadians. These case studies are short, non-technical summaries of material presented in peer-reviewed literature.

Draft theme group status and trends summaries and twelve draft case studies were presented by their authors and subsequently discussed at a synthesis workshop, held in Moncton, NB, on December 5–6, 2017 (Worshop agenda provided in Appendix 1). DFO scientists from each of the four Atlantic Regions (Quebec, Gulf, Maritimes, and Newfoundland and Labrador) along with representatives from DFO Gulf Communications Branch, DFO Science Outreach, ECCC, NIVA Inc., and the DFO National Ecosystem Reporting Steering Committee were present at the workshop (Appendix 2). The objective of the workshop was to present, discuss, and synthesize scientific knowledge in the seven theme areas to develop key messages and provide a basis for a plain language public report. Post-workshop, modifications were made to presented data to improve clarity, fill gaps, and align with other theme groups based on workshop discussions. Main additions include a biogeographic overview and information on aquatic invasive species (DFO Atlantic Zone Aquatic Invasive Species monitoring program), which were both reviewed by contributors prior to inclusion. This report contains key messages (Section 2.0), theme group summaries with biogeographic overview (Section 3.0), case studies (Section 4.0), and workshop discussions, including post-workshop discussion on Aquatic Invasive Species (Appendix 3). A list of acronyms and abbreviations, which were used throughout this report, is also included (Appendix 4).

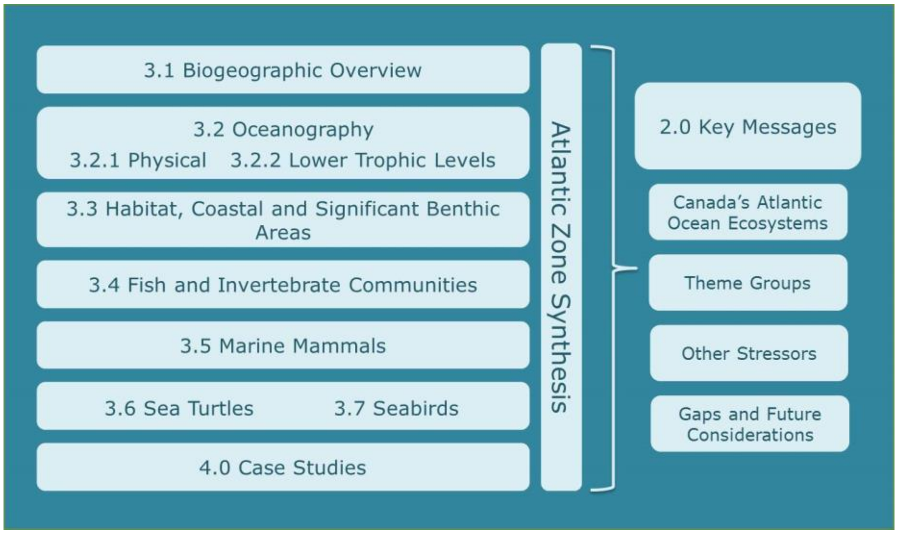

Figure 1-1. Reporting structure of the State of the Atlantic Ocean's public and synthesis reports with integration between Scotian Shelf, Gulf of St. Lawrence, and Newfoundland and Labrador Shelves within the Atlantic zone.

2.0 KEY MESSAGES

CANADA'S ATLANTIC OCEAN ECOSYSTEMS

- Ocean ecosystems are dynamic, influenced by both natural processes and human activities (e.g. fishing, coastal development, resource exploitation).
- Changes in the physical environment (e.g., warming temperatures caused by climate change) lead to direct effects (e.g., changes in growth rates) and indirect effects (e.g., changes in food web interactions) in the biological environment.
- Different ecosystems are experiencing changes in the physical and biological components at different rates and scales, and climate change is considered an important driver of these changes.
- Shifts in species distributions and changes in community composition are being observed across all trophic levels and functional groups.

OCEANOGRAPHY: PHYSICAL

- Climate change driven rise in air temperature is leading to warmer sea-surface waters, less sea ice cover, and weaker cold intermediate layers.
- Greater influence of Gulf Stream Water is leading to record high deep-water temperatures on the Scotian Shelf and in the deep channels of the Gulf of St. Lawrence.
- The rates of decrease in pH in Atlantic Canadian waters are generally higher than in other parts of the world, leading to record low pH in the St. Lawrence Estuary. This area of low pH is coincident with an area of hypoxia.

OCEANOGRAPHY: LOWER TROPHIC LEVELS

- Important changes in patterns of lower trophic level productivity were observed in the last five years.
- Declines in nutrient and chlorophyll inventories may be indicative of lower ecosystem production potential.
- A shift in zooplankton community structure, with higher abundances of smaller zooplankton and lower abundances of larger ones, may have consequences on the energy transfer efficiency from primary producers to upper trophic levels.

HABITAT, COASTAL, AND SIGNIFICANT BENTHIC AREAS

- Areas of kelp and eelgrass beds in Nova Scotia and in the Gulf of St. Lawrence are generally decreasing, but eelgrass beds in Newfoundland are increasing. Warmer temperatures may be a contributing factor to these changes.
- Coral and sponge habitats are hotspots of biodiversity in the deep sea and are threatened by resource extraction and bottom trawling. Sand dollar beds are also vulnerable to bottom trawling.

- Habitat degradation and loss in coastal regions may occur with coastal development and sea level rise and increased storm surges caused by climate change.
- Intertidal flats are ecologically and economically important habitats that may be adversely affected by warming temperatures and eutrophication.

FISH AND INVERTEBRATE COMMUNITIES

- In the early 1990s, some demersal fish populations of the Canadian Atlantic zone suffered serious declines and collapses. In some ecosystems, small pelagic fish, which are key for transferring energy from zooplankton to the top of the food web, also experienced declines. Benthic invertebrates increased and became the target of lucrative fisheries.
- In recent years, abundance of demersal fish species, such as redfish and Atlantic halibut, have increased in some areas.
- The status of small key pelagic species is poor, declining, or poorly understood.
- Recent warming trends observed across the Atlantic zone have been linked to species range expansions, shifts in distributions, and increases in abundance of warmer water species, including coastal invertebrates like American lobster and demersal fish like silver hake and Atlantic halibut. The abundance of cold water invertebrate species, such as northern shrimp and snow crab, which increased during the 1990s, has decreased in some areas in recent years.

MARINE MAMMALS

- Many marine mammal populations were heavily over-exploited over the last two centuries. There is evidence that some marine mammal populations are increasing in abundance (e.g., harp seals, grey seals, humpback whales), whereas others do not appear to be recovering (e.g., blue whales, north Atlantic right whales, St. Lawrence beluga). However, trends in most species are unknown.
- As highly mobile predators, marine mammals show shifts in distribution and abundance that reflect different prey availabilities and/or environmental conditions. For example, as northern areas warm, there appears to be a shift in temperate marine mammal species northward.

SEA TURTLES

- Canadian waters provide important sea turtle habitat for approximately six months of the year, where incidental capture in fisheries is the main threat. Throughout their life cycle, sea turtles are vulnerable to other anthropogenic threats (illegal harvesting of nesting females and eggs, habitat loss, oil and gas exploration, and ingestion of marine debris).
- Seasonal sea turtle population density in Canadian waters remains unknown for all species.

SEABIRDS

- Over the last 47 years (since 1970), most colonial nesting seabird populations have increased.
- Over the last decade, seabird population trends are more mixed with some population reductions in part due to declines in high-quality prey fish and ongoing activities associated with commercial fisheries and oil and gas exploration and production.
- Anthropogenic threats to some seabird groups (gannets, alcids) that previously led to significant adult mortality have been reduced (e.g., toxins, chronic oil pollution, inshore gill nets, and unsustainable harvesting).

OTHER STRESSORS

- Non-indigenous and aquatic invasive species (AIS) pose an ongoing threat to native species inhabiting coastal and oceanic ecosystems in Atlantic Canada.
- Successful establishment and subsequent impacts of invasive AIS are exacerbated by warming temperatures and other environmental perturbations e.g., (habitat degradation and loss) associated with climate change.

GAPS AND FUTURE CONSIDERATIONS

- Availability of status and trends data was unequal across theme groups.
- Specific knowledge gaps exist in some theme groups, for example:
    - Long-term trends of biodiversity and habitat are not always available.
    - There are many species for which abundance estimates are not available.
    - Knowledge of individual threats and their cumulative effects are not fully understood.
    - We have limited knowledge of the coastal zone.
- The aim is continued work towards development of an ecosystem approach by integrating existing physical and biological data; for example, examining the processes driving changes in species distribution and consequent potential impacts.

3.0 THEME GROUP SUMMARIES

3.1 BIOGEOGRAPHIC OVERVIEW

At the broadest scale, Canada’s Atlantic waters are divided into three large biogeographical units based primarily on oceanographic and bathymetric differences: the Scotian Shelf, the Newfoundland and Labrador Shelves, and the Gulf of St. Lawrence (Figure 3.1-1) (DFO 2009). While each area exhibits distinct differences in ecological communities and their spatial structure, the boundaries between them are transition zones rather than abrupt borders (DFO 2009). Smaller, more practical units have been defined within these larger biogeographic units, when discussing specific ecosystem components, such as fish communities (DFO 2009).

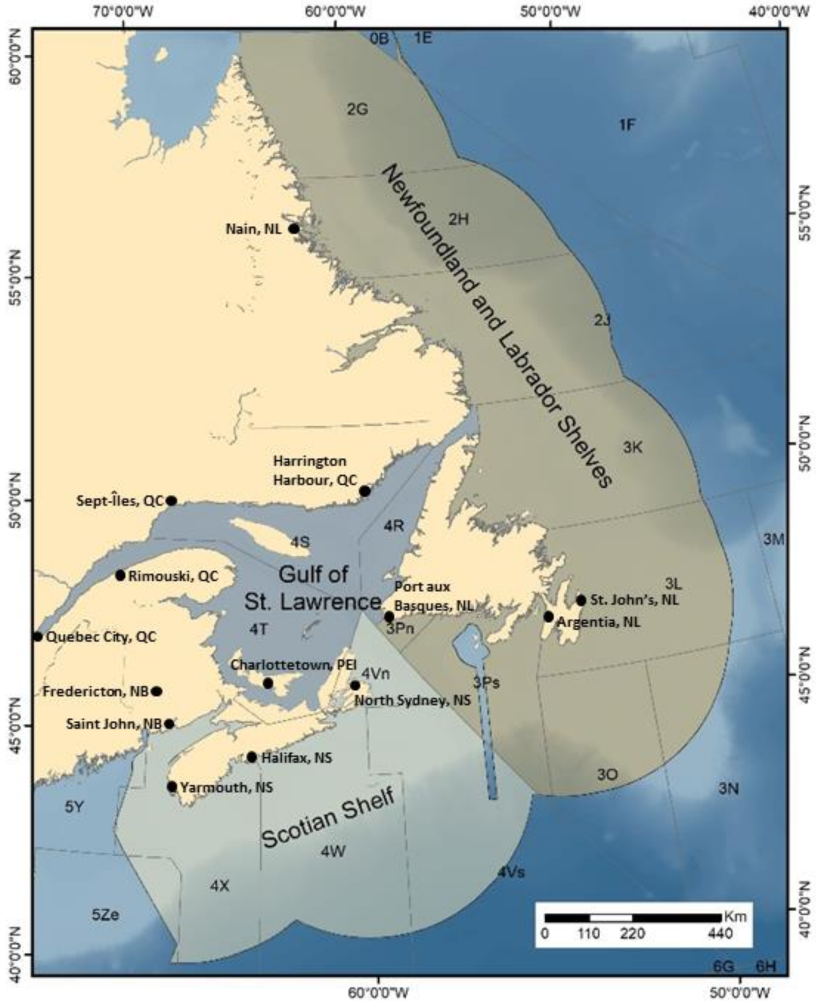

Figure 3.1-1. Map of the Atlantic zone considered for the State of the Atlantic Ocean report illustrating the three main biogeographic units as well as the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Areas. (N. Ollerhead, DFO). Management of fish and invertebrates stocks as well as oceanography data is explained within NAFO Divisions (e.g., 4R, 3Ps, 2J), which are frequently referred to throughout this report. Scientific and statistical subareas are indicated by numbers, divisions by capital letters and subdivisions by lower case letters. Place names are referred to in text.

There are many dynamic ecosystems within the temperate waters of the Canadian Atlantic that span a wide range of oceanographic conditions including strong seasonality and land-based freshwater runoff (Loder et al. 1998). To the north, the Newfoundland and Labrador Shelves are dominated by subpolar waters. The cool, fresh Labrador Current flows southward along the Newfoundland and Labrador Shelves to the south and west of the Grand Banks where it mixes with the warmer, saltier waters of the Gulf Stream which flows northward (Loder et al. 1998; DFO 2013) (Figure 3.1-2). The deep waters of the Laurentian Channel form a boundary between the Newfoundland and Labrador Shelves and the Scotian Shelf (DFO 2009), which is adjacent to the Gulf of Maine to the southwest and includes the Bay of Fundy and the eastern portion of Georges Bank. To the south, the Scotian Shelf is similarly influenced by the transition between subpolar waters and the Gulf Stream (Loder et al. 1998; DFO 2013).Waters from the Gulf of St. Lawrence outflowing from the western side of the Laurentian Channel partially feed into the Nova Scotia Current while the rest flows through the Laurential Channel and meets the Labrador Current near the shelf break. The warmer waters of the Gulf Stream mix with the cool Labrador Current along the Scotian slope (MacLean et al. 2013).

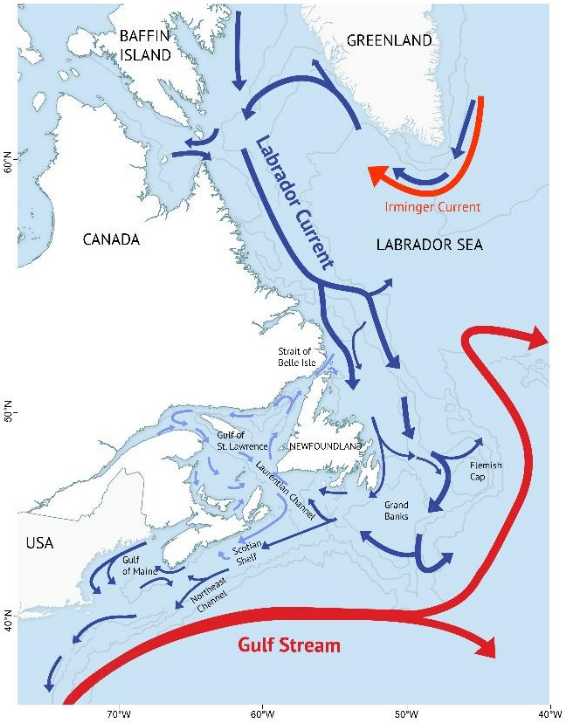

Figure 3.1-2. Schematic diagram of the general circulation patterns in the western North Altantic Ocean illustrating the two main currents influencing the Canadian Atlantic: the cold Labrador Current from the north (dark blue arrows) and the warm Gulf Stream from the south (dark red arrows).

The Gulf of St. Lawrence is defined by its distinct oceanography as a semi-enclosed inland sea (Loder et al. 1998; DFO 2009). The southern Gulf is dominated by the Magdalen Shallows which is an area of high productivity while the northern Gulf is dominated by deep channels. Differences can be found in the fish, plankton and benthic communities between the northern and southern Gulf (DFO 2009). The waters of the Gulf are largely subpolar with a large freshwater input from the St. Lawrence River and warm Atlantic water found in the deep channels (DFO 2013; Chabot and Gilbert 2013). Waters from the Labrador Current and central North Atlantic flow through the mouth of the Laurentian Channel and into the Gulf (Chabot and Gilbert 2013). The boundaries with the Scotian Shelf to the south and the Newfoundland and Labrador Shelves to the north are somewhat transitional (DFO 2009).

Seasonal changes in ice, near-surface temperatures and freshwater run-off are important drivers throughout Canada’s Atlantic zone. In particular, ice cover varies seasonally in the Gulf of St. Lawrence and sea ice moves from northern areas through the Labrador Current over the Newfoundland and Labrador Shelves (Loder et al. 1998; DFO 2009). Sea ice plays an important role in freshwater input, the timing of phytoplankton blooms, and provides habitat for organisms which live under and on top of the ice.

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3.2 OCEANOGRAPHY

The information provided in this section is derived from the Atlantic Zone Monitoring Program (AZMP) and the Atlantic Zone Offshore Monitoring Program (AZOMP). The AZMP collects data on the physical, chemical, and biological oceanographic properties on the continental shelves and slopes off Newfoundland, Nova Scotia, and in the Gulf of St. Lawrence (Figure 3.2-1) whereas the AZOMP collects this same data in the Labrador Sea and from the extended Halifax line.

To simplify the presentation of information in Sections 3.2.1 and 3.2.2, environmental conditions are usually expressed as anomalies (i.e., deviations from their long-term means) calculated using a reference period of 1999–2010 for most variables. Areas over which conditions were averaged are shown in Figure 3.2-1. Because measurements of the various physical, chemical, and biological variables are expressed using different units, each anomaly time series is normalized by dividing by its standard deviation, which is also calculated using data from the reference period. This allows a more direct comparison of the different series and ensures that the inherent local or regional level of variability (the signal detected by the program) is considered in a coherent manner for all parts of the Atlantic. A composite index for a set of variables can be calculated by summing the anomalies across all sources of information.

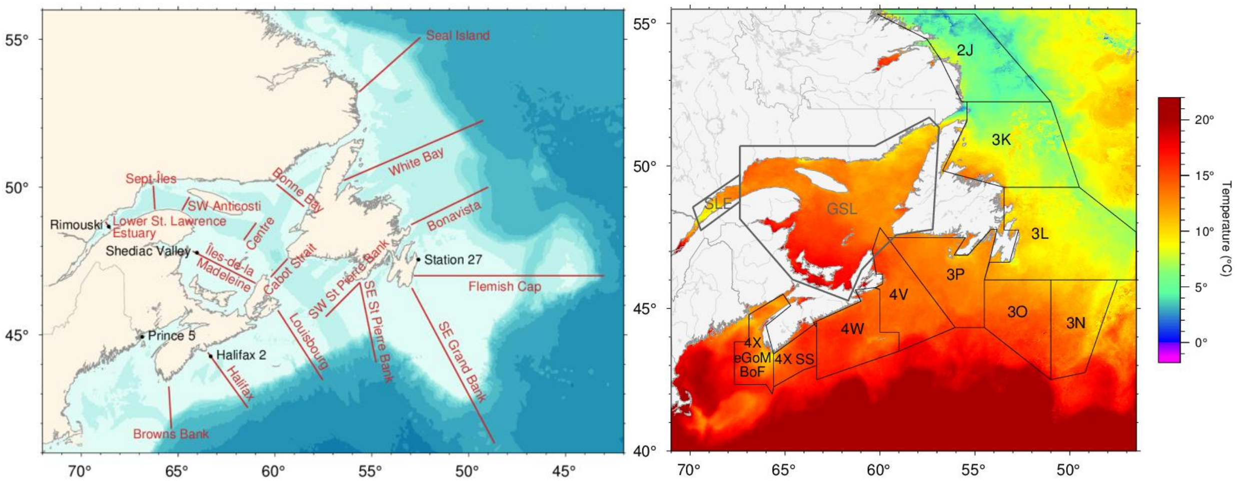

Figure 3.2-1. Left panel: Atlantic Zone Monitoring Program high-frequency sampling stations (black) and selected section lines (red). AZOMP additional sampling stations not shown. Right panel: Areas used for ocean temperature averages. North Atlantic Fisheries Organization Divisions are cut off at the shelf break. Sea-surface temperatures are shown for July 2016. GSL: Gulf of St. Lawrence, SLE: St. Lawrence Estuary.

3.2.1 Physical oceanography

Peter S. Galbraith[1], David Brickman[2], Pierre Pepin[3], Joël Chassé[4], Eugene Colbourne[3], Roger Pettipas[2], David Hebert[2], Guoqi Han[3], Michel Starr[1], Kumiko Azetsu-Scott[2], Denis Gilbert[1]

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Annual Temperature Cycle

Where depths permit, the summertime vertical structure of temperature in the Atlantic zone consists of three distinct layers: the summertime warm surface layer, the cold intermediate layer (CIL), and the deeper water layer. During fall and winter, the surface layer deepens and cools, mostly from wind-driven mixing prior to ice formation but also partly because of cooling, reduced runoff, and brine rejection associated with sea ice formation where it occurs. The surface winter layer extends to an average depth of about 75 m on the Scotian Shelf and in the Gulf of St. Lawrence by March, and can extend to the bottom (>150 m) on the Newfoundland and Labrador Shelves. Therefore, large portions of the Atlantic shelf (e.g., southern Gulf of St. Lawrence and the Grand Banks) only have one layer in winter and a two-layer vertical structure in summer, as depths are too shallow to accommodate the third deep-water layer. During spring, surface warming, sea ice melt waters, and continental runoff lead to a lower salinity and higher temperature surface layer which stratifies the water column. Below this, cold waters from the previous winter are partly isolated from the atmosphere and form the summer CIL. This cold layer persists until the next winter, gradually warming and deepening during summer and early fall (Gilbert and Pettigrew 1997; Cyr et al. 2011). The CIL is, for the most part, locally formed in winter in separate areas around the zone. For example, the temperature minimum of the winter mixed layer occurs at about the same time in March on the Scotian Shelf and in the GSL, but reaches different minimum temperatures. This is an indication of local formation rather than advection from one region to the other. However, CIL transport occurs later in the year from the Labrador Shelf to the Gulf of St. Lawrence (Galbraith 2006) and Newfoundland Shelf (Umoh et al. 1995) and from the Gulf of St. Lawrence to the St. Lawrence Estuary (Galbraith 2006) and to the Scotian Shelf (Umoh and Thompson 1994). The temperature minimum in southern parts of the Newfoundland Shelf (e.g., at Station 27) can occur well after winter; for example, in 2016 it was observed in early August (Colborne et al. 2017). Deep waters are defined here as those below the CIL that have only weak seasonal cycles, typically below 200 m in the Gulf of St. Lawrence and Scotian Shelf.

Sea-surface temperature

Sea-surface temperature is averaged over ice-free periods of the year, which may be as short as June to November on the Labrador Shelf or extending to the entire year on the Scotian Shelf (Figures 3.2-2 and 3.2-3). Sea-surface temperature is well correlated with average air temperature (Galbraith et al. 2012; Galbraith and Larouche 2013). The warming trend observed in air temperature since the 1870s of about 1°C per century is therefore also expected to have occurred in surface water temperatures across Atlantic Canada. In 2012, the Scotian Shelf, St. Pierre Bank, and the Grand Bank out to the Southeast Shoal all had their warmest ice-free period of the satellite record (since 1985 in the dataset shown here), and the St. Lawrence Estuary had its warmest ice-free period in 2016 (DFO 2017). Overall for the zone, two (2012 and 2014) of the five warmest years of the satellite record occurred during the 2012–2016 five-year period.

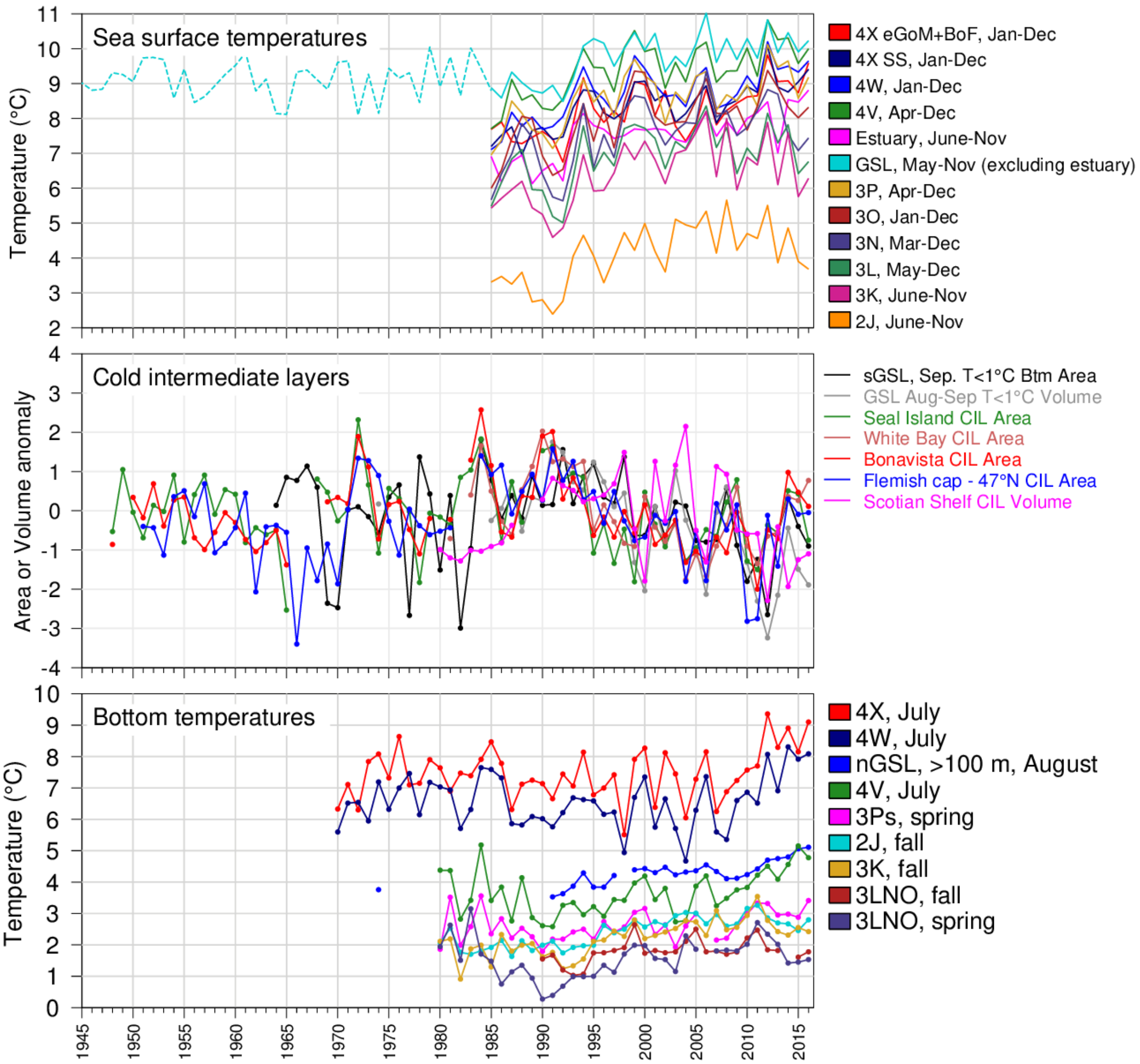

Figure 3.2-2. Time series of oceanographic variables. Sea-surface temperature for the GSL (1945–1984) is based on an air temperature proxy. Conditions are averaged over NAFO Divisions in Figure 3.2-1 (GSL: Gulf of St. Lawrence, SS: Scotian Shelf, sGSL: southern Gulf of St. Lawrence, nGSL: northern Gulf of St. Lawrence), cold intermediate layer: CIL. Refer to Figure 3.2-1 (right panel) for NAFO Divisions within Atlantic Canada identified in legends.

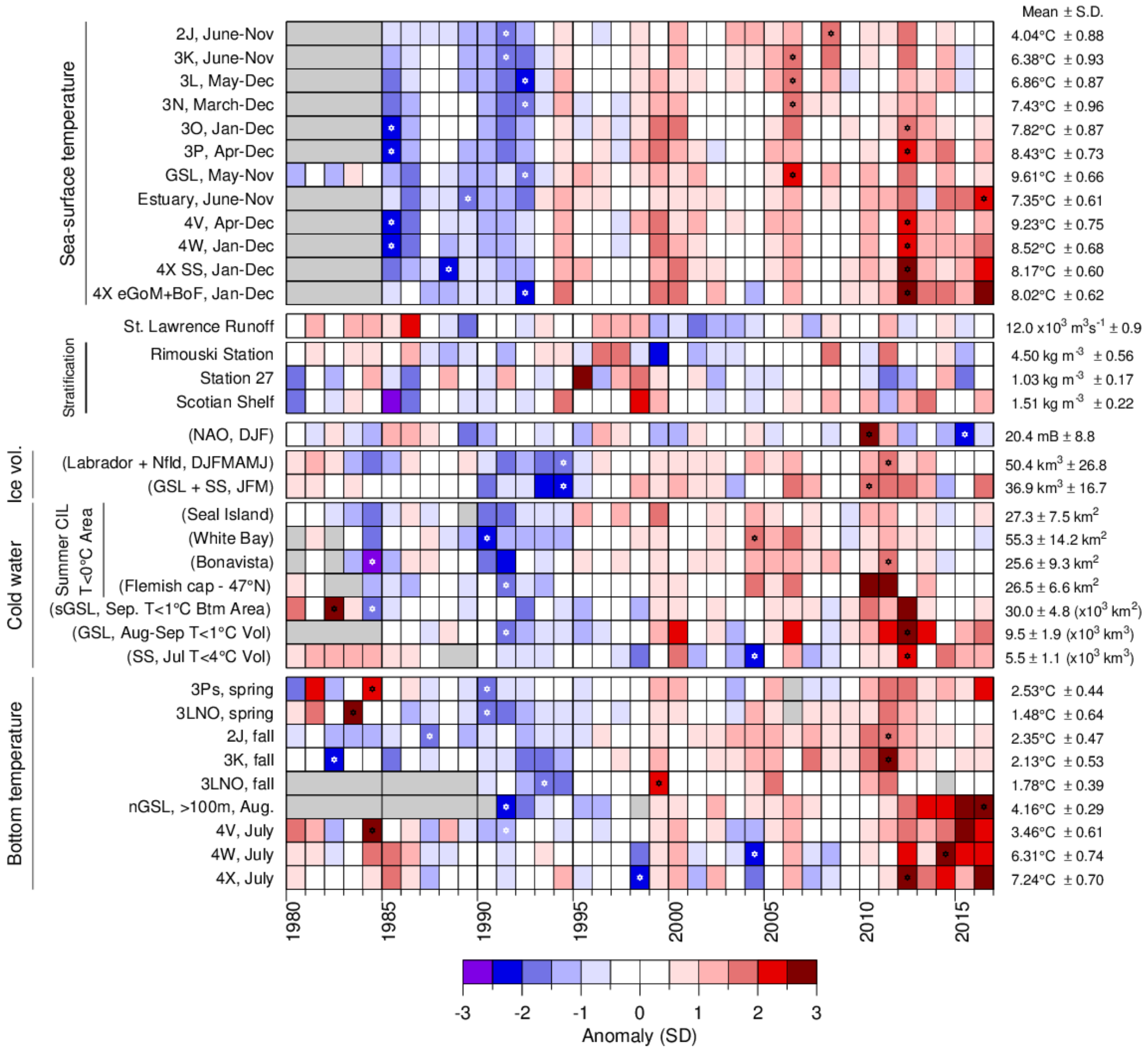

Figure 3.2-3. Time series of oceanographic variables (1980–2016). Grey cells indicate missing data; white cells have a value within 0.5 standard deviation of the long-term mean based on data from 1981 to 2010 when possible; red cells indicate above-normal conditions; and blue cells indicate below-normal conditions. Variables with names in parentheses have reversed colour coding, whereby reds are below-normal values that correspond to warm conditions. More intense colours indicate larger anomalies. Series minima and maxima are indicated by a star when they occur in the displayed time span. Long-term means and standard deviations are shown on the right side of the figure. Sea-surface temperature for the GSL (1980–1984) is based on an air temperature proxy. Stratification is expressed as the water density difference between 0 and 50 m. NAO: North Atlantic Oscillation, GSL: Gulf of St. Lawrence, SS: Scotian Shelf, sGSL: southern Gulf of St. Lawrence, nGSL: northern Gulf of St. Lawrence, cold intermediate layer CIL. Refer to Figure 3.2-1 (right panel) for NAFO Divisions within Atlantic Canada.

Cold intermediate layer

The CIL indices representing the volume of cold water are shown in Figures 3.2-2 and 3.2-3. For the Newfoundland and Labrador Shelves, the indices are the cross-sectional areas of waters with T<0°C during summer along the Seal Island, White Bay, Bonavista, and Flemish Cap AZMP sections (see Figure 3.2-1; Colbourne et al. 2017). For the Gulf of St. Lawrence, the CIL volume with T<1°C observed from August–September is used (Galbraith et al. 2017). Since the CIL reaches the bottom of the Magdalen Shallows in the southern Gulf of St. Lawrence, the area of the bottom occupied by waters colder than 1°C during the September survey is also used as a CIL index specific to that area (Galbraith et al. 2017). On the Scotian Shelf, the volume of water having T<4°C in July is used. Limited data prior to 1990 is compensated for by the use of a five-year running mean to achieve extended temporal coverage; however, this results in a loss of high-frequency variability from that part of the time series (Hebert et al. 2018). The CIL indices reported here are taken at about the same time within their respective annual cycles, although not simultaneously.

CIL volumes reached record lows in 2012 for both the Gulf of St. Lawrence and Scotian Shelf, representing record warm conditions. While conditions were warmer than normal in the Newfoundland and Labrador sections in 2013, they were followed by mostly near-normal conditions from 2014 to 2016.

Sea ice

Because the CIL and sea-ice cover are both formed in winter, it is not surprising that indices for both are well correlated with each other and with winter air temperature. On the Newfoundland and Labrador Shelves, seasonal average sea-ice volume is correlated with the CIL area along the Bonavista section (1981–2016, $R^2 = 0.58$) and with December-March air temperature at Cartwright (1981–2016, $R^2 = 0.59$). In the Gulf of St. Lawrence, the correlation between the December-March air temperature averaged over multiple meteorological stations and the annual maximum ice volume reaches $R^2 = 0.73$ (1969–2016). Air temperature is similarly well correlated to sea-ice cover area and duration ($R^2 = 0.74$–0.83). Sensitivity of the Gulf of St. Lawrence ice cover to climate change can be therefore estimated using past patterns of change in winter air temperature and sea-ice features, which indicate losses of 17 km^3, 30,000 km^2, and 14 days of sea-ice season for each 1°C increase in winter air temperature (Galbraith et al. 2017).

For the past decade, ice volumes on the Newfoundland and Labrador Shelves, the Gulf of St. Lawrence, and the Scotian Shelf have generally been lower than normal, reaching record low values in the Gulf of St. Lawrence in 2010 and on the Newfoundland and Labrador Shelves in 2011. In the seven-year period between 2010 and 2016, the Gulf of St. Lawrence average sea-ice volume had five of the seven lowest values of the series, and the Newfoundland and Labrador Shelves had three of the seven lowest.

Deep-water temperature

Interdecadal changes in temperature, salinity, and dissolved oxygen of the deep waters of the Gulf of St. Lawrence, Scotian Shelf, and Gulf of Maine are related to the varying influence of their source waters: cold–fresh/high-dissolved-oxygen Labrador Current water and warm–salty/low-dissolved oxygen Slope Water (McLellan 1957; Lauzier and Trites 1958; Bugden 1991; Gilbert et al. 2005). The deep water layer of the Gulf of St. Lawrence below the CIL, between 150 and 540 m, originates from an inflow at the entrance of the Laurentian Channel. This inflow circulates towards the heads of the Laurentian, Anticosti, and Esquiman Channels, taking as long as three to four years to travel from the entrance of the Laurentian Channel, with limited exchange with shallower upper layers (Bugden 1991; Gilbert 2004). The deep layer of the GSL is characterized by temperatures between 1°C to, recently, just above 7°C and salinities between 32.5 and 35. Similarly, deep channels of the Scotian Shelf and Gulf of Maine cut into the shelves from the shelf break to connect the deeper areas to the slope waters. Petrie and Drinkwater (1993) showed that water mass characteristics of the Scotian Shelf deep basins were strongly influenced by variations in the westward transport of Labrador Slope Water from the Newfoundland region along the shelf break. Increased transport of Labrador Slope Water through Flemish Pass was associated with below-normal deep temperatures and salinities on the Scotian Shelf and in the Gulf of Maine. Deep basins, such as Emerald Basin, undergo very large interannual and interdecadal variability of the bottom-water temperature associated with deep renewal events. More regular changes associated with circulation are observed in bottom-water temperature over the central and eastern Scotian Shelf (NAFO Divisions 4W and 4Vs, respectively; refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada). Bathymetry in these areas is fairly evenly distributed between 30 m and 170 m, with some 400–450 m depths in the Laurentian Channel included in 4Vs. Both these areas are therefore affected somewhat by CIL waters as well as the waters below the CIL.

Deep-water temperature time series are shown in Figures 3.2-2 and 3.2-3 for many of the sites shown in Figure 3.2-1. There were no negative anomalies recorded during the 2012–2016 period. Newfoundland and Labrador Shelves were characterized by above-normal bottom temperatures in the first half of this period with some near-normal averages in the later half and all anomalies were above normal on the Scotian Shelf and the northern Gulf of St. Lawrence. Series records were recorded during this period in the central (4W) and western (4X) Scotian Shelf, a 33-year record in southern Newfoundland (3Ps) as well as a 100-year record in the northern Gulf of St. Lawrence (4S and 4R) (refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada).

Figure 3.2-4 shows three annual composite index time series constructed as the sum of anomalies shown earlier, representing the state of different components of the system, with each time series contribution shown as stacked bars. The components describe sea-surface and bottom temperatures as well as the CIL and sea-ice volume which are both formed in winter. These composite indices measure the overall state of the climate system with positive values representing warm conditions and negative values representing cold conditions (e.g., less sea ice and CIL areas and volumes are translated to positive anomalies). The plots also give a sense of the degree of coherence between the various metrics of the environmental conditions and different regions across the zone. During the 2012–2016 period, CIL and sea-ice conditions alternated between warmer-than-normal and near-normal conditions. However, the surface temperature composite index and bottom-water temperature composite were well above normal every year, with a series record in the surface temperatures and series record and second place in the bottom temperatures, including a 100-year record in the northern Gulf of St. Lawrence.

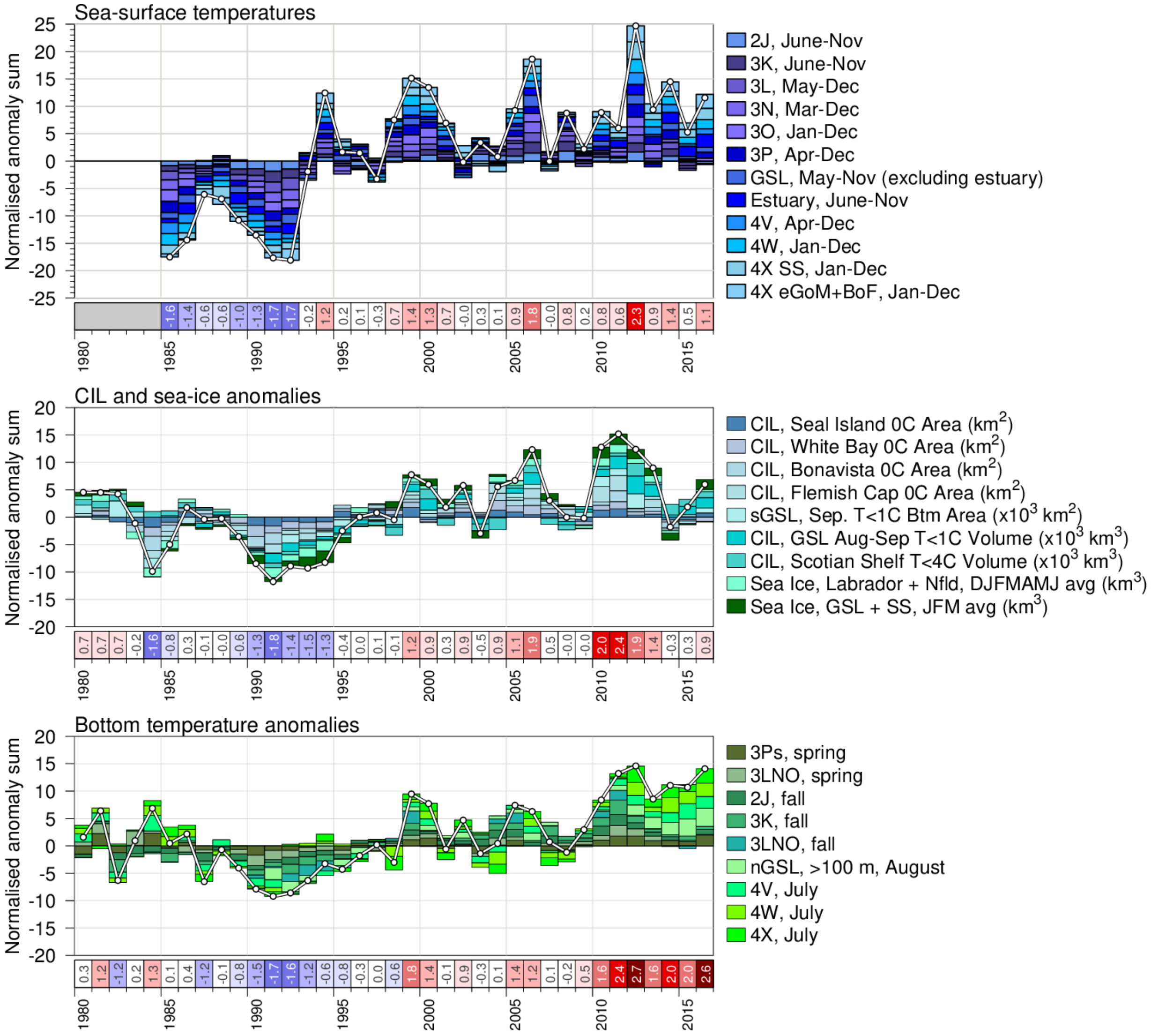

Figure 3.2-4. Composite climate indices (white lines and dots) derived by summing various standardized anomalies from different parts of the environment; coloured boxes stacked above the abscissa are positive anomalies, below are negative. Top panel sums sea-surface temperature anomalies; middle panel sums cold intermediate layer and sea-ice anomalies with areas and volumes in reversed scale (positive anomalies are warm conditions); and bottom panel sums bottom temperature anomalies. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada mentioned in legends.

Hypoxia in the GSL

During the approximately three to four years that it takes for deep waters from the mouth of the Laurentian Channel to travel to the channel heads in the St. Lawrence Estuary, the dissolved oxygen content progressively declines from respiration and oxidation of organic material. Therefore, the lowest levels of dissolved oxygen are found in the deep waters at the head of the Laurentian Channel in the estuary. These waters were briefly hypoxic (value of 100 µmol l^{-1} corresponding to approximately 30% saturation) in the early 1960s and have consistently been hypoxic since 1984 (around 20% saturation in recent years) (Figure 3.2-5). The lowest annual average was observed in 2016 at 54.1 µmol l^{-1}, corresponding to 18% saturation. Some of the variability in dissolved oxygen is associated with changing influence of water masses; the correlation between higher temperatures and lower dissolved oxygen time series in the St. Lawrence Estuary accounts for 74% of the variance in dissolved oxygen (see Figure 3.2-5), the temperature at 300 m in the estuary is also shown in Figure 3.2-5. Other factors influencing oxygen variability include interannual changes in the loading and sinking of organic matter to the bottom waters of the Lower St. Lawrence Estuary.

Acidification

The accumulation of anthropogenic CO_2 in the atmosphere and its gradual invasion into the surface ocean has led to an increase in CO_2 in the ocean and a decrease in pH. This increase in acidity makes the water more corrosive to calcium carbonate which is required for the skeleton and shells of many organisms including molluscs, crustaceans, corals and echinoderms. Associated with this is an increase in the physiological stress on these organisms.

In the waters immediately adjacent to the Newfoundland Shelf (Labrador Sea), there has been a near-linear decrease in pH from 1993 to present at a rate of about 0.02 pH units per decade. On the Scotian Shelf there has also been a decrease in pH at a rate of about 0.03 pH units per decade and the Gulf of St. Lawrence has experienced a decrease in pH of about 0.04 units per decade since 1934 (Figures 3.2-5 and 3.2-6). The rates of decrease in pH in Atlantic Canadian waters are generally higher than in other parts of the world ocean (WMO 2014).

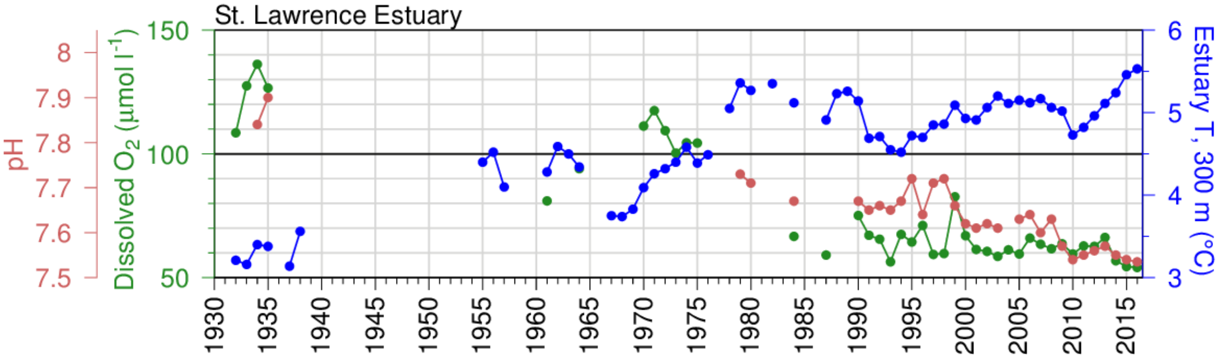

Figure 3.2-5. Acidity (pH), mean dissolved oxygen, and bottom temperature in the lower St. Lawrence Estuary between 295 m and bottom in the deep central portion of the Estuary. The horizontal line corresponds to roughly 30% saturation in dissolved oxygen (µmol l^{-1}) and marks the threshold of hypoxic conditions. The mean dissolved oxygen data (Galbraith et al. 2017) are an update to the time series presented in Gilbert et al. (2005). The Gulf of St. Lawrence Estuary pH data are from Michel Starr (DFO) and from Mucci et al. (2011).

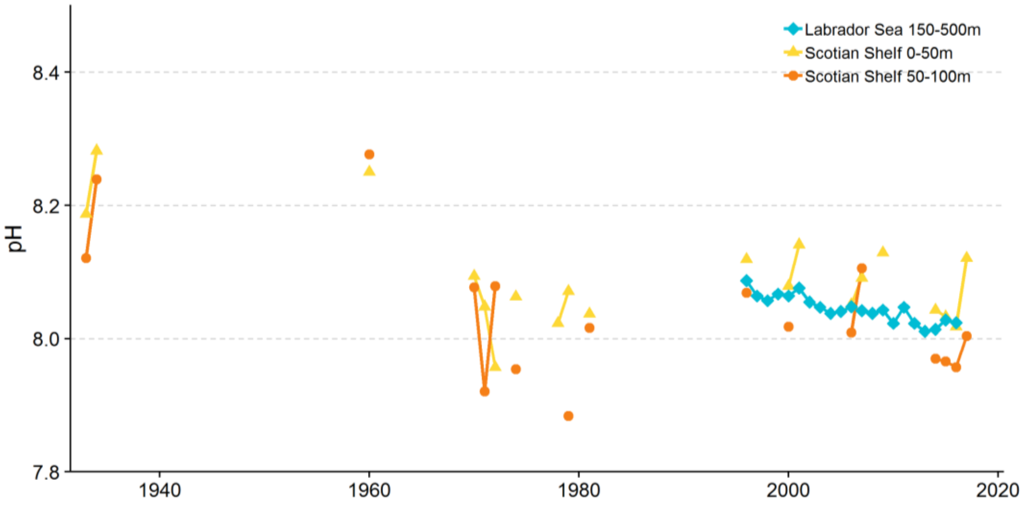

Figure 3.2-6. Acidity (pH) in the Labrador Sea (Newfoundland and Labrador Shelves) and Scotian Shelf. The pH data for the Labrador Sea and Scotian Shelf are from Kumiko Azetsu-Scott (DFO).

Runoff

Freshwater runoff in the Gulf of St. Lawrence, particularly within the St. Lawrence Estuary, strongly influences the circulation, salinity, and stratification (and hence upper water-layer temperatures) in the Gulf and, via the Nova Scotia Current, on the Scotian Shelf. The interannual variability of the seasonal (May–October) stratification (0–50 m) at the AZMP Rimouski Station in the St. Lawrence Estuary is strongly correlated with the seasonally averaged freshwater runoff of the St. Lawrence River (1991–2017; $R^2 = 0.71$). Runoff into the St. Lawrence Estuary decreased between the early 1970s and 2001, followed by an increasing trend between 2001 and 2011 and has been fairly stable from 2012 to 2016 (Figure 3.2-3). Combined with tidal and wind mixing, the runoff drives the estuarine circulation in the St. Lawrence Estuary and, to a lesser extent, in the whole GSL.

Stratification

Vertical stratification in the water column is considered to affect physical mixing properties and biological processes related to, for example, the sinking of plankton and the upward mixing of nutrients. A long-term stratification index has been created based on the density difference between the surface and 50 m (Figures 3.2-3 and 3.2-7).

At the AZMP Station 27 located off St. John's, stratification increased from below-normal values in the mid-1960s to a record high in 1995 and has been following a mostly decreasing trend since (Colbourne et al. 2017). Since 1948, there has been an increase in the mean stratification on the Scotian Shelf, resulting in a change in the 0-50 m density difference of 0.36 kg m^{-3} over 50 years. This change in mean stratification is due mainly to a decrease in the surface density (76% of the total density change), composed equally of warming and freshening (Hebert et al. 2018). As stated above, stratification in the St. Lawrence Estuary is tied to seasonal fresh water runoff and has followed a similar pattern.

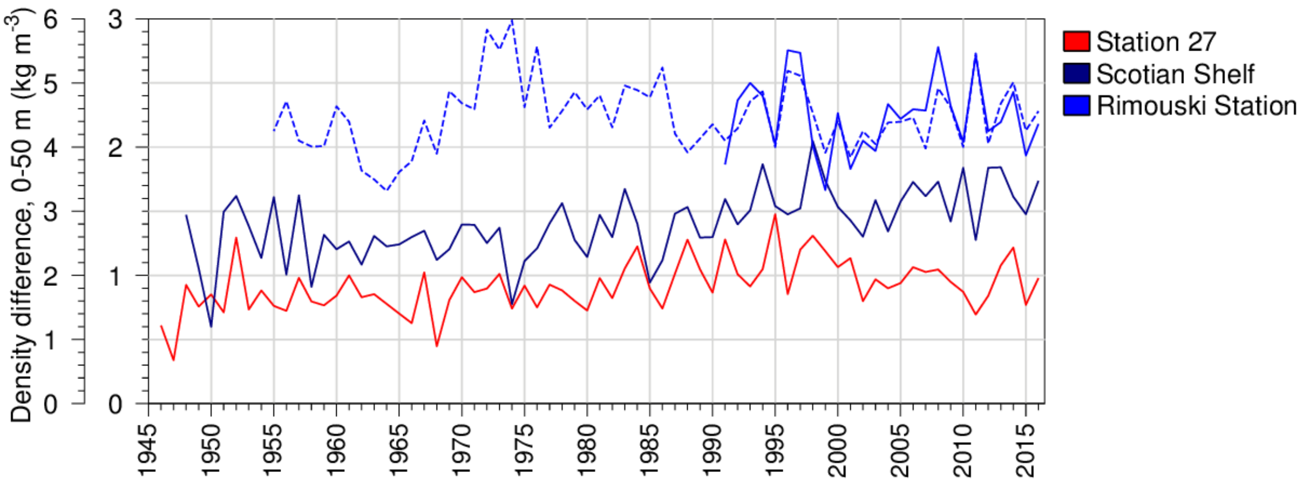

Figure 3.2-7. Stratification trends on the southern Newfoundland and Labrador Shelves (at Station 27), Scotian Shelf, and St. Lawrence Estuary (Rimouski Station). The dashed line for Rimouski Station is a proxy based on freshwater runoff. Refer to figure 3.1-1for location of place names.

The North Atlantic Oscillation

The North Atlantic Oscillation (NAO) index—a measure of the atmospheric surface pressure difference between the equatorial and North Atlantic regions—quantifies the dominant winter atmospheric forcing over the North Atlantic Ocean. It affects winds, air temperature, precipitation, and hydrographic properties on the eastern Canadian seaboard either directly or through advection. Strong northwesterly winds, cold air and sea temperatures, and heavy ice in the Labrador Sea area are usually associated with a high positive NAO index, with weaker winds and opposite effects occurring with a negative NAO index (Colbourne et al. 2017).

Changes in physical properties in Atlantic Canadian waters have been found to be related to the NAO. For example, Petrie (2007) found a relationship between changes in bottom-water temperatures and the NAO. However, there is growing evidence that in the last 15 years the NAO has become a less powerful predictor of ocean properties in the Canadian Atlantic zone. For illustrative purposes, the NAO time series is included in Figure 3.2-3 (Colbourne et al. 2017). Highlights include both the series record high (2015) and low (2010) occurring in the last decade.

Mean Sea Level

Observed local relative sea level (RSL) is influenced by ocean warming and dynamic adjustment, land-ice melt, and vertical land motion. In eastern Canada, vertical land motion associated with the post-glacial isostatic adjustment of the continent differs in the meridional direction, with the continent sinking in the south (e.g., Halifax and Saint John) and rising in the north (e.g., Harrington Harbour and Nain) (Peltier 2004). The combined mechanisms give rise to significant spatial changes in the mean RSL trend (Han et al. 2014; Figure 3.2-8). In the southern area, the RSL is rising with rates from 2 to 4 mm per year (e.g., North Sydney, Halifax, Yarmouth, Saint John, Charlottetown, St. John's, Argentia, and Port aux Basques) and falling in the north at a rate of 2 mm per year (e.g., Nain). Along the northern Gulf of St. Lawrence coast, the RSL rates change from negative (falling) at Harrington Harbour to positive (rising) at Sept-

Îles. Although the rates also change sign at Rimouski and Quebec City in the southern St. Lawrence Estuary, they are not different from zero at the 95% confidence level. These results suggest that the magnitude of the historical long-term RSL trend is small along the northern Gulf of St. Lawrence and in the St. Lawrence Estuary. Although not statistically significant, there also appears to be some acceleration of the sea level rise at some locations. For example, the RSL trend at Halifax is about 5 mm per year over 1993–2011 and 3 mm per year over 1895–2011.

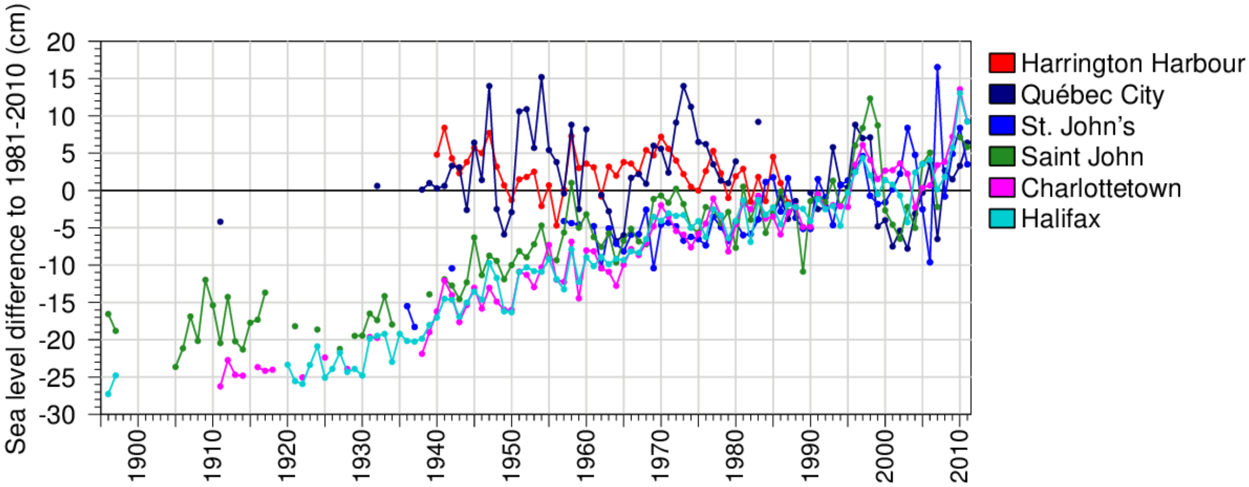

Figure 3.2-8. Annual mean of relative sea level at six sites across the Atlantic zone. Values are differences with respect to the 1981–2010 mean for each series. Refer to figure 3.1-1for location of place names.

Summary

Surface oceanic water temperatures in the Atlantic zone have been mostly tracking the climate-change driven warming trends observed in the atmosphere during ice-free months. Overall for the zone, two (2012 and 2014) of the five warmest years of the satellite record for measurements of sea-surface temperature have occurred during the 2012 to 2016 five-year period. Warming winters have also led to less sea-ice cover and weaker cold intermediate layers. The 2012 to 2016 period was characterized by record lows in 2012 for both the Gulf of St. Lawrence and Scotian Shelf CIL volumes, representing record warm conditions. For the past decade, ice volumes on the Newfoundland and Labrador Shelves, in the Gulf of St. Lawrence and on the Scotian Shelf have generally been lower than normal reaching a record-low value in the Gulf of St. Lawrence in 2010 and on the Newfoundland and Labrador Shelves in 2011.

The deep-water temperatures on the Scotian Shelf and in the Gulf of St. Lawrence are greatly influenced by an increasing proportion of Gulf Stream Current relative to Labrador Current. While the Newfoundland and Labrador Shelves were characterized by above-normal bottom temperatures in the first half of 2012-2016, with some near-normal averages in the later half, all anomalies were above normal on the Scotian Shelf and the northern Gulf of St. Lawrence during this time period. Series records were recorded during this period in central (4W) and western (4X) Scotian Shelf, a 33-year record in 3Ps (south of Newfoundland to the west of the Grand Banks) as well as a 100-year record in the northern Gulf of St. Lawrence (4S and 4R). The greater influence of Gulf Stream Water and associated warmer temperature is also contributing to increasing hypoxic conditions (low dissolved oxygen concentrations) in the St. Lawrence Estuary. The deep waters of the St. Lawrence Estuary were briefly hypoxic in the early 1960s and have consistently been hypoxic since 1984. Dissolved oxygen decreased to its lowest annual average in 2016, corresponding to 18% saturation.

The accumulation of anthropogenic CO_2 in the atmosphere and its gradual invasion into the surface ocean has led to an increase in CO_2 in the ocean and a decrease in pH. The rates of decrease in pH in Atlantic Canadian waters are generally higher than in other parts of the world ocean. Record low values were recorded in the St. Lawrence Estuary in 2016.

3.2.2 Lower trophic levels

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Introduction

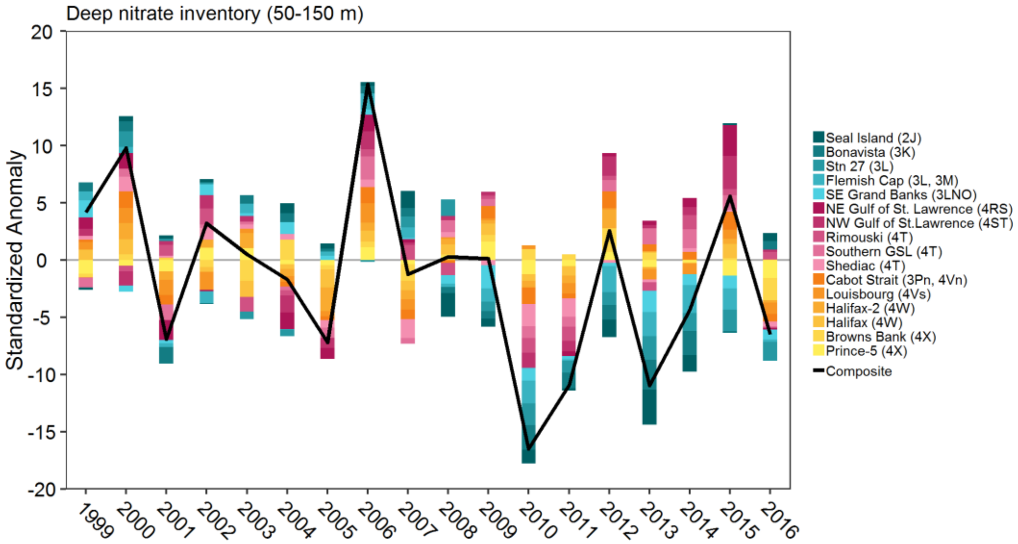
Lower trophic levels are the components of marine food webs that channel the sun’s energy to upper trophic level animals, such as shellfish (e.g., crabs, lobsters, scallops, and mussels), finfish (e.g., cod, herring, and halibut), marine mammals (e.g., seals and whales) and seabirds. Lower trophic level organisms include phytoplankton and zooplankton. Phytoplankton are microscopic plants that occupy a position in the marine food web similar to that of plants on land. Zooplankton are a broad variety of small animals ranging from 0.2 to 20 mm in length that drift with ocean currents. There is a wide variation in the size of phytoplankton, from large diatoms to the smaller flagellates, each taxon fulfilling a different ecological function. Phytoplankton are the primary food source for zooplankton, which are the critical link between phytoplankton and larger organisms. There are many types of animals in the zooplankton community, such as copepods, gelatinous filter-feeders and predators, and ephemeral larval stages of bottom-dwelling invertebrates. As with phytoplankton, there is a broad range of sizes of zooplankton. Smaller stages and species are the principal prey of young stages of fish and larger copepods are eaten predominantly by juvenile and adult fish that forage near the surface. However, because copepods are the dominant zooplankton group by number and biomass in the western North Atlantic, this section will focus only on patterns of change in copepod abundance.

Productivity of marine ecosystems depends on photosynthesis, the synthesis of organic matter from carbon dioxide and dissolved nutrients by phytoplankton. Light provides the energy necessary for the transformation of inorganic elements into organic matter. The growth rate of phytoplankton is dependent on the availability of light and nutrients in the form of nitrogen (nitrates, nitrites, and ammonium), phosphorous (phosphate), and silica (silicate), with the latter being essential for production of diatoms. In continental shelf waters, nitrate, the dominant form of nitrogen, is usually the limiting nutrient for phytoplankton growth. Phytoplankton undergoes a spring–summer explosion in abundance known as the spring bloom. The spring bloom occurs principally in near-surface waters in the mixed layer, the depth range in which physical properties of the water are relatively similar but separated from the deeper ocean by a sharp gradient in density called the pycnocline. The magnitude of the spring bloom is partly dependent on the amount of nutrients that are mixed into surface waters over the course of the winter. Productivity during the summer is maintained through mixing and the excretion of ammonium by phytoplankton and zooplankton. The characteristics of the bloom (amplitude, magnitude, timing, and duration) provide important information about regional variations in ecosystem productivity and are linked to the productivity of organisms that depend on lower trophic levels. In fall, a second, less intense bloom also contributes to the functioning of the marine ecosystem.

The information reviewed in this section is derived from the Atlantic Zone Monitoring Program (AZMP) (DFO 2017; Maillet et al. 2017). Data presented below are gathered from 14 oceanographic sections that are sampled seasonally and five nearshore sites that are sampled once or twice a month. We report on the amount of nutrients available for phytoplankton, the overall abundance of phytoplankton and important features of the spring bloom, and the abundance of zooplankton species that are key prey for upper trophic level animals based on the data available from 1999 to the present.

Nutrients

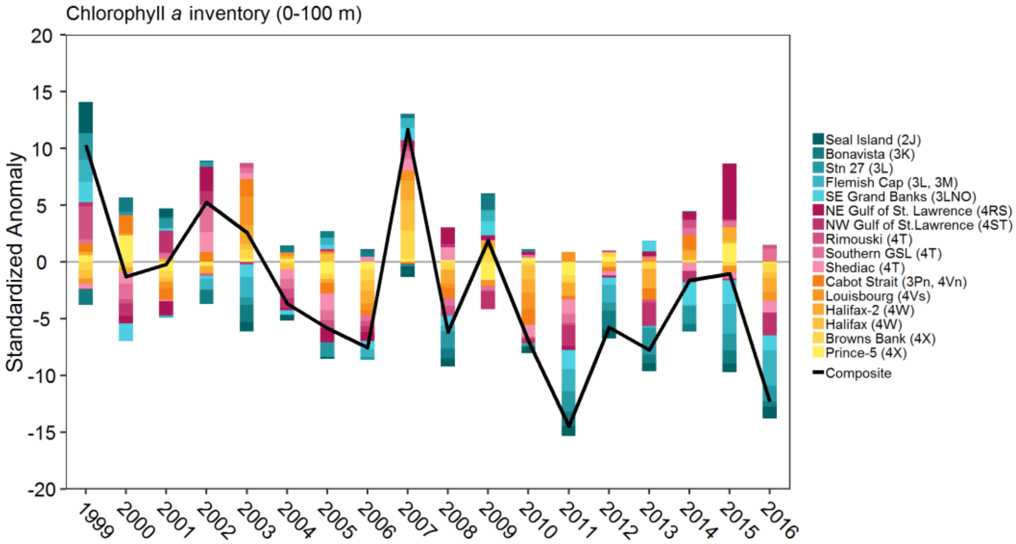
Changes in the amount of nutrients were not uniform in all parts of the Atlantic; nutrient amounts are highly variable in the short term, with frequent observations of conditions well below the long-term average in different parts of the Northwest Atlantic over the last five years. The greatest declines, which persisted until 2014/2015, occurred on the Newfoundland Shelf. Conditions in the Gulf of St. Lawrence and Scotian Shelf had more moderate shifts in nutrient concentrations over time although the most recent states are near and below normal, respectively. The amount of nitrate contained in waters below the surface mixed layer at depths of 50–150 m is called the deep water nitrate inventory. Generally, this inventory is not greatly influenced by the growth of phytoplankton, so it provides a good indicator of resources that can be mixed into the water column during winter or summer and fall through upwelling to become available for phytoplankton growth. Nitrate inventories, and the relative abundances of other nutrients, are mostly dependent on the source waters that make up the deep water on continental shelves, which can vary from year to year. Deep water inventories of nitrate show patterns of variation in the Atlantic characterized by a general declining trend from 1999 to 2010, when a minimum was reached, followed by a general return to average conditions from 2010 to 2016 (Figure 3.2-9).



3.2-9. Summary of nitrate inventories (combined nitrate and nitrite, which represents the principal limiting nutrient for phytoplankton growth) in the lower water column (50–150 m or bottom if shallower) from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program from 1999 to 2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999–2010) divided by the standard deviation for each oceanographic section. Each section is identified based on DFO (2017) along with the North Atlantic Fisheries Organization Subareas; the solid line represents the composite index, which is the sum of the anomalies for each year. The contribution from each section is represented by colour and height of the vertical bar. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

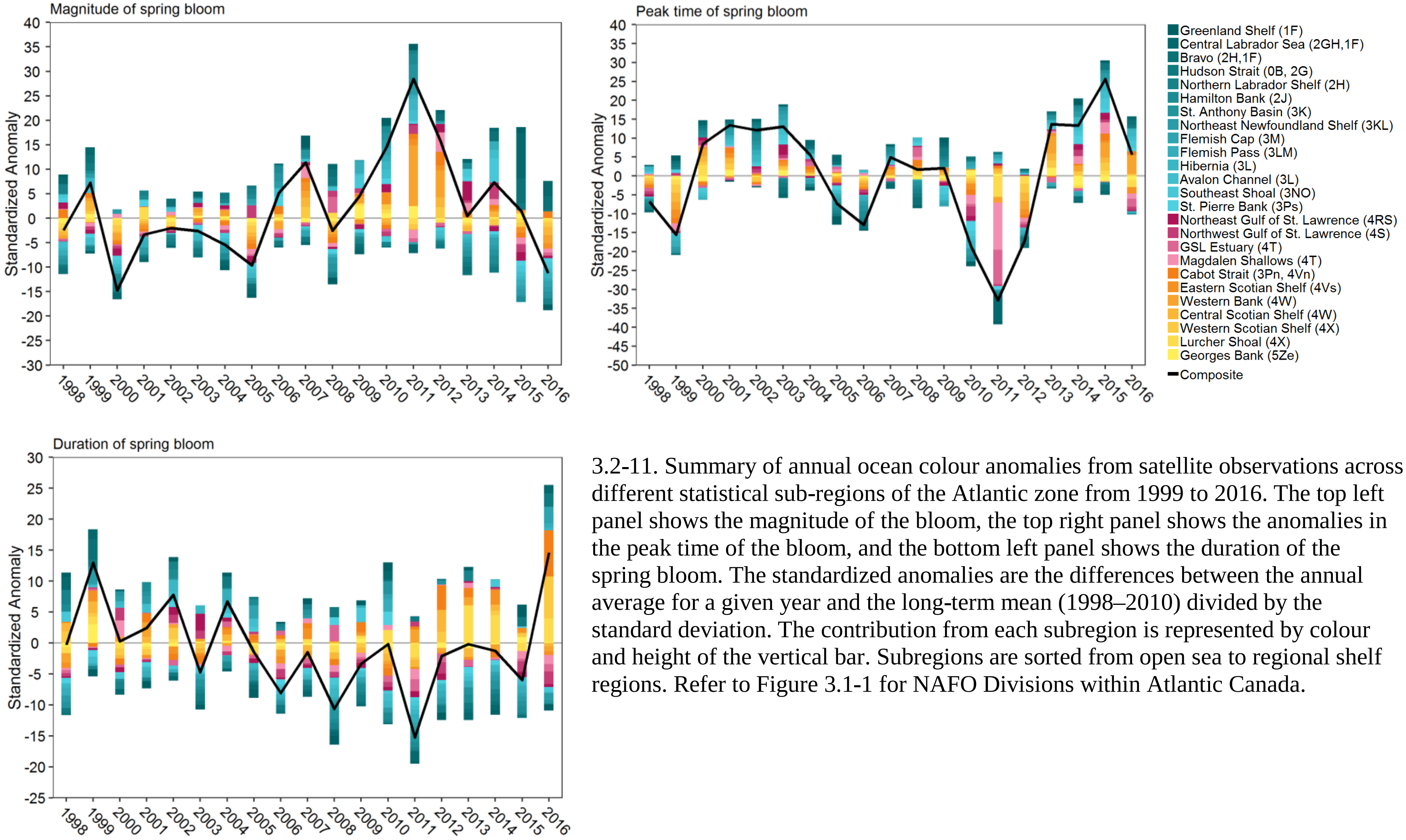
Phytoplankton

Chlorophyll inventories in the upper ocean (0–100 m) represent phytoplankton biomass. These demonstrated a high degree of year-to-year variability, including exceptional values either above or below the long-term average (3.2-10). The general trend has seen a gradual decline in overall phytoplankton abundance in the Atlantic. There was a general decline from 1999 to a minimum in 2011 followed by a gradual recovery to average conditions in 2015, but in 2016, most parts of the region had phytoplankton levels well below normal. Conditions were generally below average in 2016 in all regions. Patterns of variation in phytoplankton abundance are generally similar to what was reported for deep nitrate inventories, but they lag behind nutrient variability by about one year. Although the relationship is weak and explains only 23% of the variation in the data, the link between available nutrients and the standing stock of phytoplankton is noteworthy.



3.2-10. Summary of chlorophyll inventories (representing phytoplankton biomass) in the upper water column (0–100 m or bottom if shallower) from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program from 1999 to 2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999–2010) divided by the standard deviation for each oceanographic section. Each section is identified based on DFO (2017) along with the North Atlantic Fisheries Organization Subareas; the solid line represents the composite index which is the sum of the anomalies for each year. The contribution from each section is represented by colour and height of the vertical bar. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

There have been relatively consistent patterns of variation in the features of the spring phytoplankton bloom across the Northwest Atlantic (Figure 3.2-11). The magnitude of the spring bloom increased from 1999 to 2011, when it reached its highest peak then declined to an average state by 2016. Spring bloom amplitude, which is not shown, varied in a similar pattern. The day of year at which the bloom reaches its maximum amplitude (peak time) has been more variable from year to year than the bloom amplitude, shifting from either generally early or late relative to normal over periods of 3 to 5 years. During the very warm 2010–2012 period, spring phytoplankton blooms were early, but the subsequent gradual cooling of ocean conditions appears to have resulted in a general delay in the onset of the bloom from 2013–2016. Duration of the bloom varies greatly among the different parts of the Northwest Atlantic. However, there was a general decline in the overall duration of the bloom from 1999 to 2011 after which it returned to near normal from 2012 to 2015, followed by a record peak in 2016. Many environmental features contribute to the initiation and seasonal progression of the spring bloom, notably the rate of warming, strength of winds, mixing and stability of the water column’s density, ice cover extent and duration, and the nutritive content of deep water masses. Therefore, the features of the bloom in any part of the Atlantic are impacted by the combined effects of broad scale longer-term trends in the physical environment and local or regional conditions that vary on shorter time scales. The variability of spring bloom parameters (e.g., amplitude, magnitude, timing, and duration) will likely have different consequences on other organisms of higher trophic levels (i.e., zooplankton, fish, marine mammals, seabirds) in the Northwest Atlantic ecosystem, and these consequences are under investigation (refer to case studies 4.4 and 4.7 of this report).



3.2-11. Summary of annual ocean colour anomalies from satellite observations across different statistical sub-regions of the Atlantic zone from 1999 to 2016. The top left panel shows the magnitude of the bloom, the top right panel shows the anomalies in the peak time of the bloom, and the bottom left panel shows the duration of the spring bloom. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998–2010) divided by the standard deviation. The contribution from each subregion is represented by colour and height of the vertical bar. Subregions are sorted from open sea to regional shelf regions. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

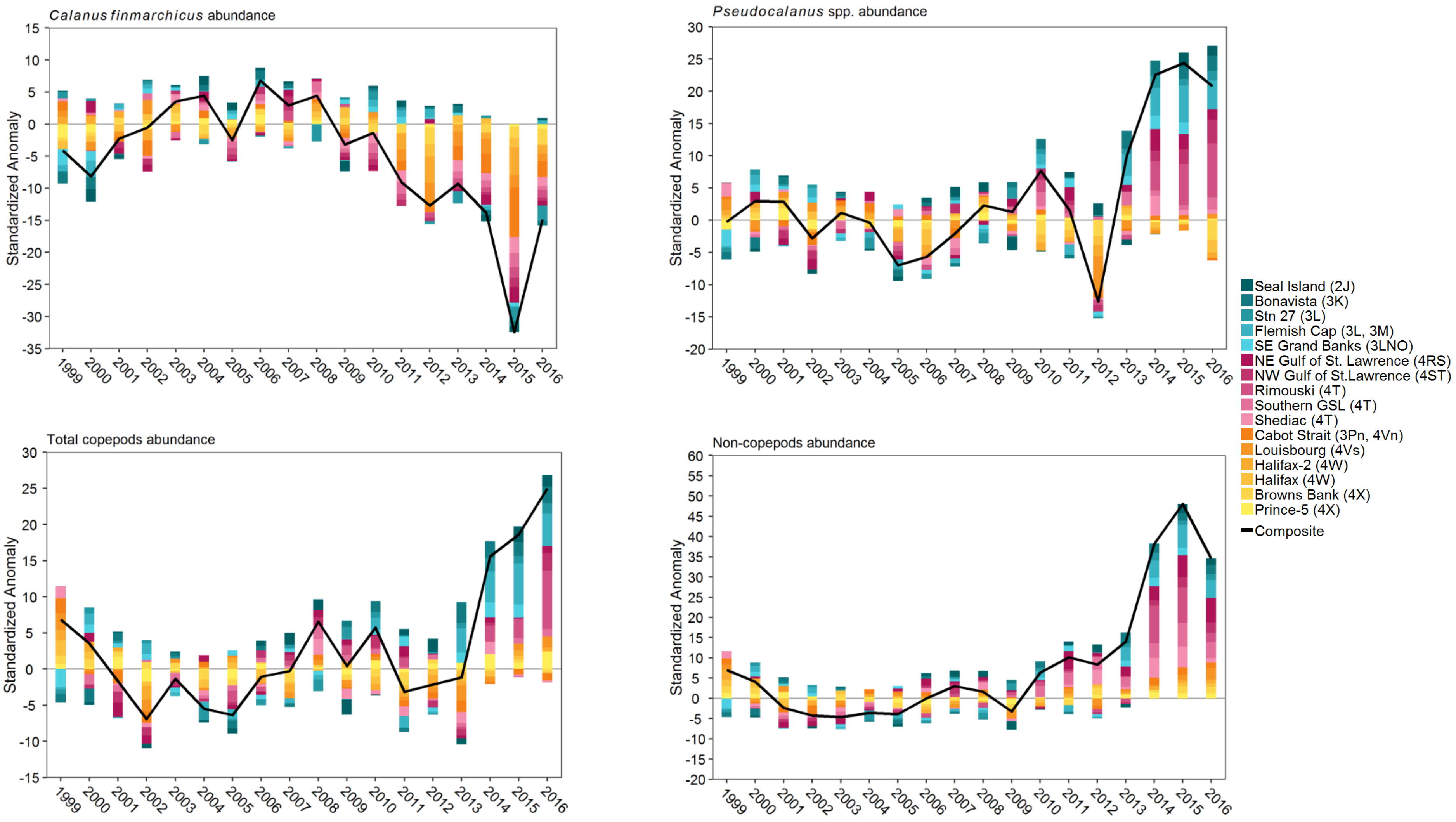
Zooplankton

Zooplankton community structure is strongly influenced by depth, temperature, and season, and the complexity of the community differs substantially among the three bioregions of the Northwest Atlantic. Despite its complexity and diversity in different parts of the region, four indices of abundance provide good indicators of the state of the zooplankton community. Zooplankton abundance indices demonstrate a high degree of large spatial scale coherence in their signal across different parts of the Atlantic zone. Two copepod taxa serve to represent different broad groups with similar life histories: *Calanus finmarchicus* and *Pseudocalanus* spp. *Calanus finmarchicus* is a large, ubiquitous copepod that develops large energy reserves in later developmental stages and is therefore a rich source of food for pelagic fish and a dominant species by biomass throughout much of the region. *Pseudocalanus* spp. are small copepods that are widespread throughout the Atlantic zone and individually have much smaller energy reserves relative to *C. finmarchicus*, but their life history features are generally representative of smaller taxa in the copepod community. The other indices provide information on the total abundance of copepods and non-copepod taxa.

A zooplankton community shift has been observed in recent years, characterized by lower abundance of the large energy-rich copepod *C. finmarchicus*, higher abundances of small and warm-water copepods, and higher abundance of non-copepods (Figure 3.2-12). The strongest negative anomalies in *C. finmarchicus* occurred on the Scotian Shelf, closest to the southern edge of its range in the Gulf of Maine. In general terms, the abundance of *C. finmarchicus* has been in decline since 2009 as has the abundance of two similar Arctic *Calanus* species. In contrast, the abundance of *Pseudocalanus* spp. has demonstrated a general pattern of increase during at least a decade. Despite a drop to very low abundance levels in 2012, it reached record abundance throughout much of the Atlantic zone. Total copepod abundances have also increased to higher than normal levels since 2014. Non-copepod zooplankton, which are much less abundant than copepods and consist mostly of larval stages of benthic invertebrates, carnivorous groups that feed on other zooplankton, and small-particle feeders, were consistently above average throughout the zone starting in 2010, with record high values observed in all three bioregions since 2014. The strongest positive anomalies in *Pseudocalanus* spp. and non-copepods occurred in the Gulf of St. Lawrence and on the Newfoundland Shelf; total copepod positive anomalies were strongest on the Newfoundland and Labrador Shelves and in the Gulf of St. Lawrence. Overall, these recent changes in zooplankton community structure (e.g., shifts in abundance of copepod species and relatively greater increase in abundance of non-copepods versus that of copepods) indicate that important shifts in the flow of energy among lower trophic levels of the marine ecosystem in Atlantic Canadian waters are taking place, but the consequences to higher trophic levels will require further investigation.

Summary

Overall, there appear to have been important changes in general patterns of productivity of lower trophic levels in the last five years. General declines in nutrient and chlorophyll inventories may be indicative of lower ecosystem production potential than in the previous decade and the shift in zooplankton community structure from large lipid-rich copepods to smaller taxa may have consequences for the transfer efficiency from primary producers to upper trophic levels.



3.2-12. Time series of dominant copepods *Calanus finmarchicus* (upper left panel), *Pseudocalanus* spp. (upper right panel), total copepod (lower left panel) and non-copepod (lower right panel) abundance anomalies from different oceanographic transects and fixed stations from the Atlantic Zone Monitoring Program from 1999 to 2016. Standardized anomalies are the differences from the long-term mean (1999–2010) divided by the standard deviation. The contribution from each section is represented by colour and height of the vertical bar. The solid black line is the cumulative (composite) anomaly across all sections in a given year. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

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3.3 HABITAT, COASTAL, AND SIGNIFICANT BENTHIC AREAS

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Introduction

Atlantic Canada has diverse coastal and offshore environments that form habitat for all species. To demonstrate this diversity and the varied, important roles different habitats play in Atlantic ecosystems, we selected representative habitats from coastal to offshore (intertidal flats, eelgrass, kelp beds, corals and sponges, and sand dollars). This selection was partly based on the availability of published and peer-reviewed information. Future reports may add additional habitats as data become available. There is, in general, limited information available to assess status and trends of habitats and therefore these summaries largely focus on distribution and ecological importance.

Intertidal flats

Intertidal flats are important habitats in the Atlantic from both an ecological and socioeconomic perspective. These habitats occur just beyond the shoreline in coastal and estuarine areas and are submerged by seawater during high tide and exposed to the air during low tide. Intertidal flats are typically devoid of vegetation, although seagrasses can grow and reside on some intertidal flats. These habitats consist of soft sediments that can be classified according to the size of individual grains (Wentworth 1922); sediments found in intertidal flats are typically particles smaller than granules (2–4 mm in diameter). Because sediments can be dislodged and moved easily, the distribution and shape of intertidal flats is highly dynamic. Like other soft-sediment habitats, intertidal flats are three-dimensional, as organisms can move in both horizontal and vertical directions above and below the surface of the sediment. Typically, larger sediments are found closer to shore and smaller sediments are found further from shore. The zonation of sediments depends on the slope of the intertidal flat and the degree of wave action. In addition, organisms residing in these soft-sediment intertidal habitats can also display distinct zonation patterns driven by species tolerances to environmental conditions (Peterson 1991).

Substantial marine biodiversity resides above and below the sediment surface in intertidal flats. Animals living above the sediment are called epifauna and those below the sediment are called infauna. Epifaunal invertebrates (e.g., crabs) and vertebrates (e.g., fish and shorebirds) (DFO 1996) are found above the sediment; below the sediment live a suite of deposit- and suspension-feeding invertebrates such as bivalves, herbivorous and carnivorous gastropods, and a wide variety of worms, amphipods, isopods, and shrimp (Table 3.3-1). These animals can be an important food source for fish and seabirds and play an integral role in bioturbation—disturbing sediment at the surface and linking conditions below the sediment to those in the overlying water above the sediment (De Backer et al. 2011).

Because these habitats are submerged at high tide and exposed to the air at low tide, life can be challenging for organisms residing in intertidal flats. Most soft-sediment intertidal animals are active during high tide. During this time, many infaunal animals feed by filtering microscopic plants and animals out of the overlying water; epifaunal animals, such as crabs and fish, are also present. During low tide, many soft-sediment intertidal organisms are inactive and buried in the sediment to avoid desiccation, overheating, physiological stress caused by drastic changes in salinity. Epifaunal animals like crabs and fish most often retreat with the tide to remain submerged, but some animals, such as mudsnails (*Tritia obsoleta*), remain active.

Of the intertidal flats in Atlantic Canada, some of the most important are the mudflats of the Bay of Fundy. These mudflats are the result of erosion and deposition of sedimentary rock from the coastal bedrock and many are associated with extensive salt marshes (DFO 1996). Because of the Bay of Fundy's extreme tides, mudflats in its upper reaches extend for many kilometres and are among the largest in the world (DFO 1996). In these mudflats, amphipods like the mud shrimp (*Corophium volutator*) can reach outstanding densities (>40,000/ m^2) that vary across the mudflats (Barbeau et al. 2009). These high densities of amphipods are a major food source for migrating shorebirds and are thought to be responsible for the fact that the Bay of Fundy supports approximately 75% of the global population of semipalmated sandpipers (*Calidris pusilla*), consisting of 2–3 million birds (DFO 1996). The mudflats of the Bay of Fundy also support high densities of clams and worms which have been harvested recreationally and commercially by humans for over a century in Nova Scotia and New Brunswick (DFO 1997; Sullivan 2007). Other intertidal flats outside of the Bay of Fundy are also commercially and recreationally harvested (e.g., Scotian Shelf and the Northumberland Strait).

Table 3.3-1. Important taxa and their major roles in intertidal flats of Atlantic Canada. Note that this list is not an exhaustive list of taxa inhabitating intertidal flats, but summarizes some of the ‘most common’ taxa occurring in this habitat. * indicates non-indigenous invasive species.

Taxon	**Scientific name**	**Common name**	**Major role**
Invertebrates			
Bivalves	*Ensis directus*	Atlantic jackknife clam	Food for other species
	Macoma balthica	Baltic macoma	Bioturbation; food for other species
	Mercenaria mercenaria	hard clam	Food for other species; commercially harvested
	Mya arenaria	soft-shell clam	Food for other species; commercially harvested
	Spisula solidissima	Atlantic surf clam	Food for other species; commercially harvested
Worms	*Arenicola marina*	Lugworm	Bioturbation
	Cerabratulus lacteus	milky ribbon worm	Bioturbation; major predator of clams
	Glycera sp.	Bloodworm	Bioturbation; food for other species; commercially harvested
	Lumbrineris versicolor	Ragworm	Bioturbation; major predator of clams
	Alitta virens	sandworm; king ragworm	Bioturbation; major predator of clams
Amphipods	*Corophium volutator*	mud shrimp	Bioturbation; food for other species (NB keystone species in Bay of Fundy)
Shrimp	*Crangon septemspinosa*	sand shrimp	Bioturbation; food for other species
Gastropods	*Tritia obsoleta*	Mudsnail	Bioturbation; major grazer
	**Littorina littorea*	Periwinkle	Bioturbation; major grazer
	Euspira heros	Moonsnail	Predator of clams and other molluscs
Crabs	*Cancer irroratus*	rock crab	Major predator of infaunal animals
	**Carcinus maenas*	European green crab	Major predator of infaunal animals
Vertebrates			
Fish	*Fundulus diaphanus*	banded killifish	Major predator of infaunal animals; prey for larger fish and birds
	Fundulus heteroclitus	Mummichog	Major predator of infaunal animals; prey for larger fish and birds
	Gasterosteus aculeatus	three-spine stickleback	Prey for larger fish and birds
Birds	*Calidris pusilla*	semipalmated sandpiper	Major predator of infaunal animals (NB: 75% of global population use Bay of Fundy mudflats during migrations)
	Charadrius melodus	piping plover	Major predator of infaunal animals (NB: globally threatened and endangered)
	Charadrius semipalmatus	semipalmated plover	Major predator of infaunal animals
	Pluvialis squatarola	black-bellied plover	Major predator of infaunal animals
	Tringa flavipes	lesser yellowlegs	Major predator of infaunal animals
	Tringa melanoleuca	greater yellowlegs	Major predator of infaunal animals

A number of threats exist to organisms in intertidal flats, with climate change and disease being particularly pressing. Animals residing in these habitats are already exposed to extreme environmental conditions, but are also affected by climate change. For example, warming temperatures and eutrophication can increase algal mat densities in intertidal flats, which can alter the burrowing behaviour of commercially and ecologically important bivalves (Auffrey et al. 2004), which is likely to cause major biogeochemical changes. Warming ocean temperatures and increasingly acidic sediments can also lead to alterations in burrowing behaviours in juvenile clams, which could affect their populations and further affect biogeochemistry (Clements et al. 2016, 2017). Increasingly acidic sediments can have other impacts on infaunal bivalves as well (see Clements and Hunt 2017 for review). Similarly, ocean acidification can alter the behaviour of fish, such as three-spine sticklebacks (*Gasterosteus aculeatus*) (Jutfelt et al. 2013). Further, physical consequences of climate change, such as coastal erosion, increased storm severity, and coastal squeeze (Amos et al. 1992; Pontee 2011), can contribute to changes in sediment characteristics, the distribution and structure of intertidal flats, and the loss of intertidal flat habitat. Unfortunately, our understanding of the ecological impacts of climate change on soft-sediment intertidal flats is not well developed. Another threat to organisms in intertidal flats is disease. For example, increases in agriculture and forestry activities raise the possibility of haemic neoplasia episodes in *Mya arenaria* (Mateo et al. 2016), and paralytic shellfish poisoning has long been an issue for intertidal clams (Prakash et al. 1971). Further, human activity like altering waterways (e.g., building or destroying dams) can adversely change habitats for *M. arenaria* (Leblanc 2015). QPX, a parasite found in quahogs in the area, is temperature sensitive; more studies linking environmental factors and QPX infection are necessary (Perrigault et al. 2010). The impact of disease in these habitats may be affected by climate change (Marcogliese 2008), but studies specific to the Atlantic zone are lacking. Finally, aquatic invasive species, such as the predatory European green crab (*Carcinus maenas*), also pose a threat to inhabitants of intertidal flats (Klassen and Locke 2007).

Eelgrass

Eelgrass (*Zostera marina* (L.)) is a common perennial or, in some cases, annual (Keddy and Patriquin 1978) aquatic plant that can form extensive intertidal and subtidal meadows in estuaries and coastal bays along the southern Arctic coast (James Bay) and the Atlantic coast from Labrador in Canada to North Carolina in the United States. Eelgrass is an angiosperm; a flowering plant that reproduces from flowers and seeds, but it also reproduces vegetatively from below by means of ground rhizomes. An annual variety of eelgrass grows in some intertidal mudflats and occurs in areas where ice scour is greatest, thus plants overwinter as seeds instead of investing energy into a below ground root system (ground rhizomes) (Robertson and Mann 1984; Vandermeulen 2005).

Eelgrass is found in estuaries, lagoons, and coastal bays in Atlantic Canada and Quebec. In New Brunswick, it occurs primarily along the Gulf of St. Lawrence and is mostly absent from the Bay of Fundy, possibly due to turbid conditions and large tides. In Nova Scotia, eelgrass is found along both the Gulf of St. Lawrence and Atlantic coastlines (DFO 2009). Eelgrass is distributed along the entire coastline of Prince Edward Island. In Quebec, eelgrass beds are geographically distributed throughout the St. Lawrence Estuary and Gulf of St. Lawrence (Martel et al. 2009). The westernmost eelgrass beds lie in the upper estuary near Baie-Saint-Paul. There are a few large eelgrass beds, such as the one in Manicouagan Peninsula (>1400 ha), that are well documented (Grant and Provencher 2007). In Newfoundland, eelgrass is distributed around the entire island with the greatest abundance on the southwest coast, where there is more suitable habitat for its growth. Aerial surveys and groundtruthing have been conducted in Newfoundland in several locations, but the information is incomplete and largely unquantified (Rao et al. 2014). Information on general eelgrass distribution is based on interpretation of air photos and satellite images (by aerial and boat surveys) and from local knowledge (DFO 2009; Vandermeulen 2011, 2014). Bay-wide surveys have been conducted in New Brunswick and Prince Edward Island using LIDAR remote sensing technology to quantify eelgrass coverage. Of the six bays surveyed in 2011, eelgrass coverage ranged from 26% of the total bay area in St. Marys Bay, PE to 94% in Bedec Bay, NB (Niles et al. 2014).

Eelgrass plants show seasonal growth patterns in Atlantic Canada's temperate latitudes (Wong et al. 2013). Shoot density and plant biomass are highest in late spring and early summer, a result of high light and nutrient availability as well as warming water temperatures. In the fall, plants start to die back—this is often observed as large amounts of wrack on shorelines near eelgrass beds. Low densities of eelgrass plants persist over the winter by using stored carbohydrate reserves in the root-rhizome system. Eelgrass wrack has insulating properties and is still sometimes used in and around homes in Atlantic Canada (Wyllie-Echeverria and Cox 1999).

Eelgrass depth distribution depends on light penetration into the water column. Eelgrass generally occurs in water depths of less than 4–5 m in the southern Gulf of St. Lawrence but light availability allows it to reach greater depths in parts of Nova Scotia (6 m) and Newfoundland (12 m) (DFO 2009; Wong 2017). Eelgrass has an optimal salinity range of 20 to 26‰ for growth, but it is tolerant of salinity levels ranging from fresh to marine for shorter periods of time (Vandermeulen 2005). It grows well over a wide range of temperatures (10–25ºC) and survives in temperatures from freezing to 35ºC along the coast of Atlantic Canada; however, long periods spent above 28ºC can reduce plant growth and survival (Wong et al. 2013). Eelgrass is vulnerable to disease, such as slime mould (e.g., *Labyrinthula zosterae*), at higher salinities and temperatures. This slime mould eliminated 90% of the eelgrass population on the Atlantic coast in the 1930s and populations did not recover until the 1960s (DFO 2009).

Eelgrass habitats are highly productive environments that typically support high densities and diversity of fish and invertebrates when compared to nearby unvegetated habitats (Orth et al. 2006; DFO 2009; Barbier et al. 2011; Joseph et al. 2013; Wong and Dowd 2015; Wong et al. 2016). The nursery function for important commercial and recreational species, such as juvenile cod and white hake (*Urophycis tenuis*), has been demonstrated in research studies in the Atlantic (Gotceitas et al. 1997; Laurel et al. 2003; Gregory et al. 2006; Wong and Dowd 2015). The bed's structural complexity provides cover from predation and enriched food supply via blades acting as substrate for epiphytes and bacteria, which are then consumed (Figure 3.3-1). Eelgrass beds provide high secondary production from associated macrobenthic infaunal and epifaunal invertebrates (Wong 2017). Eelgrass habitats filter water, stabilize sediments, and act as a shoreline buffer (DFO 2009). They also play an important role in nutrient cycling and production and export of detritus (Heck et al. 2003) since animals do not typically eat live eelgrass. The only large herbivores that consume significant quantities of eelgrass are Canada geese (*Branta canadensis*) and other brants (Seymour et al. 2002); numbers of these grazing birds have been correlated with eelgrass availability (Seymour et al. 2002). Because the perturbation of this one species (i.e., eelgrass) is expected to have substantially greater ecological consequences than would be expected of a similar loss of any other species associated with that ecological community (DFO 2009), eelgrass was designated an Ecologically Significant Species (ESS) for Atlantic Canada.

Figure 3.3-1 Rock Gunnel in coastal eelgrass habitat Newman Sound, Newfoundland in July 2007. (Photo: DFO diver)

Current known threats to eelgrass in Atlantic Canada include nutrient loading (i.e., nitrogen from artificial fertilizers and sewage) leading to eutrophication (Lotze et al. 2006; Schmidt et al. 2012), aquaculture structures (Skinner et al. 2013, 2014), and invasive species, such as European green crabs (*Carcinus maenas*) (Garbary et al. 2014) and colonial tunicates (Wong and Vercaemer 2012). Eutrophication can cause dramatic declines in eelgrass abundance as excess nutrients enter the coastal system, favouring opportunistic algal species, such as sea lettuce (*Ulva* spp.) and other filamentous forms of algae, which replace eelgrass. The main cause of eelgrass loss under eutrophic conditions is the reduced light penetration caused by algal mats, increased epiphytic growth (algae growing on eelgrass blades), and phytoplankton. Eelgrass is also intolerant to low oxygen levels (hypoxia) and complete lack of oxygen (anoxia) in the water column and sediments, which are a consequence of the decomposition that occurs when algal mats die off (Deegan et al. 2002; Lotze et al. 2006; Schmidt et al. 2012). In surveys assessing eutrophication effects in 2012, Prince Edward Island estuaries with higher levels of eutrophication showed a decrease in below-ground biomass in eelgrass likely caused by anoxia in the sediment (Schmidt et al. 2012). Change from eelgrass to sea lettuce (*Ulva lactuca*) alters species composition and thereby the functions of these coastal habitats (Schein et al. 2011). With increasing levels of eutrophication, coastal ecosystems experience a decrease in species richness and a shift in species composition (Coffin et al. 2017; Schmidt et al. 2017). Bivalve aquaculture activity has also been demonstrated to have negative impacts on eelgrass on a local scale. Suspended bag oyster aquaculture structures decrease light levels causing a reduction in eelgrass productivity and biomass (Skinner et al. 2013, 2014). Green crabs decrease eelgrass biomass in some beds mainly via their burrowing behavior, which has led to a decline in juvenile Atlantic cod abundance (Morris et al. 2011; Matheson et al. 2016). Invasive colonial tunicates, such as the violet and golden star tunicates, settle on eelgrass blades reducing light transmission and photosynthesis rates (Wong and Vercaemer 2012), reducing shoot growth and survival.

Several effects of climate change will also likely influence eelgrass beds of Atlantic Canada (Short and Neckles 1999). Warmer water temperatures could lead to temperature-related death, especially in shallow beds (Moore and Jarvis 2008; Moore et al. 2012). Predicted increase in storm frequency could also cause habitat loss from wave action and decreased plant production from increased light attenuation from increased suspended sediments (Vandermeulen et al. 2012). Sea level rise could change bed distribution due to the decreased light. Increased CO_2 may lead to short-term increases in photosynthesis and growth, although long-term consequences are hard to predict.

Eelgrass declines in the recent decade have been reported in the southern Gulf of St. Lawrence and on the Atlantic coast of Nova Scotia (Hanson 2004; AMEC Earth & Environmental 2007; DFO 2009; Matheson et al. 2016). In some locations in the Maritimes, a 30% to 95% loss in eelgrass beds was observed over scales ranging from 2 to 20 years. Possible reasons for these declines in eelgrass distribution include eutrophication, disturbance (uprooting and grazing) by invasive European green crab, human activities, and environmental changes (DFO 2009). In Prince Edward Island, eutrophication and nutrient enrichment of bays and estuaries is contributing to reductions in eelgrass distribution and threatening its persistence (Schmidt et al. 2012). In Newfoundland, there appears to be a general increase in eelgrass abundance in the past 15 years (Warren et al. 2010). The increases in some locations may be due to improved conditions for eelgrass, including milder temperatures and less sea ice (DFO 2009).

Kelp beds

Kelp beds are usually found in rocky shallow subtidal zones of temperate and Arctic coastal ecosystems worldwide and can form large, dense forests given the right environmental conditions (e.g., depth, nutrient levels, cooler waters, light availability). Kelps are brown algae from the order Laminariales and are the largest biogenic structure-producing seaweeds in marine ecosystems. An individual kelp plant is typically anchored to the substrate by a holdfast, from which a semi-flexible stipe (stem) extends vertically into the water column. Multiple blades or a single blade extend from the end or the sides of the stipe; blades can be continuous or divided. Because kelps do not have an underground root system, nutrients are absorbed across the entire length of the blade directly from the water column. Individual plants form dense aggregations often called kelp beds or forests. Three guilds of kelps are recognized based on their morphology: canopy kelps are the largest and form floating canopies on the ocean surface; stipitate kelps have a stiff centre and grow in dense, short aggregations; and prostrate kelps lie across the sea bottom (Steneck et al. 2002).

Kelps alternate between two life history stages: the macroscopic sporophyte and the microscopic gametophyte (Dayton 1985). Observations on kelp biomass and abundance are based only on the macroscopic phase of the life history; little is known about the distribution of microscopic kelp gametophytes, although it has been suggested that they may act analogously to terrestrial seed banks.

In Atlantic Canada, kelp beds are mostly composed of prostrate kelps. Species diversity of kelp is relatively low (~six species), with key species being *Saccharina latissima*, *Laminaria digitata*, *Saccharina nigripes*, *Alaria esculenta* and *Agarum cribrosum*. These five species have been historically (pre-2000) and recently (post-2000) observed in the Bay of Fundy and Atlantic coast of Nova Scotia (McDevit and Saunders 2010; Merzouk and Johnson 2011). In the Gulf of St. Lawrence and St. Lawrence Estuary, these species have only been historically observed and are not common now (Merzouk and Johnson 2011). *Laminaria digitata* and *S. nigripes* tend to dominate wave-exposed shores and are often found in mixed kelp assemblages. *Saccharina latissima* is more abundant in protected bays with less wave exposure. *Saccharina latissima* is the dominant kelp species in Atlantic Nova Scotia, the Gaspé Peninsula, and the St. Lawrence Estuary, and has historically reached very high abundance (60 individuals m^{-2}) and biomass (5–25 kg m^{-2}), especially in the absence of grazing fauna.

Kelps inhabit a narrow strip of the coast from the low intertidal to the maximum depth of light penetration (<20 m) and are influenced by several environmental factors (Mann 2000). Adequate light for photosynthesis is required at all life stages and can vary with turbidity or the density of the plants themselves (self-shading) (Dayton 1985). Nutrients, especially dissolved nitrogen, are also necessary for kelp growth and survival, and kelps can store nutrients in tissues for use when nutrients are limited (Dayton 1985). Water temperature has direct physiological effects on kelps by scaling photosynthetic and metabolic rates, whereby high temperatures reduce growth rates, cause mortality, and reduce recruitment (Simonson et al. 2015). Water temperature also has indirect effects through interactions with nutrient delivery and light availability. Finally, hydrodynamic regime has long been recognized as an important structuring force for kelp communities (Dayton 1985). Wave action and currents create physical disturbance, resulting in plant dislodgement and mortality. Kelps also have morphological responses to wave exposure, whereby holdfast size and blade thickness increase with exposure.

Kelp beds are among the most productive ecosystems in the world (Mann 2000) and provide a multitude of valuable ecosystem functions and services. Kelp beds are sites of high fish and invertebrate biodiversity relative to nearby sand flats. Fish often use kelp beds for feeding, protection from predators, and as nursery grounds. In Atlantic Canada, several important commercial fish and crustaceans use kelp beds during juvenile stages or throughout their lifetime: Atlantic cod (*Gadus morhua*), Atlantic tomcod (*Microgadus tomcod*), white hake, American lobster (*Homarus americanus*), rock crab (*Cancer irroratus*), and Jonah crab (*Cancer borealis*). In addition to providing critical fish habitat, kelp beds are sites of high primary production and export detritus to deeper offshore waters, fueling food webs (Krumhansl and Scheibling 2011). Kelp beds are also important for coastal defence, reducing coastal erosion by dampening and attenuating waves. Finally, the kelp plant itself is harvested in the wild and grown by aquaculture in Atlantic Canada by several companies for use in seaweed-based products for human consumption, animal feed, and agricultural use.

Kelp ecosystems are threatened by a range of anthropogenic pressures, the most important of which is increasing seawater temperature from climate change. Increased water temperature is predicted to affect the distribution, structure, productivity, and resilience of kelp beds worldwide (Harley et al. 2012). In the Bay of Fundy, warming water has been correlated with decreasing abundance of kelp (Longtin and Saunders 2016). Shifts in kelp dominance to turf-forming algae from warming temperature have also been increasingly observed. At a few sites on the central Atlantic coast of Nova Scotia, kelp biomass has declined by 85% to 99% over the last four to six decades, causing a dramatic dominance shift from lush kelp beds to turf-forming invasive algae (Filbee-Dexter et al. 2016). This shift has been strongly associated with warming seawater temperature, which slows growth, encourages epiphyte overgrowth on kelp blades, and causes cellular damage that decreases blade strength and increases mortality (Simonson et al. 2015). Increasing temperature also encourages growth of the invasive bryozoan *Membranipora membranacea* on kelp blades, which decreases blade strength and increases blade breakage during storms (Krumhansl et al. 2011). Kelp defoliation by *M. membranacea* facilitates colonization by the invasive seaweed *Codium fragile fragile* (Scheibling and Gagnon 2006), which also benefits from warming temperatures.

Recovery of kelp beds in Atlantic Nova Scotia is currently hindered by turf algae that limit kelp recruitment, intensive grazing of kelp in degraded beds by snails, low density of reproductive adults, and high mortality of juvenile kelp (O'Brien et al. 2015; O'Brien and Scheibling 2016). Transition of kelp beds to turf algae will be more prevalent in protected bays, whereas kelp beds on exposed headlands in cooler waters may be less susceptible to the effects of warming water temperature (O'Brien 2018).

Historically, the green sea urchin (*Strongylocentrotus droebachiensis*) destructively grazed kelp beds in Atlantic Canada, converting kelp beds to coralline algae–dominated barrens (Scheibling et al. 1999). Episodic disease outbreaks in urchins caused their periodic mass mortality and allowed reestablishment of the kelp beds (Scheibling and Hennigar 1997). Warming seawater and increased tropical storms from climate change increase urchin disease prevalence, preventing the regrowth of urchin populations. While this limits destruction of kelp beds, low levels of urchin grazing likely allows turf algae to persist.

Other factors known to influence kelp beds worldwide include changing oceanographic conditions (e.g., ocean acidification), eutrophication, sediment loading, and bacterial disease (Campbell et al. 2011; Case et al. 2011; Harley et al. 2012; Mineur et al. 2015). However, Atlantic Canada has a relatively small human population and anthropogenic stressors such as eutrophication and sediment loading likely represent minor impacts for kelp ecosystems. Increasing water temperature and invasive species remain the two major threats for kelp beds in Atlantic Canada.

There are many key knowledge gaps for kelp: lack of long-term datasets and monitoring; impacts of kelp loss for faunal diversity, secondary production, and ecosystem functioning; long-term persistence of kelp losses and recovery mechanisms; species-specific responses to a warming climate; role of headlands in providing refuge populations; impacts of kelp and turf algae detrital export on adjacent ecosystems; and information on the microscopic life history stage.

Corals and sponges

Corals and sponges are both considered to be ecosystem engineers (organisms that alter the structure of the ecosystem in ways that are used by other organisms) and their importance to ecosystem function has been recently reviewed (Boutilier et al. 2010). Coral and sponge habitats provide shelter from predation for small fish and invertebrates, serve as foraging centres particularly for grazers and predators with sit-and-wait predation strategies, offer feeding advantage points for other suspension feeders (Krieger and Wing 2002), and provide resting sites from strong currents. As a result, coral communities and sponge grounds are among the most species-rich areas of marine ecosystems with hundreds of associated species creating hot spots of biodiversity (Beazley et al. 2013; Rossi et al. 2017).

In Canada, corals and sponges are protected under the *Policy on Managing the Impacts of Fishing on Sensitive Benthic Areas*. In March 2016, a Canadian Science Advisory Secretariat process was conducted to identify Significant Benthic Areas in Canada's Atlantic and Eastern Arctic waters, during which significant benthic areas for corals and sponges in eastern Canada were identified (Figure 3.3-2) (DFO 2017).

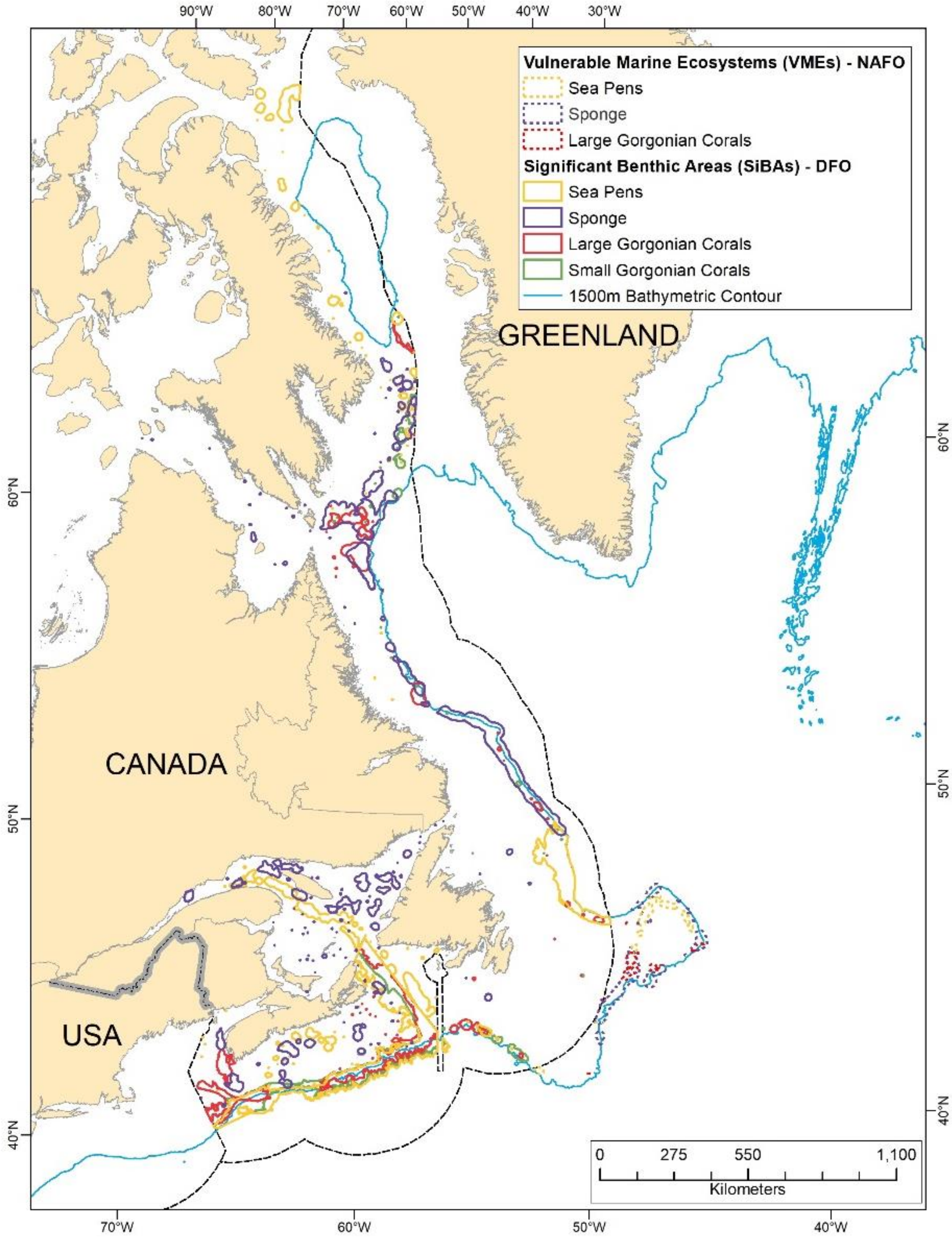

Figure 3.3-2. Map of significant benthic areas (SiBAs) and vulnerable marine ecosystems (VMEs) for sponges, sea pens, large and small gorgonian corals on the east coast of Canada. SiBAs are identified by DFO within the 200 nautical mile Exclusive Economic Zone (EEZ) boundary (dashed line) while VMEs are outside the EEZ as identified by NAFO.

Although deep-water corals are found around the world and are important components of deep-water ecosystems, they have received very little scientific attention compared to their shallow-water relatives, in large part because of the logistic difficulties in studying them. More than 700 species of deep-water corals occur worldwide, and approximately 40 species are known from eastern Canada; however, the taxonomy of many groups is under revision and so it is difficult to draw a complete list at this time (Wareham and Edinger 2007; Cogswell et al. 2009; Murillo et al. 2011). Most corals grow attached to stable substrate (e.g., cobbles, boulders, and bedrock), some anchor in finer sediments (e.g., sea pens and the large bamboo coral *Keratoisis*), and others lie on the seafloor (e.g., *Flabellum* cup corals). All corals are epibenthic (bottom dwelling) and most corals documented in Canada have arborescent (tree-like) growth forms. They can range in size from just a few centimetres to over three metres as seen in Baffin Bay with the giant sea pen (*Umbellula encrinus*) (see Figure 3.3-3).

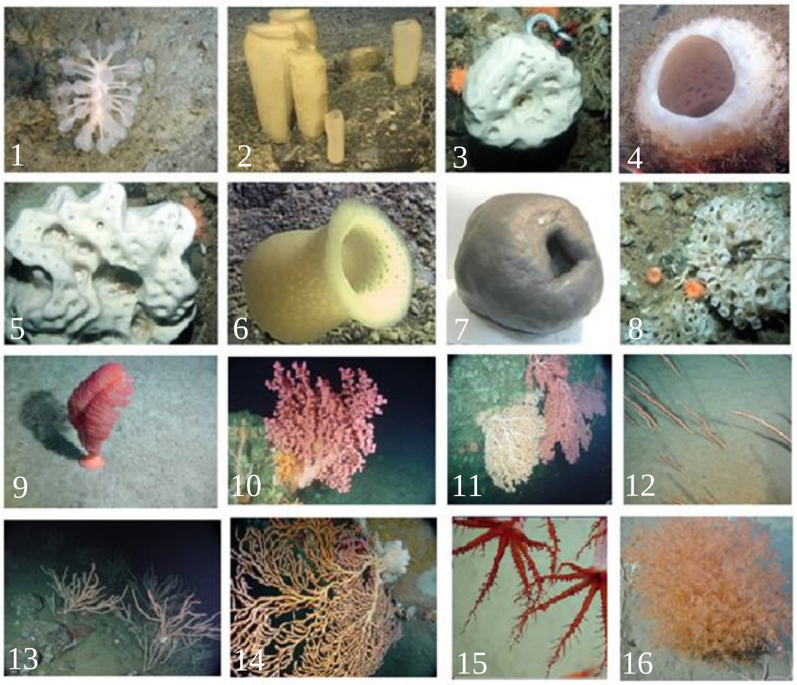

Figure 3.3-3. Sponges: 1) *Chondrocladia grandis*, 2) Rosellidae sp., 3) Demospongiae sp., 4) *Vazella pourtalesi*, 5) Demospongiae sp., 6) *Lyssacinosida* sp., 7) *Geodia barretti*, 8) *Asconema foliate*. Sea pens: 9) *Pennatula* sp., 12) *Halipteris finmarchia*,15) *Umbellula* sp. Large gorgonian corals: 10) *Paragorgia arborea*, 11) *Paragorgia arborea*, 13) *Keratoisis grayi*, 14) *Paramuricea* sp. Small gorgonian coral: 16) *Acanella arbuscula*. (Photos: DFO)

Deep-water corals are adapted to live without light and at relatively low temperatures (4–13°C). They feed by capturing zooplankton and organic particles from the surrounding water. Growth rates are very low and colonies can range in age from decades to centuries (Sherwood and Edinger 2009). This means they can provide insight into past environmental conditions through chemical analyses of their skeletons. The iconic gorgonian corals (so named for the protein in their skeletons) *Primnoa resedaeformis* (sea corn) and *Paragorgia arborea* (bubblegum coral) are the large deep-water corals found on the continental slopes from the United States border to the Eastern Arctic. Deep-water corals occur in eastern Canada at depths in the range of 200 to 1500 m. They can form dense aggregations or “forests” providing habitat for other species. The only known coral reef in eastern Canada is formed by the reef-building coral *Lophelia pertusa* and found at about 300 m on the Scotian Shelf, where it has been protected. The *Lophelia pertusa* reef complex is approximately 0.6 km^2 and is comprised of live colonies, dead blocks, and skeletal rubble. Corals can provide structural habitat when they are alive as well as dead as their skeletons can persist long after the coral has died. In the Gulf of St. Lawrence, dense aggregations of sea pens are found (Murillo et al. 2018), forming habitat for other species.

The importance of corals in the Gully, a large canyon incised into the Scotian Shelf, played a role in the design of the large marine protected area (2,364 km^2) designated there in 2004. Prior to 2000, most knowledge of deep-water corals was anecdotal and based primarily on fishing bycatch information. The distribution of deep-water corals is patchy and influenced by several environmental factors including substrate, temperature, salinity, and currents. Human activities such as fishing with bottom-contact gears and hydrocarbon extraction have the potential to seriously impact deep-water corals.

Known to exist for over 600 million years, sponges (Phylum Porifera) are the oldest living animal group on the planet. With over 8,500 species described and more than 25,000 species estimated to exist, they present a remarkable diversity in the world’s oceans (Maldonado et al. 2016). Sponges provide a potential for biotechnology and innovation because sponges contain a great diversity of microbial symbionts. Sponges and their associated microorganisms are the richest and most prolific source of marine natural products with human health applications, with more than 30% of the total number—or nearly 5,000 compounds—discovered to date derived from sponges. One remarkable feature is the filtration capacity of sponges. Due to their large filter-feeding capacity (up to 14 litres of seawater $g^{-1}h^{-1}$), a diet mainly composed of dissolved organic matter, and a silicified skeleton, sponges are known to be major players in bentho-pelagic coupling, contributing significantly to the nitrogen, carbon, and silicon cycles.

Sponge diversity on the east coast of Canada is still under investigation; however, recent work to identify sponges from trawl surveys in Davis Strait, Eastern Arctic, has identified 94 different species. Three were new to science. Other sponge investigations using Remotely Operated Vehicle (ROV) surveys have identified another 12 species to add to the growing list. In many areas, sponges are by far the dominant organism in terms of abundance (up to 16 individuals m^{-2}) and biomass (over 90% of total invertebrate biomass) (Murillo et al. 2012; Beazley et al. 2013) forming structurally complex ecosystems known as sponge grounds, gardens, aggregations, and reefs.

In the Eastern Arctic the most frequently encountered species were *Asconema foliata* and *Mycale* (*Mycale*) *lingua*; the latter is also found in the Gulf of St. Lawrence along with species of *Halichondria* and *Polymastia*. *Geodia barretti* and closely related species form dense sponge grounds on the continental slopes from the Davis Strait to the Grand Banks, while *Vazella pourtalesi* forms dense aggregations on the Scotian Shelf (see Figure 3.3-3).

Sponge ecosystems in eastern Canada are found along continental shelves, slopes, canyons and deep fjords, at depths varying from 30 to approximately 3000 m, which places them in direct contact with some of the most important commercial fisheries. Left undisturbed, sponge grounds can persist for thousands of years, and even after death, glass spicules they leave behind can form distinctive benthic habitats for macrofauna living on or in the seabed (Murillo et al. 2016).

Sponge ecosystems, are considered very sensitive to human impacts on account of their longevity, unknown reproduction patterns and expected long recovery times. Bottom-contact gears are known to damage and remove sponges as well as alter community composition. However, the true impact cannot be determined until knowledge gaps are filled including sponge reproduction, population dynamics, and ecosystem roles.

Deep-water corals and sponges are highly vulnerable to human activities, in particular fishing, and there is a strong international conservation movement for their protection. Canada is doing its part to protect deep-sea corals and sponges (DFO 2013) through the development of a Coral and Sponge Conservation Strategy for Eastern Canada (DFO 2015) and the delineation of areas with significant concentrations of corals and sponges (Figure 3.3-2; Kenchington et al. 2016; DFO 2017). The next steps will be to implement protective measures in consultation with stakeholders and socioeconomists to ensure the long-term conservation of corals and sponges in Canada while promoting sustainability of fisheries.

Sand dollars

Sand dollars are considered to be ecosystem engineers because they are bioturbators. Bioturbation, the biogenic modification of sediments through particle reworking and burrow ventilation, is a key aspect of many important geochemical processes in marine systems. Sand dollar beds are formed by the common sand dollar (*Echinarachnius parma*), which is found from Labrador in Canada to Cape Hatteras, North Carolina in the United States from shallow intertidal waters to the offshore continental shelves (Figure 3.3-4). *Echinarachnius parma* is circumpolar and also occurs in Alaska, British Columbia, Washington to Puget Sound, Siberia, and Japan where it can be found to depths of 1600 m.

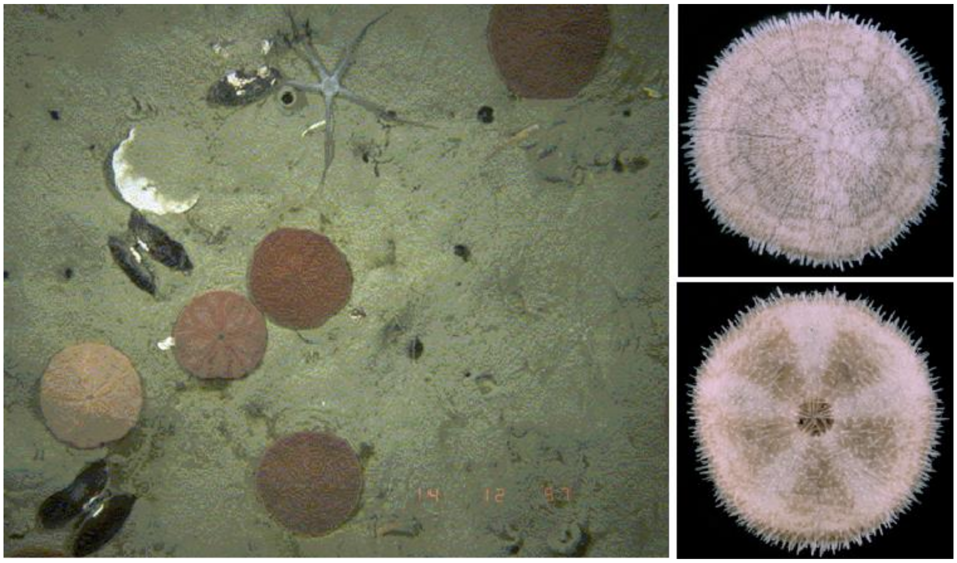

Figure 3.3-4. Sand dollars (*Echinarachnius parma*) living on a sandy bottom on Banquereau Bank on the eastern Scotian Shelf (left panel). Close up of the upper surface (right, top photo) and lower surface (right, bottom photo) showing the extended small tentacles used to move through the sediment.

Due to its large size (>50 mm) and tendency to form dense aggregations or beds with hundreds of individuals per m^2, *E. parma* has been considered a keystone species (Steimle 1989), and sand dollar beds have been considered in the development of Ecological or Biological Significant Areas (EBSAs) (Kenchington 2014). This species is particularly abundant in the Bay of Fundy, eastern Scotian Shelf (Figure 3.3-5), Georges Bank (Steimle 1989), Gulf of St. Lawrence (Brunel et al. 1998; DFO Gulf Region, unpublished sand dollar data from scallop surveys), and the Grand Banks (Kenchington et al. 2001) and has the largest geographical and ecological distribution of any other flattened sand dollar (Ghiold 1983). On the Scotian Shelf, sand dollars are second in importance, after storm events, in bioturbation of surface sediments (Stanley and James 1971). On Sable Island Bank they were found to modify at least a third of the total surface in one study area and achieved densities of 180 individuals m^{-2} (Stanley and James 1971). On Georges Bank, they form 40% to 50% of the total benthic macrofaunal biomass (Steimle 1989).

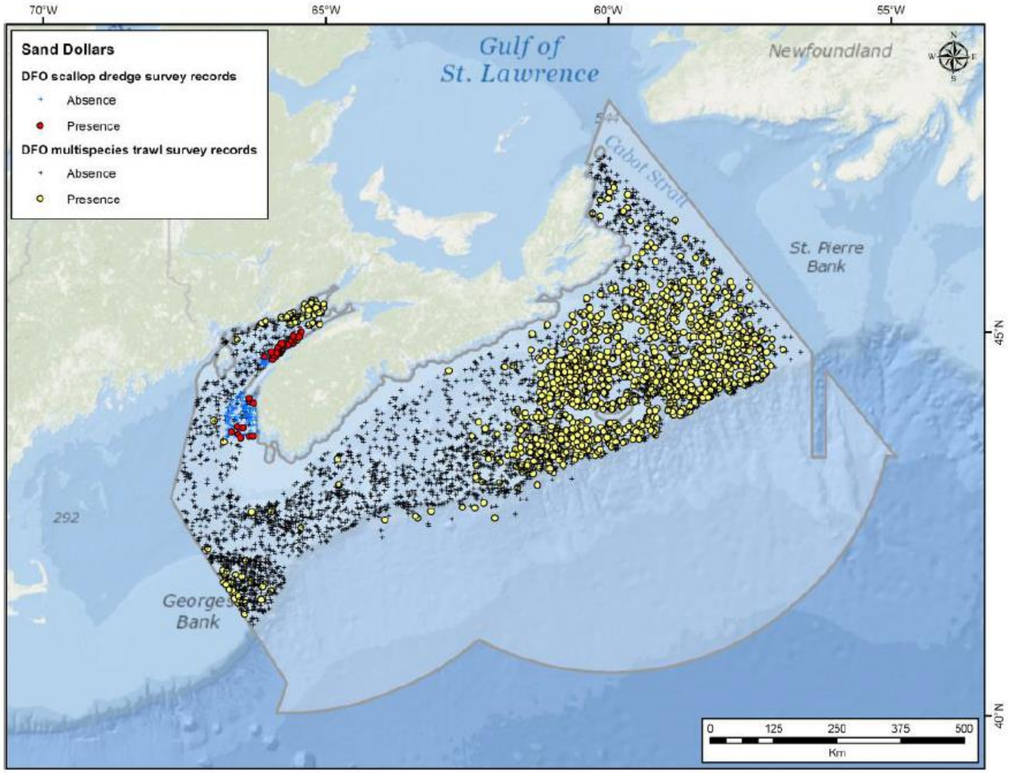

Figure 3.3-5. Distribution of sand dollars (*Echinarachnius parma*) in the DFO Maritimes Region from DFO multispecies trawl surveys (1999–2015) and scallop stock assessment surveys (1997, 2007). Reproduced with permission from Beazley et al. (2017).

In the intertidal zone, sand dollars often bury or situate in drainage channels at low tide to reduce the effects of exposure to air (Harold and Telford 1982). The calcareous shells of dead sand dollars are commonly found washed up on beaches. Contrary to its name, sand dollars can be found on a range of sediment types from coarse gravelly sand to fine silt (Harold and Telford 1982). They feed on benthic diatoms (algae), detritius, and other small particles while burrowing (Ghiold 1983). *Echinarachnius parma* is also eaten by a number of fish, including haddock

(*Melanogrammus aeglefinus*), summer flounder (*Paralichthys dentatus*), American plaice (*Hippoglossoides platessoides*), and yellowtail flounder (*Limanda ferruginea*), although its nutritional content is low compared with other benthic prey (Steimle 1989).

Bottom trawling is a known threat to this species, with one study on the Grand Banks showing a 37% reduction immediately after trawling (Kenchington et al. 2001). However, this species has regular recruitment and may spawn more than once a year, at least in some parts of its range (Steimle 1989), which favours recovery. Undisturbed populations experience temporal variation (Steimle 1989; Kenchington et al. 2001) in abundance but the location of beds is stable at larger spatial scales. Given their relatively high biomass and abundance, bioturbation activities, and trophic position, more information on their role in the ecosystem is warranted.

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3.4 FISH AND INVERTEBRATE COMMUNITIES

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Introduction

Marine communities consist of species that swim in the open water and those that are linked to the seafloor. Fish and invertebrates within these communities are part of a complex ecological network that integrates them with the physical, chemical and biological environment in which they live. Marine fish and invertebrates occupy different levels of the food web and play an important role in the transfer of energy between various trophic levels. Some species, such as American lobster (*Homarus americanus*), snow crab (*Chionoecetes opilio*), northern shrimp (*Pandalus borealis*), and Atlantic cod (*Gadus morhua*), are familiar because they are targeted by fisheries, but marine communities also include less familiar species which play important roles in the ecosystem. For instance, many species are important in transferring energy from lower to higher trophic levels, including well-known species such as capelin (*Mallotus villosus*) and Atlantic herring (*Clupea harengus*) as well as lesser-known prey species, such as sand lance (*Ammodytes dubius*) and lanternfish (Myctophidae).

Assessing the state of marine fish and invertebrate communities requires careful monitoring and scientific analysis. Fisheries provide useful information (i.e., commercial fisheries landings), but they also target specific species, thus, data from these fisheries do not fully reflect the overall fish and invertebrate community. To compensate, scientific surveys (multi-species trawl surveys and acoustic surveys) are routinely conducted by researchers in some areas to collect additional data and provide information on wider marine communities. However, some of these scientific surveys have sampling limitations as some species are not effectively sampled by certain types of sampling equipment, such is the case with the assessment of pelagic fish and invertebrates using bottom trawl gear. Therefore, species-targeted surveys may be conducted in some bioregions for certain pelagic stocks (e.g., acoustic surveys for capelin in Newfoundland and Labrador Shelves).

Here we summarize key information on the fish and invertebrate communities in Atlantic Canadian waters. Information is first presented according to bioregion (Gulf of St. Lawrence, Scotian Shelf, and Newfoundland and Labrador Shelves). These regional synopses are followed by a summary section that synthesizes common trends and differences across regions. We also complement these ecosystem-wide summaries with specific examples for key species.

Gulf of St. Lawrence

In the Gulf of St. Lawrence, two major bottom trawl surveys are conducted annually to estimate the relative abundance of demersal fish and benthic invertebrates; one in August (started in 1990) in the St. Lawrence Estuary and northern Gulf of St. Lawrence and one in September (started in 1971) in the southern Gulf of St. Lawrence. For this reason, the two subregions are presented separately.

The northern Gulf demersal fish community, in particular Atlantic cod, collapsed in the early 1990s (Figure 3.4-1). This collapse has been attributed to overfishing and unfavourable environmental conditions as this period was very cold (Chouinard and Fréchet 1994; Dutil et al. 1999; Dutil and Lambert 2000). During the late 1990s and early 2000s, the demersal fish community in offshore waters saw little improvement, except for the Greenland halibut (*Reinhardtius hippoglossoides*), a species that inhabits only the deep channels, which increased in abundance during the 1990s and has remained at high abundance until 2015, but has been decreasing ever since (Bourdages et al. 2017; DFO 2017a; MPO 2018a). After 2010, demersal fish showed a very important increase, mainly driven by redfish species, but also by Atlantic halibut (*Hippoglossus hippoglossus*) (DFO 2016a, 2018a; MPO 2018a, 2018b) (Figure 3.4-1). Atlantic cod abundance increased slowly during the period 2000–2016, but declined again in 2017, catches in the 2017 Research Vessel survey being similar to the average for 1990–2016 (DFO 2017b; MPO 2018b).

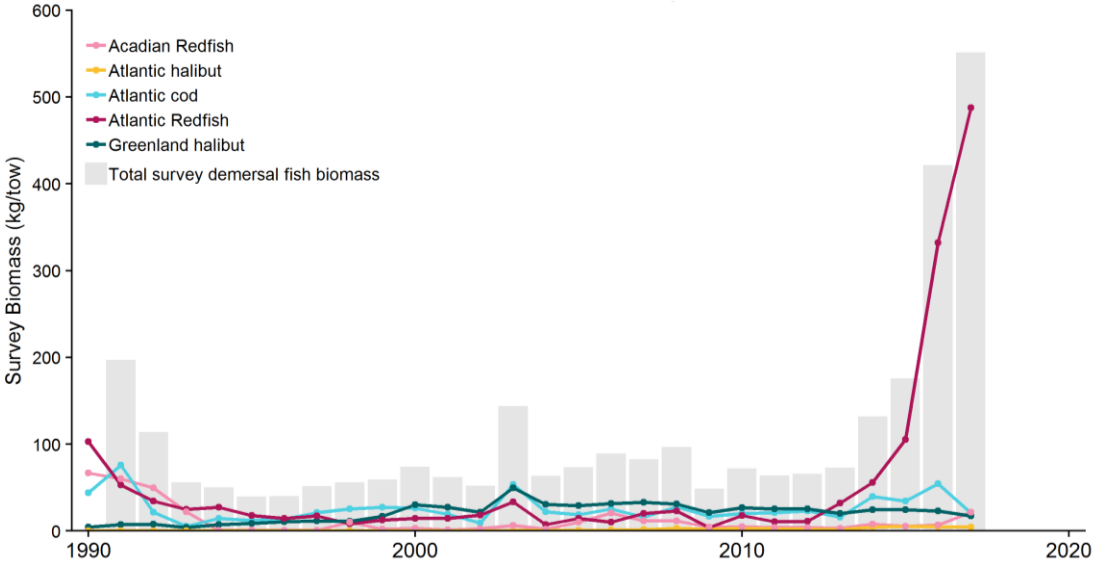

Figure 3.4-1. Research survey index of biomass (kg/tow) for total demersal fish and individual species in the northern Gulf of St. Lawrence.

There are three dominant, commercially exploited pelagic fish in the northern Gulf of St. Lawrence: Atlantic herring, Atlantic mackerel (*Scomber scombrus* L.), and capelin. Changes in abundance of Atlantic mackerel and of two of the herring stocks are shown in Figure 3.4-2. Of these, Atlantic herring and Atlantic mackerel have shown poor recruitment in recent years and some of the herring stocks are considered depleted. Environmental conditions of the past two decades are believed to contribute to the poor herring recruitment (DFO 2016b, 2017d). For

Atlantic mackerel, the poor state is not limited to the northern Gulf as these mackerel are part of and reflect the status of a large population that occupies waters off the east coast of Canada and the United States. This broad mackerel stock declined in the 1990s, improved somewhat in the 2000s, then collapsed in the 2010s due to overfishing (DFO 2017e). Capelin is a short-lived species and abundance can vary greatly within a short time. Although average capelin landings from commercial fisheries have declined in the Gulf of St. Lawrence (NAFO Divisions 4RST), DFO currently has no scientific survey aimed at estimating capelin abundance in this area (DFO 2013, 2015a).

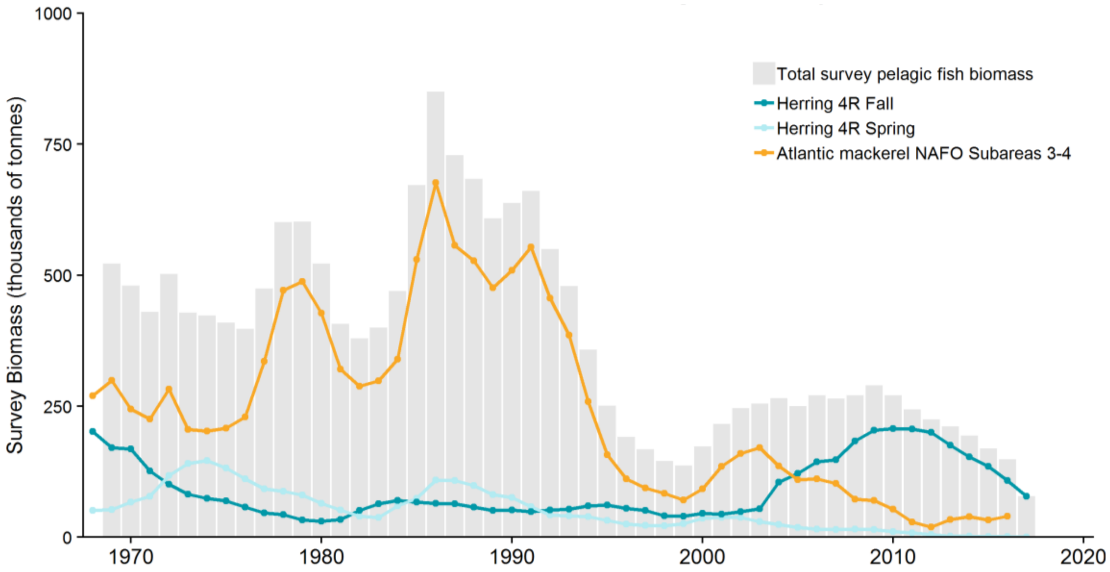

Figure 3.4-2. Survey biomass for total pelagic fish, Atlantic mackerel and two of the herring stocks (NAFO zone 4R, spring and fall) of the northern Gulf of St. Lawrence. Not shown (and excluded from total biomass) are capelin and 4S spring and fall herring. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

Many benthic invertebrate species are sampled by the research vessel survey. However, commercially important northern shrimp is the most dominant invertebrate species sampled in these surveys. Trends for northern shrimp in the northern Gulf were opposite to those observed for demersal fish, except for the Greenland halibut. Northern shrimp abundance increased steadily during the 1990s until about 2005 (Figure 3.4-3). Presumably, this was because of lower rates of predation by demersal fish and favourable conditions (cold water) (DFO 2017c). Since 2005, northern shrimp has been declining (Figure 3.4-3). This decline has been attributed to unfavourable warming conditions (Galbraith et al. 2017) and increased predation pressure by demersal fish, in particular by redfish, which shows the most rapid increase in abundance (Bourdages et al. 2017) and is a known shrimp predator in the Gulf of St. Lawrence (Dutil et al. 2003; Savenkoff et al. 2006).

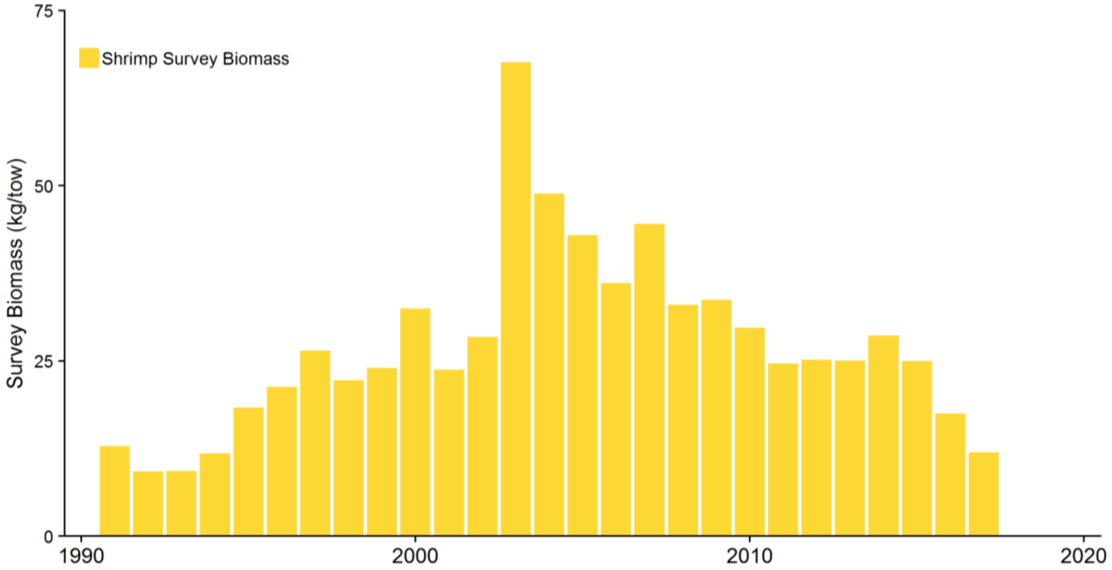

Figure 3.4-3. Survey biomass (kg/tow) for northern shrimp in the northern Gulf of St. Lawrence.

The coastal community in the St. Lawrence Estuary and northern Gulf of St. Lawrence is not sampled by comprehensive surveys, thus, trends in landings are used instead. Note that changes in fishing effort can cause changes in landings, so landings do not always reflect changes in abundance. The landings of coastal invertebrates show a major jump with the start of the snow crab fishery in the early 1980s (Figure 3.4-4). New fisheries for green sea urchin (*Strongylocentrotus droebachiensis*), sea cucumber (*Cucumaria frondosa*), and Arctic surf clam (*Mactromeris polynyma*) were introduced during the 1990s and 2000s, which also contributed to higher landings in recent years (DFO 2015b, 2016c, 2017f) (Figure 3.4-4). The overall trend is for large increases in landings from the early 1980s to the present, driven largely by changes in landings of American lobster and snow crab, with large fluctuations caused by the natural cycles in recruitment of snow crab (DFO 2016d, 2016e, 2016f, 2017g). Recent warming of surface, coastal, and deep waters has started to influence landings and possibly abundance of invertebrates. For example, snow crab is a cold-water species that prefers temperatures between -1 to 4°C and the bottom surface area within this range has started to shrink. Surface waters have also become warmer in summer (Galbraith et al. 2017), which has been linked to increased productivity and distribution of American lobster, a species known to be more productive in temperatures warmer than what they encounter in the northern Gulf at present (DFO 2016e).

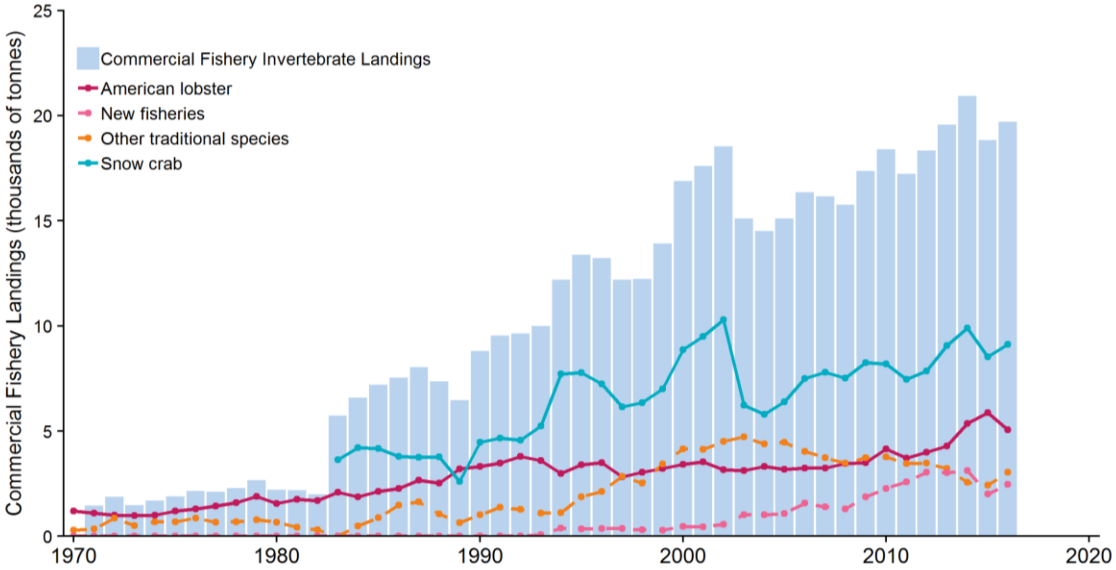

Figure 3.4-4. Commercial fishery landings for benthic invertebrates along with individual species in the northern Gulf of St. Lawrence. New fisheries include green sea urchin, sea cucumber and Arctic surf clam. Other traditional species are Atlantic rock crab, *Hyas* crab, giant scallop, whelk, common softshell clam, Atlantic jacknife clam and Atlantic Surfclam.

Like its northern Gulf counterpart, the southern Gulf of St. Lawrence marine community has also undergone considerable change. Survey data show that over the long term, the fish community in the southern Gulf has shifted dramatically from one dominated by large demersal fish, such as Atlantic cod, to one with a greater proportion of smaller-bodied pelagic fish, such as Atlantic herring (Figure 3.4-5). This dominance change is attributed to the collapse of demersal fish by the early 1990s and the relative increase in some pelagic species like Atlantic herring that began in the 1980s (Figure 3.4-5).

The collapse of demersal species in the southern Gulf is considered to be largely the result of intense harvest of commercial species. Despite little fishing on demersal fish since the 1990s, there has been little recovery of several previously abundant demersal fish species, such as Atlantic cod and American plaice (*Hippoglossoides platessoides*) (Figure 3.4-6). Only a few demersal species have increased in biomass in recent years, including redfish and Atlantic halibut (Figure 3.4-6). High natural mortality of commercial-sized individuals is believed to be the most important factor limiting the recovery of many demersal fish like the once abundant Atlantic cod (DFO 2007; Swain et al. 2011; Swain and Benoît 2015). Predation by the rapidly growing grey seal population in the southern Gulf is thought to be an important source of natural mortality (Chouinard et al. 2005; Benoît et al. 2011; Swain et al. 2011).

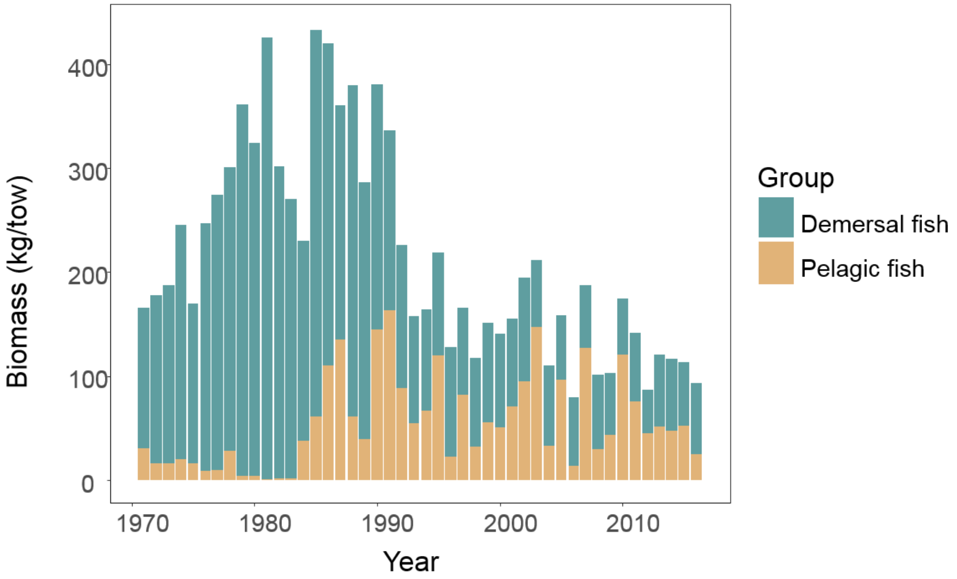

Figure 3.4-5. Proportion of demersal fish to pelagic fish biomass (kg/tow) in the southern Gulf of St. Lawrence research trawl survey (1971–2016). Biomass values were standardized across the time series according to Benoît and Swain (2003) using the Gulf R package 1.0.7 (Surette and Vergara 2014).

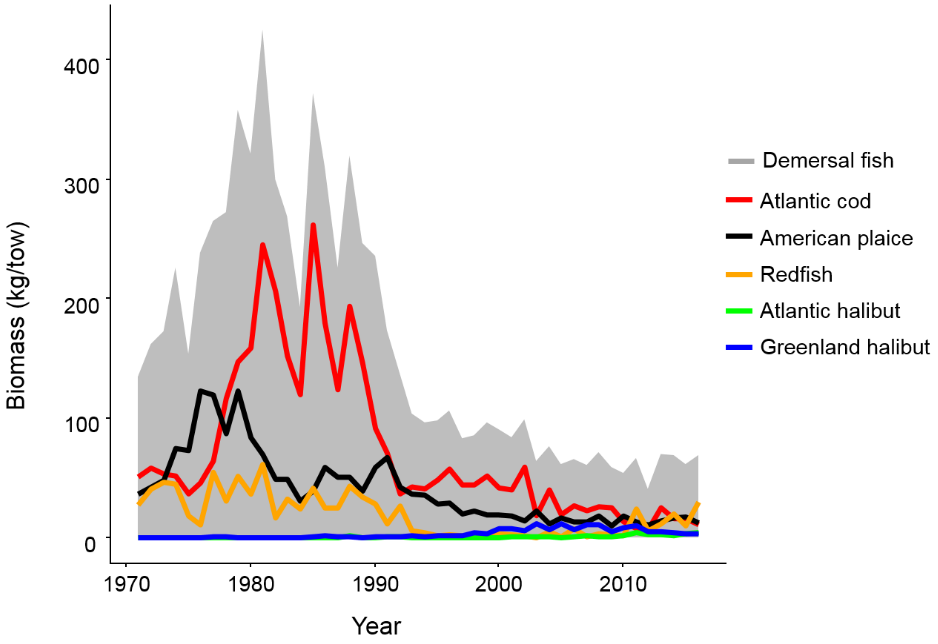

Figure 3.4-6. Research vessel survey index of demersal fish biomass (kg/tow) in the southern Gulf of St. Lawrence (1971–2016). The area shaded grey reflects the sum of mean biomass per tow for all demersal fish. Coloured lines represent each of the top five taxa ranked according to 2016 values. Biomass values were standardized across the time series according to Benoît and Swain (2003) using the Gulf R package 1.0.7 (Surette and Vergara 2014).

Pelagic fish biomass increased in the southern Gulf survey in the late 1980s compared to levels observed since the early 1970s. This was largely due to an increase in Atlantic herring biomass (Figure 3.4-7). Nevertheless, Atlantic herring and other pelagic fish have shown some decreases since 2011 (Figure 3.4-7). In particular, spring-spawning herring biomass is presently declining and at low levels in the southern Gulf (DFO 2016g). As reported in many other areas, the Atlantic mackerel population in the southern Gulf from 2012–2016 has low biomass and average individual size has decreased (DFO 2017e).

The southern Gulf of St. Lawrence is home to a wide variety of benthic invertebrates, including commercial species like American lobster and snow crab. While benthic invertebrate biomass in the southern Gulf research survey has fluctuated less over time than the biomass of demersal and pelagic fish (Figure 3.4-8), some changes have been observed. For example, research survey data show that American lobster biomass has increased substantially in recent years (Figure 3.4-8). This increase has been attributed to warming temperatures, which may have expanded lobster habitat in some areas of the southern Gulf, and management practices that increased the minimum size of harvested lobster (DFO 2016h). Snow crab biomass in the research survey has fluctuated (Figure 3.4-8). The biomass of harvestable-size snow crab appears to have a periodicity; recent survey data peaked in 2006 and again in 2016 (Benoît 2017).

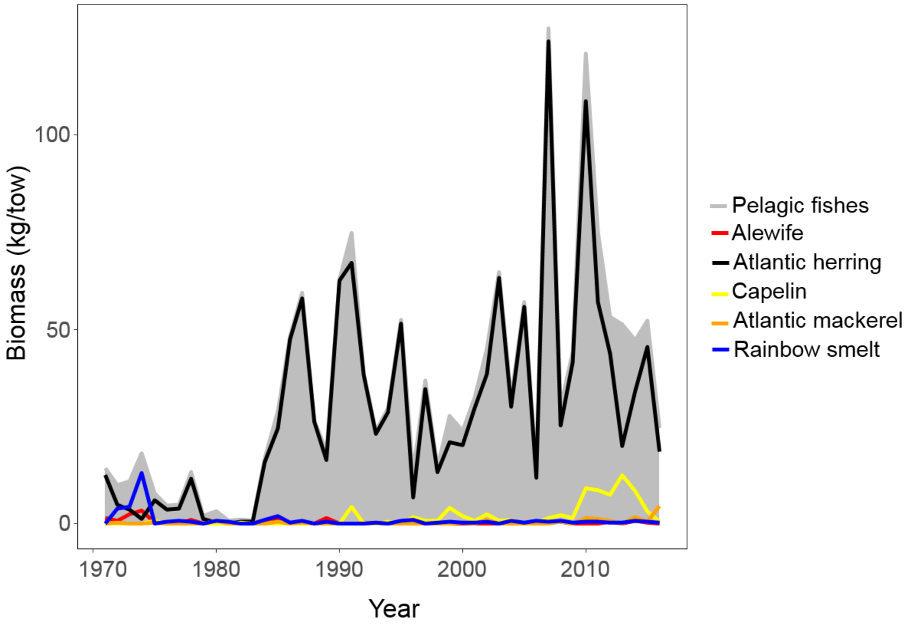

Figure 3.4-7. Research vessel survey index of pelagic fish biomass (kg/tow) in the southern Gulf of St. Lawrence (1971–2016). The area shaded grey reflects the sum of mean biomass per tow for all pelagic fish. Coloured lines represent each of the top five taxa ranked according to 2016 values. Biomass values were standardized across the time series according to Benoît and Swain (2003) using the Gulf R package 1.0.7 (Surette and Vergara 2014).

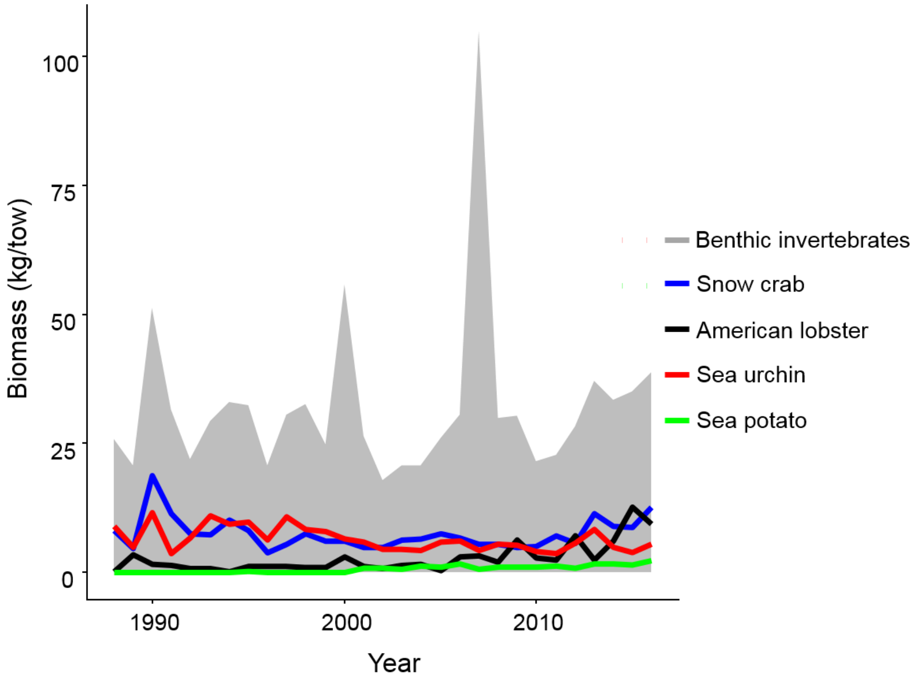

Figure 3.4-8. Research vessel survey index of demersal invertebrate biomass (kg/tow) in the southern Gulf of St. Lawrence (1988–2016). The area shaded grey reflects the sum of mean biomass per tow for all benthic invertebrates. Coloured lines represent each of the top four taxa ranked according to 2016 values. Biomass values were standardized across the time series according to Benoît and Swain (2003) using the Gulf R package 1.0.7 (Surette and Vergara 2014).

Scotian Shelf

The Scotian Shelf can be divided into two broad regions to describe the fish and invertebrate community: the eastern Scotian Shelf (4W, 4Vs) and the western Scotian Shelf (4X) (refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada). The eastern Scotian Shelf was historically dominated by demersal fish, particularly Atlantic cod and haddock (*Melanogrammus aeglefinus*), which were the main target of commercial fisheries. On the western Scotian Shelf, there was also a large abundance of Atlantic herring, which supported an important pelagic fishery.

Fishing pressure was very high across the Scotian Shelf during the 1960s and early 1970s, with catches above the sustainable capacity of these ecosystems (Zwanenburg et al. 2006). Even though fisheries catches were reduced (most likely due to declining stocks) in the 1980s (Figure 3.4-9), many stocks had not recovered from the previous decade of exploitation.

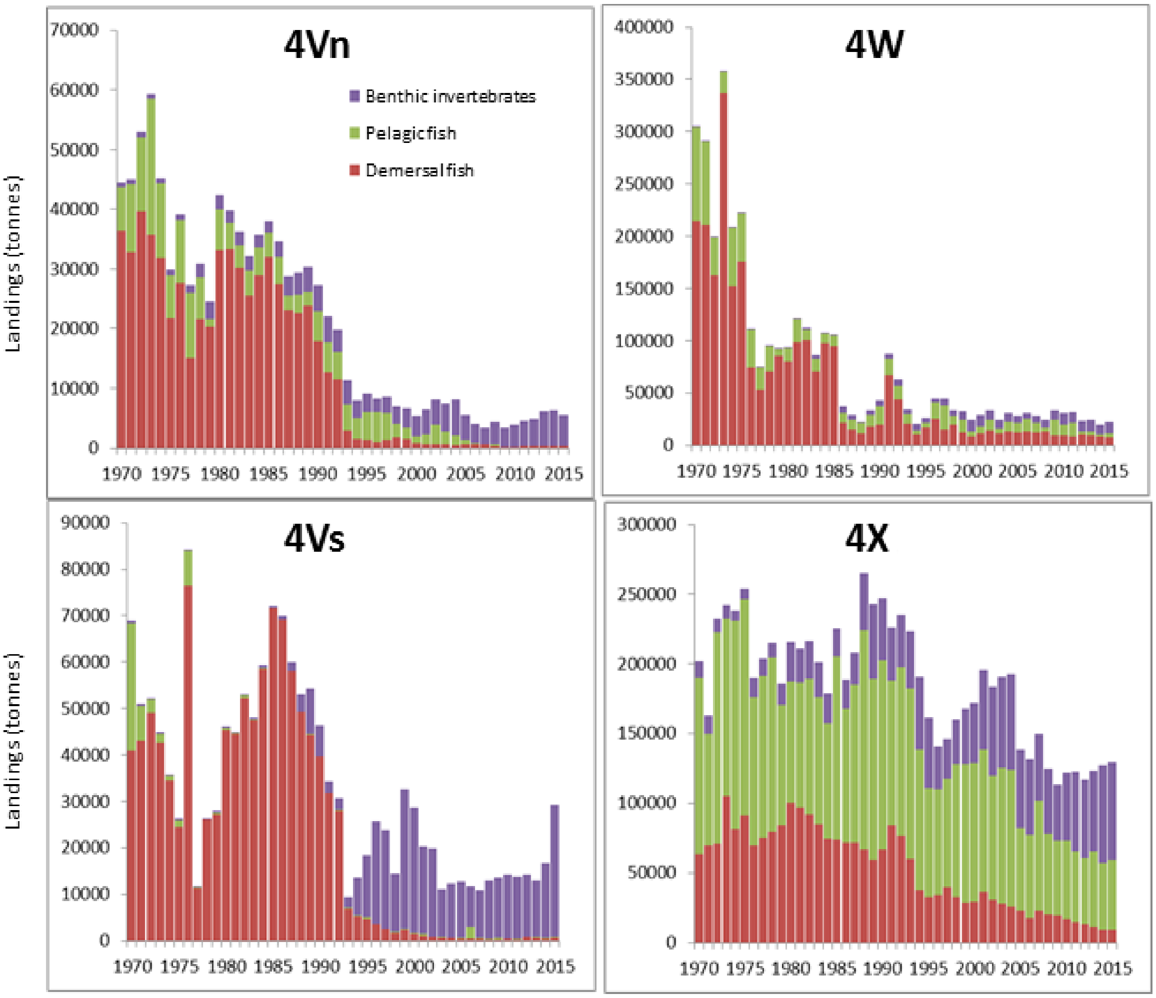

Figure 3.4-9. Scotian Shelf fish landing (tonnes) for different NAFO Divisions (1970–2015). Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

On the eastern Scotian Shelf, environmental conditions were also becoming less favourable for demersal fish production from the mid-1980s through the 1990s (Zwanenburg et al. 2006). Cooler waters in the east favoured benthic invertebrate species, such as northern shrimp and snow crab. As a consequence of these combined fishing and environmental pressures, the Scotian Shelf ecosystem changed dramatically during the late 1980s and early 1990s, with major declines in biomass of demersal fish (both commercial and non-commercial species) over the entire Scotian Shelf (Breeze et al. 2002; Zwanenburg et al. 2006) (Figures 3.4-10 and 3.4-11).

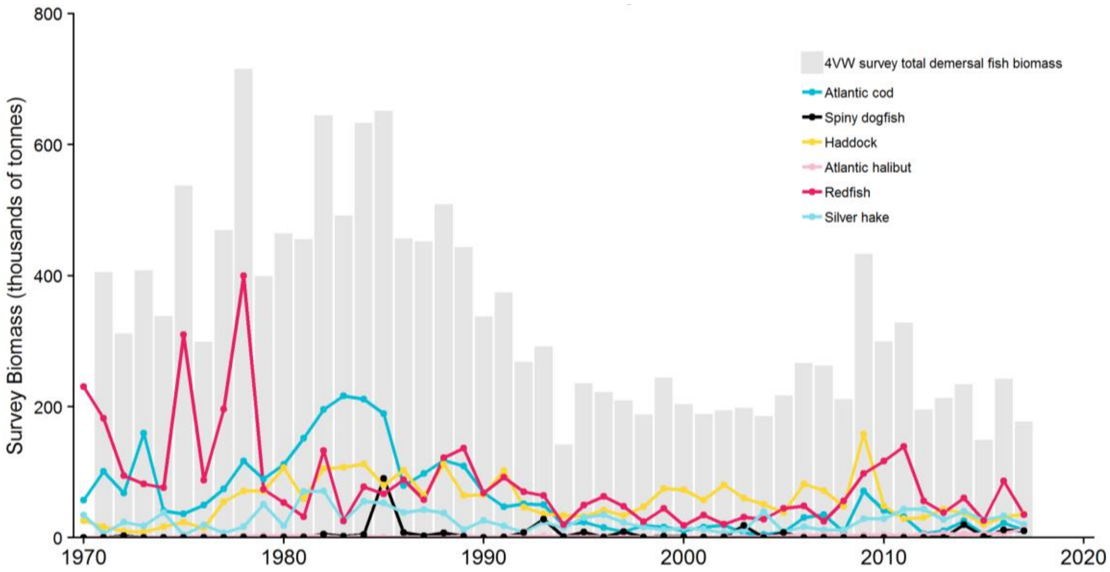

Figure 3.4-10. Research survey biomass for demersal fish and individual species on the eastern Scotian Shelf (4VW). Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

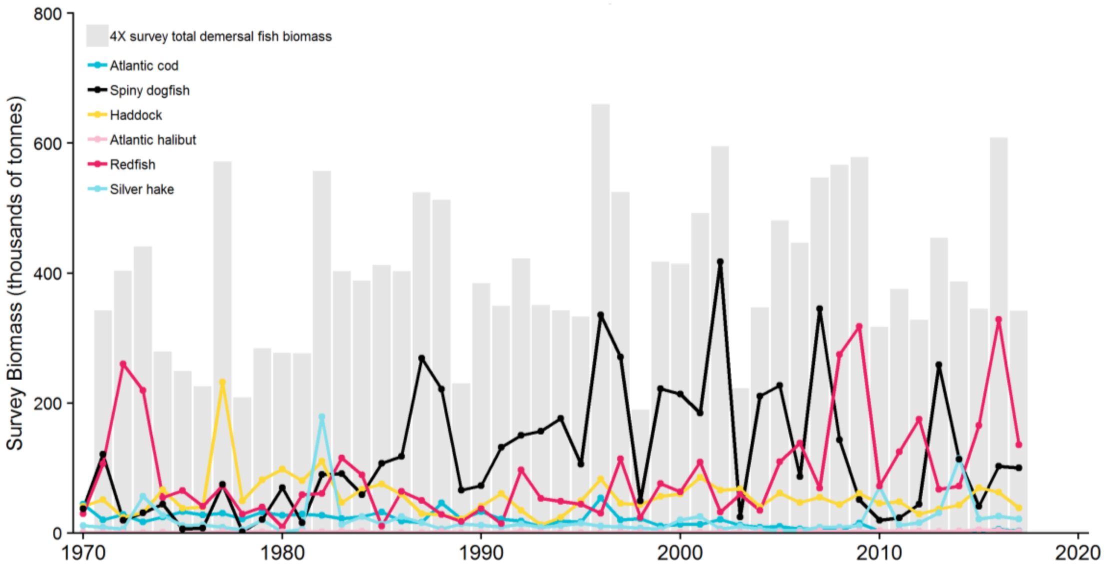

Figure 3.4-11. Research survey biomass for demersal fish and individual species on the western Scotian Shelf (4X). Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

In the east, this change was severe, with the total collapse of the Atlantic cod and Atlantic herring fisheries and dramatic declines in a number of demersal fish, such as haddock, white hake (*Urophycis tenuis*), pollock (*Pollachius virens*), silver hake (*Merluccius bilinearis*), and thorny skate (*Amblyraja radiata*) in the early 1990s (DFO 2003; Bundy 2005). Information from research vessel surveys suggested increased abundances of small pelagic fish on the eastern Scotian Shelf. However, the extent of this increase is not known because bottom trawl survey methodology used in this area was not designed to monitor pelagic fish and no reliable survey-based data series exists (Bundy and Fanning 2005; McQuinn 2009).

In the western Scotian Shelf, declines in commercial demersal fish stocks were less severe and total demersal biomass was highly variable, driven by the variability in spiny dogfish (*Squalus acanthias*) biomass (Shackell and Frank 2007) (Figure 3.4-11). However, the Atlantic herring stock experienced important declines in stock size in the late 1980s and early 1990s, leading to a continuous decline in that fishery ever since (Power et al. 2011). Demersal fish and Atlantic herring fisheries continue in this region, but catches are low relative to earlier periods (Figures 3.4-9 and 3.4-12).

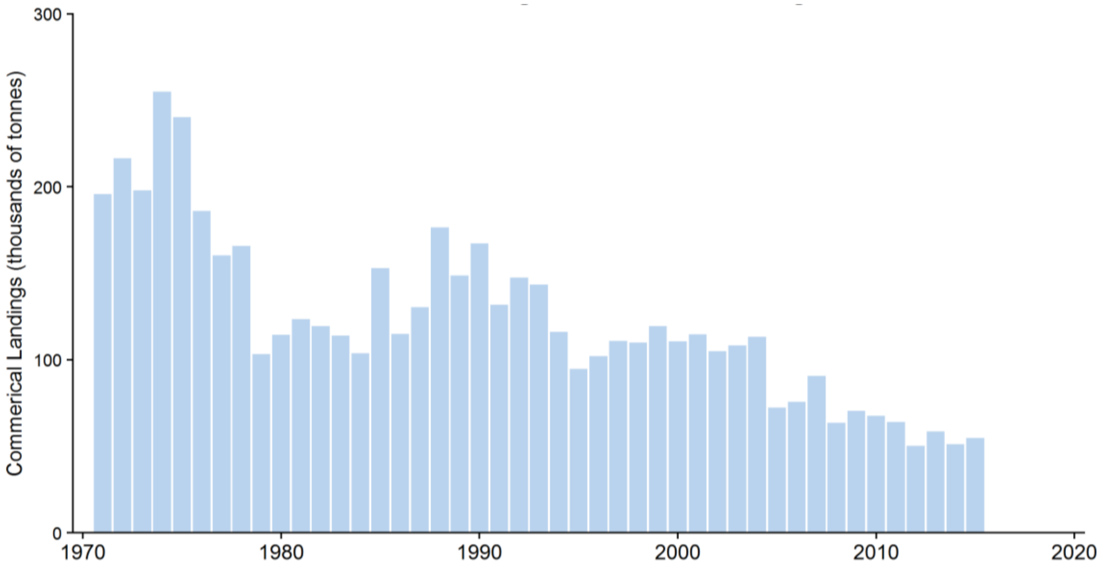

Figure 3.4-12. Pelagic fish commercial landings (thousands of tonnes) along the Scotian Shelf.

Across the Scotian Shelf, demersal fish biomass remains low but variable. In recent years, there have been increases of some demersal fish species, such as 4X haddock, and Scotian Shelf silver hake. Biomass of some demersal species such as 4X redfish and Atlantic halibut on the Scotian Shelf are at the highest levels ever observed. Despite some promising early signals, there has been no recovery of Atlantic cod (Figure 3.4-10 and 3.4-11).

Meanwhile, landings and biomass of benthic invertebrates have increased over the entire Scotian Shelf and are supporting important fisheries throughout the region (Figure 3.4-13). Pelagic invertebrate biomass recorded in research surveys is dominated by short-fin squid (*Illex illecebrosus*) and has fluctuated over time with no trend (not shown). Presently, as water temperatures rise across the bioregion, cold-water species like northern shrimp and snow crab are declining. In contrast, American lobster, which benefits from warmer temperatures, has seen its biomass rapidly increase since 2010 in the western Scotian Shelf (4X) and has expanded its distribution further east (4W) and into deeper water (Figure 3.4-13) (refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada).

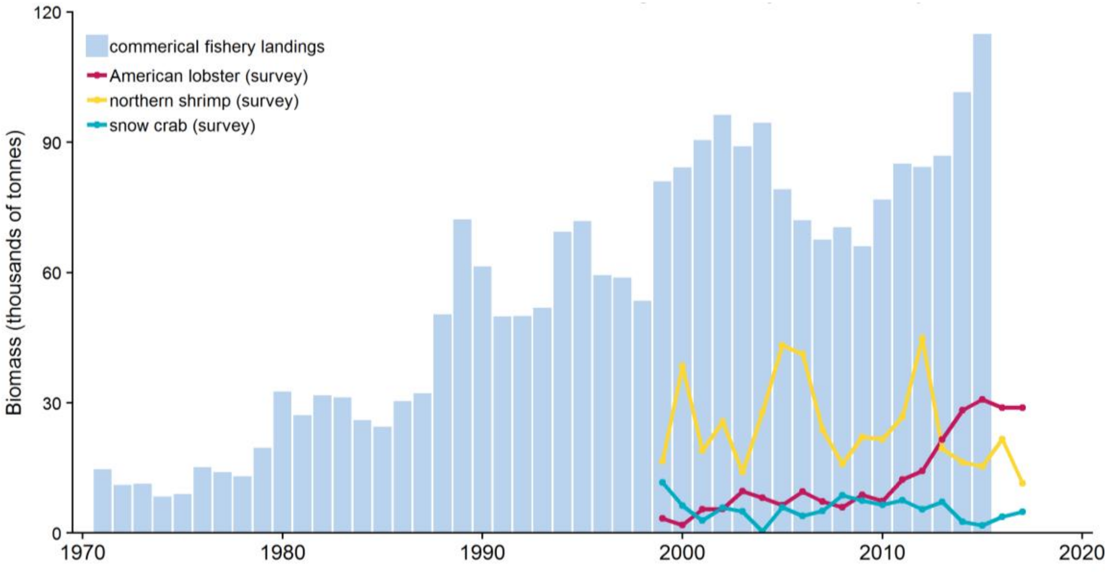

Figure 3.4-13. Scotian Shelf commercial landings for benthic invertebrate species and survey biomass (thousands of tonnes) for individual benthic invertebrate species. Commercial fishery landings show a long-term increasing trend. Collection of research survey data began in 1999.

Newfoundland and Labrador Shelves

There are four functional ecosystems currently identified in the Newfoundland and Labrador Shelves bioregion, three of which have long-term data: the Newfoundland Shelf, the Grand Bank, and Southern Newfoundland. These ecosystems were historically dominated by demersal fish, particularly Atlantic cod, which were also the main target of their fisheries (Figure 3.4-14).

Fishing pressure on these ecosystems was very high during the 1960s and early 1970s, with fishing catches at levels above the sustainable capacity of these ecosystems. Even though fisheries catches were lower in the 1980s, many stocks had not recovered from the previous decade of exploitation and some continued to be overfished at a time when environmental conditions were becoming less favourable for demersal fish production (Koen-Alonso et al. 2010, 2013; NAFO 2010, 2014, 2015a, 2016).

In the late 1980s and early 1990s, the entire bioregion underwent an abrupt shift in community structure (DFO 2006, 2014; NAFO 2010; Koen-Alonso et al. 2010; Dawe et al. 2012; Dempsey et al. 2017; Pedersen et al. 2017). Changes were observed earlier and were more dramatic in the northern area (Newfoundland Shelf) and were comparatively less severe in the south (Southern Newfoundland) but were felt all around. These changes involved major declines in demersal and pelagic fish, commercial and non-commercial species, most prominently the collapse of the northern cod stock. Capelin, a key forage species, collapsed in 1991 and has yet to rebuild to its pre-1991 levels. During this period, the cold environmental conditions together with reduced predation pressure from demersal fish is thought to have allowed the build-up of benthic invertebrates, such as northern shrimp and snow crab (Figures 3.4-14 and 3.4-15). Even though changing environmental conditions were important drivers of this abrupt ecosystem change, the overfishing experienced by many important fish stocks is believed to have weakened the ability of these ecosystems to tolerate environmental perturbations (Koen-Alonso et al. 2010, 2013;

Buren et al. 2014; Pedersen et al. 2017). The compounding effects of climatic and human forces created the perfect ecological storm.

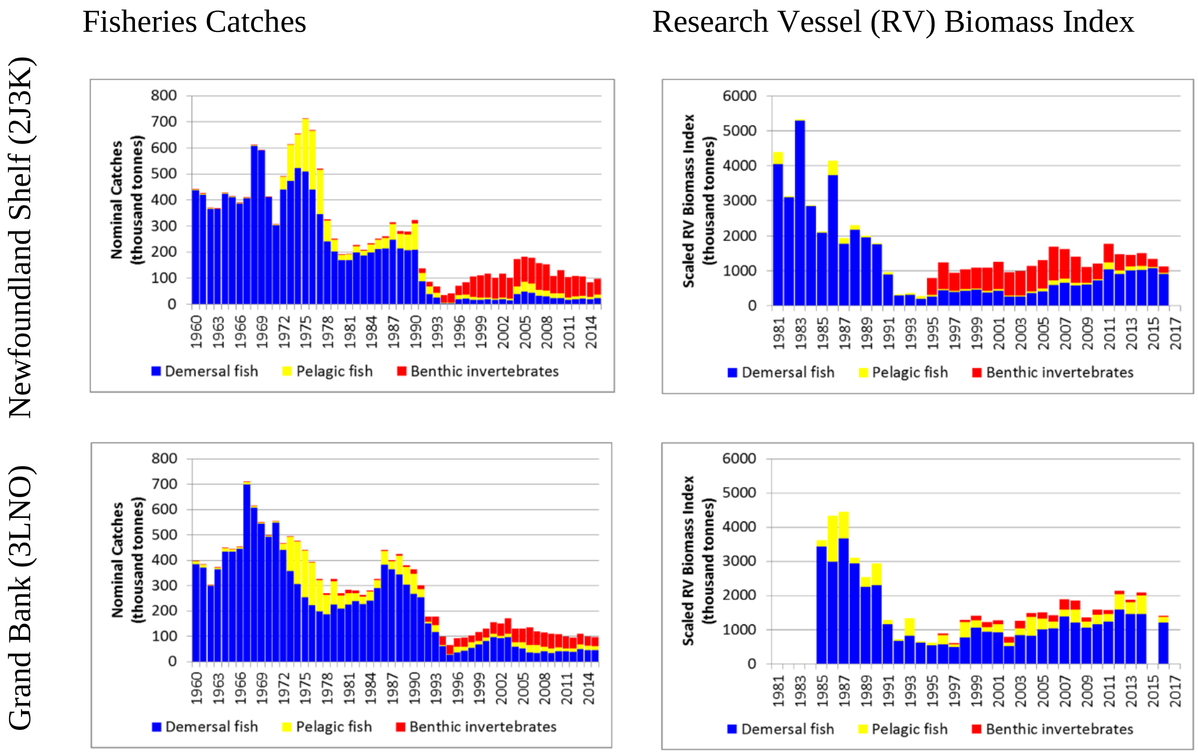

Figure 3.4-14. Fisheries catches and marine community trends in two functional ecosystems within the Newfoundland and Labrador Shelves bioregion: the Newfoundland Shelf (top) and the Grand Bank (bottom). Graphs on the left show nominal fisheries catches (summed weight of landed catches excluding unreported discarded catch); graphs on the right show trends in species aggregates from research vessel bottom trawl surveys. Refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada.

Sampling gear for research vessel bottom trawl surveys (Figure 3.4-15) was changed in 1994–1995, so scaling factors were applied to make biomasses coarsely comparable (NAFO 2014; Dempsey et al. 2017). Benthic invertebrate data are only available after the gear change; however, notwithstanding this limitation, benthic invertebrate biomass (dominated by northern shrimp) was at lower levels in the 1980s than what was observed in the 2000s (Lilly et al. 2000; DFO 2018b).

In the late 1990s and early 2000s, limited changes occurred in the fish community, with no obvious growth in demersal fish and high biomasses of benthic invertebrates. It is during this period that the shrimp and snow crab fisheries became dominant fisheries in this bioregion (DFO 2014; NAFO 2014, 2015b).

By the mid-late 2000s, the first signs of change appeared. Warmer environmental conditions, more favourable to demersal fish than cold-water invertebrate production, together with some modest improvements in capelin levels prompted an increase in demersal fish biomass while benthic invertebrates declined (DFO 2014) (Figure 3.4-15). These trends also reflect a changing internal structure of these ecosystems, with demersal fish regaining their dominance in the marine community. However, these changes do not necessarily mean a return to the same ecosystem structure that existed before the 1990s. Warmer water species like silver hake are becoming more dominant in some areas (Figure 3.4-16), signaling the kind of changes we could see in the future as climate change continues to unfold.

Despite the recent build-up of demersal fish, the total biomass in these ecosystems remains well below pre-collapse levels. Since the mid-2010s, there have been signs of reduced productivity, and in some cases, declines in total biomass (Figure 3.4-16).

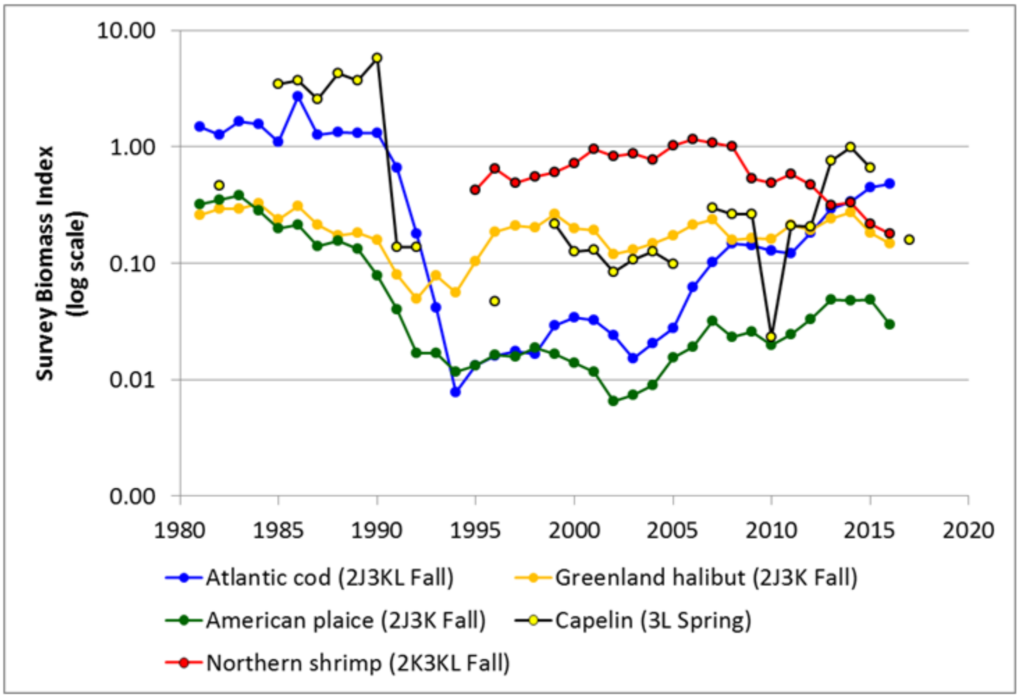

Figure 3.4-15. Research survey biomass trends for key fish stocks within NAFO Divisions 2J3K, 2J3KL, and 3L in the Newfoundland and Labrador Shelves bioregion (refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada). These biomass indices are based on bottom trawl surveys except capelin which is based on acoustic surveys, a better estimation method for small pelagic fish. Survey season and spatial coverage, denoted by NAFO Divisions, are indicated in parentheses beside each species name. Trends are presented in logarithmic scale, with each horizontal gridline representing a tenfold increase in biomass with respect to the preceding one for better visualization of trajectories at lower biomass levels. Shrimp survey data are only available since 1995.

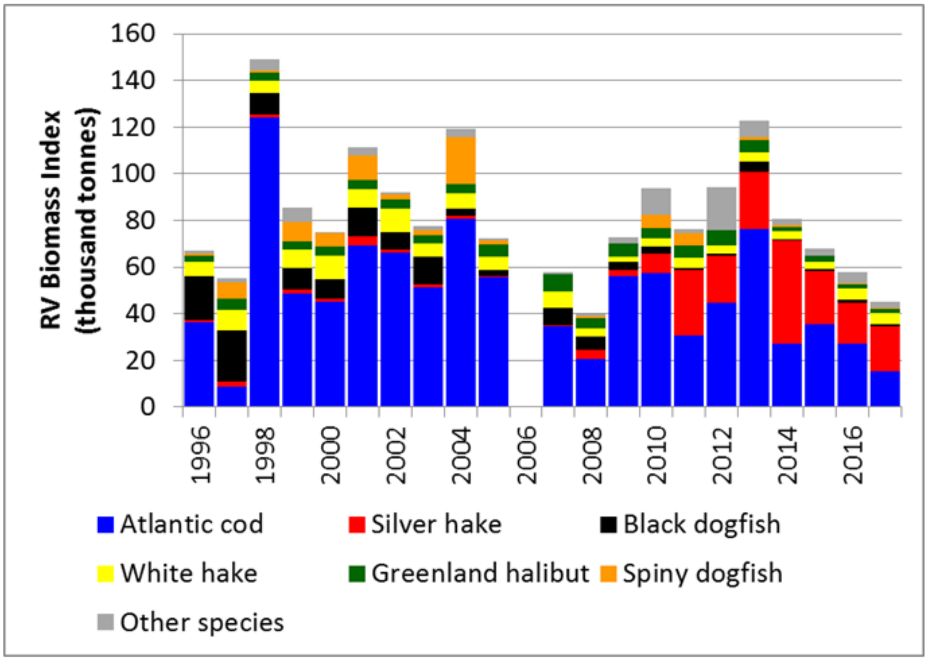

Figure 3.4-16. Research Vessel (RV) biomass trends from spring surveys for piscivore (primarily fish eaters) demersal fish in the Southern Newfoundland ecosystem (NAFO Sub-Division 3Ps; refer to Figure 3.1-1 for NAFO Divisions within Atlantic Canada). Atlantic cod has been the historically dominating species within this group, but silver hake has been increasing in dominance in recent years. Overall biomass of this group of species has been declining since 2014.

Summary

Marine fish and invertebrate communities across Atlantic Canadian waters experienced dramatic changes during the late 1980s and early 1990s. A major change across all bioregions of the Northwest Atlantic was the collapse of demersal fish. At the same time, cold-water benthic invertebrates like northern shrimp and snow crab increased rapidly in many areas. Atlantic mackerel declined across the entire Northwest Atlantic, but as a group, pelagic fish did not have consistent trends across the three bioregions. Important pelagic fish collapsed in some regions, like capelin in the Newfoundland and Labrador Shelves, and Atlantic herring in the western Scotian Shelf.

Since the mid-1990s, environmental conditions have generally been warming, with record highs across the bioregions in the late 2000s and 2010s. These warmer conditions may have improved conditions for coastal benthic invertebrates like American lobster, which increased in many areas, both in abundance and distribution. This warming trend also appears associated with increases and/or northward expansion of warm-water demersal fish (e.g., silver hake and Atlantic halibut). In contrast, cold-water benthic invertebrates (e.g., northern shrimp and snow crab) declined in some areas; this decline has been attributed to increased predation for northern shrimp in some areas and warming conditions for both northern shrimp and snow crab.

In recent years, early signals of the rebuilding of demersal fish were observed in some bioregions but not others. During the mid to late 2000s, demersal fish in the Newfoundland and Labrador

Shelves, including Atlantic cod, started to increase. Similarly, demersal species (mostly redfish but also Atlantic halibut, Greenland halibut, and Atlantic cod) increased in the northern Gulf of St. Lawrence, although Greenland halibut has declined recently, and Atlantic cod has declined in 2017. Atlantic cod has not recovered on the Scotian Shelf and the southern Gulf Atlantic cod continues to decline as a result of high natural mortality. Further, the increase in overall demersal fish biomass in the Newfoundland Shelf ecosystem has stalled and demersal fish biomass in the Grand Bank has declined.

Many pelagic fish that declined in the early 1990s have yet to show signals of rebuilding. Several populations, including those that did not collapse, have shown declining trends in the 2010s. These include Atlantic herring in the entire Gulf of St. Lawrence and western Scotian Shelf, and Atlantic mackerel, which collapsed across the North Atlantic. Capelin has once again shown declines since the mid-2010s in the Newfoundland and Labrador Shelves, after some modest improvements in the late 2000s and early 2010s. Pelagic species are an important food source for many demersal species, and as such, declines in pelagic fish may influence the recovery of demersal species.

This synthesis has revealed some additional emerging patterns that are important for understanding and assessing the state of marine fish and invertebrate communities in the Northwest Atlantic. First, although fish and invertebrate communities show some common trends and similar drivers across bioregions, there are also many important differences among bioregions. Second, fish and invertebrate communities have undergone numerous changes since the 1980s. This historical pattern of change should serve to caution against making the assumption that recent community trends will continue far into the future. Third, several of the changes in fish and invertebrate communities that were documented, like the collapse of demersal fish species, are thought to be brought about by a long history of overfishing, a rapidly changing environment and trophic interactions, but many of these trends in marine communities remain to be fully explained. Together these patterns suggest that conservation and management of the fish and invertebrate community in Canada’s Atlantic waters requires monitoring (including in the coastal zone) and research aimed to understand the impacts of a complex set of ecosystem drivers such as fishing, climate, and species interdependencies.

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3.5 MARINE MAMMALS

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The Northwest Atlantic is a transition zone between Arctic and tropical ecosystems. As such, several marine mammal species in the Northwest Atlantic have adapted to life at high latitudes to the degree that they spend their whole life within the region. These include both seal and whale species. Additionally, several cetacean species migrate into the northern waters to take advantage of high summer productivity, and hence feeding opportunities, but spend the rest of the year in their broader, largely temperate distributional ranges. Marine mammals are consumers of secondary production at most trophic levels in the Northwest Atlantic; some feed on zooplankton (e.g., blue whales; Beauchamp et al. 2009)) while others are high-level predators (e.g., harp seals; Lawson and Stenson 1997). As a result of high abundance (e.g., harp seals) or large biomass (e.g., large cetaceans), marine mammals are key trophic species in the Northwest Atlantic where they have important top-down influences on the structure and function of the communities they occupy. Comprehensive information is available on species that have been or are still being harvested and those of conservation concern, whereas other species are poorly known.

The northern portion of the area is dominated by the Labrador Current, which brings cold Arctic water down the Newfoundland and Labrador Shelves, which is the southernmost penetration of polar waters in the northern hemisphere (Rice 2002). The southern portion of the area, the Scotian Shelf, is warmed by Gulf Stream Current coming from the south, resulting in a rich mixing environment that produces an area of high productivity. The Gulf of St. Lawrence is a semi-enclosed area with marine input from the Labrador Current through the Strait of Belle Isle and to the Cabot Strait, and fresh water from the St. Lawrence River. As such, each area has a varying mix of Arctic and temperate species of marine mammals.

There are approximately 30 species of pinnipeds and cetaceans found in the Northwest Atlantic (Table 3.5-1). Several species, including Atlantic walruses, ringed seals, bearded seals, beluga whales, narwhals, and bowhead whales are considered Arctic species and have a circumpolar distribution (CAFF 2017). There are a number of vagrant species that occur only occasionally (Table 3.5-1).

Table 3.5-1. Residency status, availability of abundance estimates and trends in abundance of marine mammals in the Northwest Atlantic. * indicates species which are listed as species at risk under the Species at Risk Act (SARA) in Atlantic Canadian waters.

Common Name	Scientific name	Residency status	Abundance	Trend	Reference
Pinnipeds					
Atlantic walrus*	*Odobenus rosmarus*	Year-round resident	No	Unknown	
bearded seal	*Erignathus barbatus*	Year-round resident	No	Unknown	
grey seal	*Halichoerus grypus*	Year-round resident	Yes (2016)	Increasing	Hammill et al. (2017a)
harbour seal	*Phoca vitulina*	Year-round resident	Approximate	Unknown	Hammill and Stenson (2000)
harp seal	*Pagophilus groenlandicus*	Year-round resident	Yes (2014)	Stable	Hammill et al. (2015)
hooded seal	*Cystophora cristata*	Year-round resident	Yes (2006)	Increasing/Unknown	Hammill and Stenson (2006)
ringed seal	*Pusa hispida*	Year-round resident	No	Unknown	Kingsley (1998)
Cetaceans					
blue whale*	*Balaenoptera musculus*	Seasonal migrant; some wintering individuals	Approximate	Stable or declining	Beauchamp et al. (2009)
fin whale*	*Balaenoptera physalus*	Seasonal migrant	Yes (2007)	Unknown	Heide-Jørgensen et al. (2010); NAMMCO 2016; Lawson and Gosselin (2009)
humpback whale	*Megaptera novaeangliae*	Seasonal migrant	Yes (2007)	Increasing	Heide-Jørgensen and Laidre (2015); NAMMCO 2016; Lawson and Gosselin (2009)
minke whale	*Balaenoptera acutorostrata*	Seasonal migrant	Yes (2007)	Unknown	Lawson and Gosselin (2009); Heide-Jørgensen et al. (2010); NAMMCO 2016
bowhead whale	*Balaena mysticetus*	Year-round resident	Yes (2013)	Increasing	Doniol-Valcroze et al. (2015a)
beluga whale*	*Delphinapterus leucas*	Year-round resident	Yes (2015)	Decreasing	Marcoux et al. (2016); Mosnier et al. 2015; NAMMCO 2016
narwhal	*Monodon monoceros*	Year-round resident	Yes (2013)	Unknown	Doniol-Valcroze et al. (2015b); NAMMCO 2016
North Atlantic right whale*	*Eubalaena glacialis*	Seasonal migrant	Yes (2016)	Declining	Pace et al. 2017
sperm whale	*Physeter macrocephalus*	Year-round resident	No	Unknown	
sei whale	*Balaenoptera borealis*	Seasonal migrant	No	Unknown	
killer whale	*Orcinus orca*	Year-round resident	Approximate	Unknown	J.W. Lawson, DFO, unpublished data
northern bottlenose whale -Scotian Shelf population*	*Hyperoodon ampullatus*	Year-round resident	Nova Scotia: Yes (2009)	Stable	COSEWIC (2011)
-Davis Strait/Baffin Bay/Labrador Sea population			Davis Strait: Unknown	Unknown	
long-finned pilot whale	*Globicephala melas*	Year-round resident	Yes (2007)	Unknown	NAMMCO 2016; Lawson and Gosselin (2009)
harbour porpoise*	*Phocoena phocoena*	Year-round resident	Yes (2007)	Unknown	NAMMCO 2016; Lawson and Gosselin (2009)
white-beaked dolphin	*Lagenorhynchus albirostris*	Year-round resident	Yes (2007)	Unknown	NAMMCO 2016; Lawson and Gosselin (2009)
Atlantic white-sided dolphin	*Lagenorhynchus acutus*	Year-round resident	Yes (2007)	Unknown	Lawson and Gosselin (2009)
common dolphin	*Delphinus delphis*	Year-round resident	Yes (2007)	Unknown	Lawson and Gosselin (2009)
Sowerby’s beaked whale*	*Mesoplodon bidens*	Year-round resident	No	Unknown	
Cuvier’s beaked whale	*Ziphius cavirostris*	Year-round resident	No	Unknown	
True’s beaked whale	*Mesoplodon mirus*	Year-round resident	No	Unknown	
bottlenose dolphin	*Tursiops truncatus*	Summer migrant	No	Unknown	

Historically, walrus and bowhead whales were found in the Gulf of St. Lawrence and on the Scotian Shelf, but they were extirpated due to hunting by the early 1800s. Harp seals and hooded seals are seasonally resident in the Arctic regions of the Northwest Atlantic, but most individuals move southward to breed and feed near the southern edge of the seasonal pack ice during the winter.

A number of temperate species are present year round, primarily in southern areas: harbour seals, grey seals, northern bottlenose whales, Atlantic white-sided dolphins, harbour porpoises, white-beaked dolphins, long-finned pilot whales, and killer whales. Many of the large cetaceans are summer migrants in the higher latitudes: common dolphins, bottlenose dolphins, North Atlantic right whales. They are thought to give birth and mate in temperate and tropical waters during winter then move northward to feed in highly productive ecosystems where cold and warm waters mix. These whales exploit a variety of fish and crustacean species and sizes but generally selectively forage on capelin, Atlantic herring, and krill (e.g., Stevick et al. 2003; Wassmann et al. 2006). When they arrive at their northern feeding grounds they are extremely lean, but during their stay, particularly during late summer and autumn (July–September; Næss et al. 1998), they build up energy reserves, which are deposited in their blubber layer. However, even among this group, a number of individuals may remain in northern waters during the winter, such as minke whales and blue whales.

Our understanding of marine mammal distribution varies significantly among species. For some, particularly harp seals, hooded seals, and grey seals, we have been able to monitor movements and diving behaviour with satellite telemetry (e.g., Bailleul et al. 2012; Harvey et al. 2012; Andersen et al. 2013; Lesage et al. 2016). From this we have determined seasonal distribution and habitat use (e.g., hooded seals, Figure 3.5-1). For many cetaceans, our understanding of their distribution is based on sightings from surveys and opportunistic reports (Figure 3.5-2). Habitat models developed from this information provide us with insights into where marine mammals might occur and what factors influence their distribution. For example, Gomez et al. (2017) identified potential habitat for blue whales and northern bottlenose whales in Canadian waters using a model that incorporated available sighting data, physical features, and primary productivity (persistent chlorophyll) (Figure 3.5-3). Models predicted priority areas for blue whales along the outer margins of the eastern and western Scotian shelf and southern portions of the Newfoundland Shelf. Areas of low priority for blue whales were in northern Labrador and off eastern Newfoundland. For northern bottlenose whales, depth was the primary predictor and primary areas were predicted along the outer margins of the Scotian Shelf and Newfoundland and Labrador Shelves. To date, most habitat models have relied primarily on physical variables (e.g., depth, sea-surface temperature, topographic complexity, and chlorophyll) as proxies for other factors that animals respond to directly. As we gain a better understanding of how prey abundance influences distribution of predators (e.g., Laidre et al. 2010) and how, in turn, prey abundance responds to changes in the physical environment (e.g., Fossheim et al. 2015), our ability to understand which habitats are used by these species will improve and we will be better able to predict the impact of changes in their ecosystems.

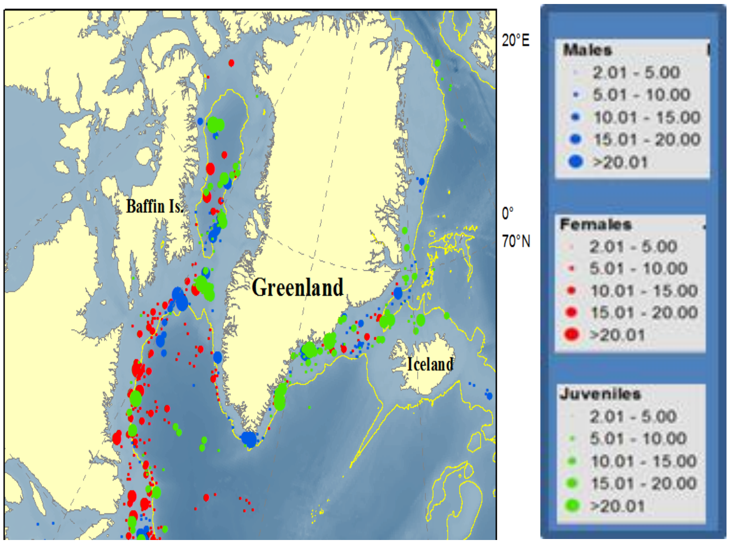

Figure 3.5-1. Important areas used by hooded seals during the fall and winter (from Andersen et al. 2013).

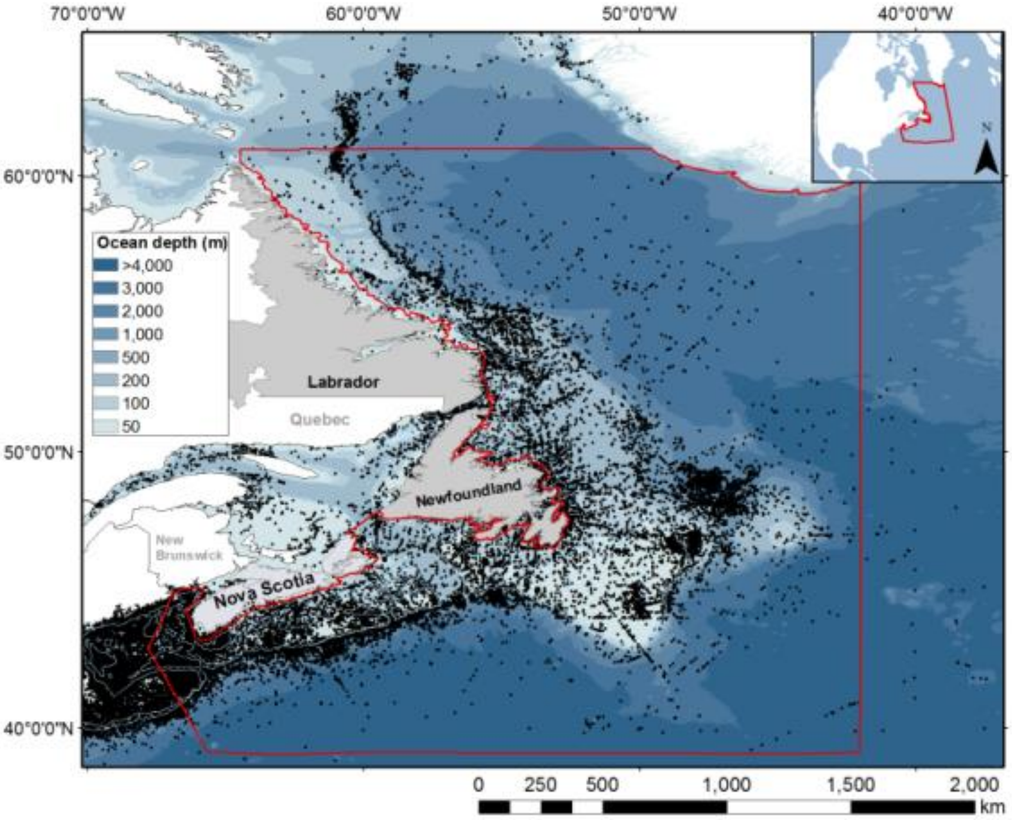

Figure 3.5-2. Sighting records of cetaceans (all species combined) during the post-whaling period (1975–2015) (J.W. Lawson, DFO, unpublished data).

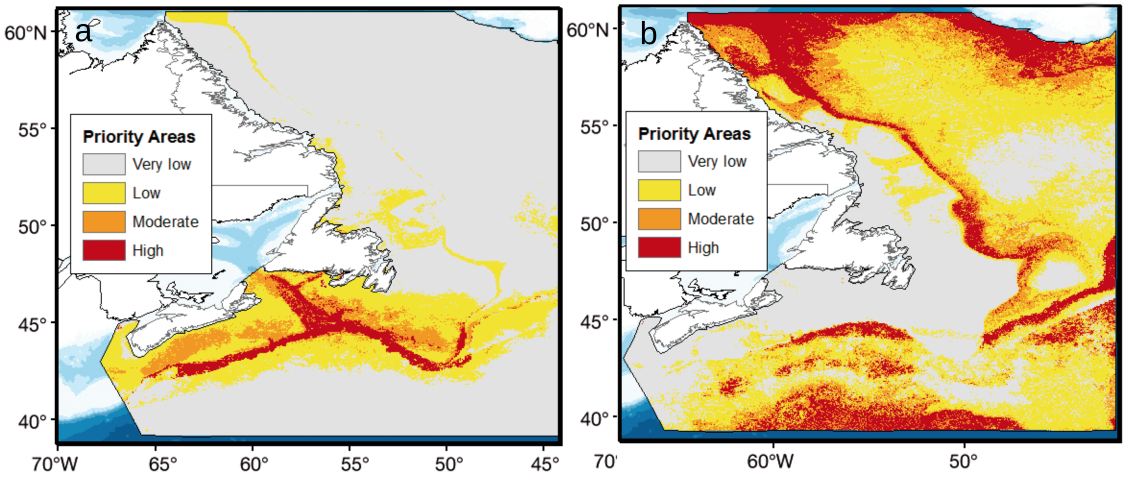

Figure 3.5-3. Results of a habitat model identifying priority areas for a) blue whales and b) northern bottlenose whales (from Gomez et al. 2017).

Unfortunately, although general distribution, particularly along the coasts, is reasonably well known, abundance and trend information are not available for many species of marine mammals (Table 3.5-1). The best estimates of population size and trends are for species taken in the subsistence harvest in the Arctic (e.g., beluga whales, narwhals, and bowhead whales), taken in commercial hunts (e.g., harp seals, hooded seals, and grey seals), or studied as SARA-listed species (e.g., St. Lawrence Estuary beluga whales and North Atlantic right whales). Abundance estimates, which are usually obtained from aerial surveys, are available for some of the other large cetaceans (although many of these estimates are old), but many species, particularly small cetaceans and the other seals, are not known (Table 3.5-1). With few exceptions, data on trends in abundance are absent (Figure 3.5-4). For example, the first comprehensive survey of cetaceans along the Canadian continental shelf was carried out in 2007 (Lawson and Gosselin 2009). It estimated the total number of cetaceans in the area from the northern tip of Labrador to the southern Scotian Shelf and Gulf of St. Lawrence as part of a trans-Atlantic study of cetacean abundance and distribution (referred to as the TNASS). Many of these estimates will be updated in the near future, when results from a survey in the same area in 2016 become available.

Given the wide-ranging movements of many marine mammals that respond to ecosystem changes on an ocean basin level, it can be difficult to determine if changes in abundance observed between surveys are due to real changes in abundance or simply changes in distribution that will impact stock estimates and perceived population trends. For example, off West Greenland, estimates of abundance for minke, fin, and humpback whales were lower in 2015 than in 2007 (NAMMCO 2016). Although these species are hunted to an extent, catches do not seem to account for enough removals to explain the lower estimates, and it is speculated that many simply moved to East Greenland where the abundance of many prey species has increased. While we tend to manage marine mammals on the basis of feeding areas, the genetic data for many marine mammals (e.g., hooded seals and minke whales; Coltman et al. 2007) suggest larger scales of distribution, at least within the Northwest Atlantic. Therefore, it is important for better understanding of trends in abundance that coordinated, basin-wide surveys are carried out similar to those that were conducted in 2007.

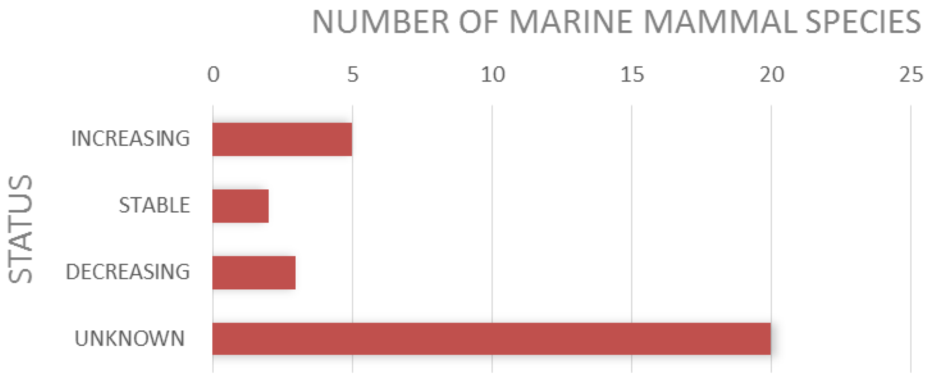

Figure 3.5-4. Current population trends of marine mammals in the Northwest Atlantic summarizing available data from literature cited in Table 3.5.-1.

As abundant, high trophic level predators, marine mammals are important components of their ecosystems and can serve as indicators of ecosystem change. The high mobility of many species allows them to shift distributions, which may indicate different prey availabilities and/or environmental conditions. For example, the large number of mortalities of endangered North Atlantic right whales observed in 2017 appears to be, in part, due to a redistribution of whales from the Bay of Fundy summer feeding grounds to the southern Gulf of St. Lawrence, likely in response to change in prey availability. The combination of their unique behavior and changes in their distribution from traditional areas has increased their risk of exposure to entanglement with fishing gear and ship strikes, which are important sources of mortality for right whales as well as other species (Van der Hoop et al. 2012; Baumgartner et al. 2017).

Marine mammals are subject to a variety of stressors from increasing oil and gas exploration and production (e.g., sound and contaminants), marine mining (e.g., contaminants), commercial fisheries (e.g., bycatch and entanglements), tourism (e.g., noise and disturbance), pollution (e.g., contaminant loading, and lethal and sub-lethal impacts), and shipping (e.g., noise and vessel strikes). Together, these stressors may impact marine mammal populations and in turn, their ecosystems. Noise, for example, can cause interference with feeding and/or social communication. These stressors are superimposed on a period of tremendous environmental change related to climate in the Northwest Atlantic, with Arctic and sub-Arctic areas expected to show the most rapid changes, including in temperature, ocean circulation, pH, sea ice cover, and sea level (McCarthy et al. 2001; IPCC 2007; Walsh 2008). The potential impact of climate change on marine mammals has been reviewed by a number of authors (e.g., Kovacs and Lydersen 2008; Laidre et al. 2008, 2015; Kovacs et al. 2011; Stenson and Hammill 2014; Haug et al. 2017). Higher primary productivity in northern areas could result in higher concentrations of zooplankton which may benefit some marine mammals, such as bowhead whales, but the loss of prey species that depend on cold waters (e.g., Arctic cod and amphipods) could have negative impacts on other marine mammals, such as ringed seals (Eamer et al. 2013). The changes associated with climate change are likely to be most severe on ice-dependent species, particularly those that inhabit the rapidly changing southern ice edge (Walsh 2008).

One of the first expected, observable responses due to changes in sea ice extent and a northward shift in prey distribution in the highly mobile pinnipeds and cetaceans would be changes in distribution. For example, warmer water and less ice appear to have resulted in higher frequencies of visits by killer whales to the northern areas of the Atlantic. This will most likely result in higher rates of predation among endemic and other ice-associated Arctic marine mammals (Kovacs et al. 2011; Higdon et al. 2012). Warming temperatures at the southern limits may also favour northward expansion of fish that prey on marine mammals, such as sharks (Cairns et al. 2008). Although changes in temperature might encourage northward range expansions by some marine mammal species, migrants among the summer residents may face risks of insufficient energy availability if their timing of arrival on the feeding grounds does not match the peak abundance of prey on which they usually rely (Learmonth et al. 2006; Kovacs and Lydersen 2008) or if they must occupy areas where food resources are more difficult to access (Hamilton et al. 2015). Nevertheless, if temperate species were to expand their ranges northwards and for longer seasons, such that their diets and spatial distributions overlap with resident populations, this may potentially add competitive stress on resident populations (Kovacs et al. 2011). Such conditions might be particularly serious for small, already threatened populations, such as St. Lawrence Estuary beluga whales, which appear to have limited opportunities to expand their distribution due to a combination of cultural inertia, life history limitations, and anthropogenic stressors (DFO 2014).

The observed decline in sea ice has a direct impact on a number of species, particularly ice-breeding seals. For example, the decline in sea ice has resulted in increased mortality of harp seals that pup on ice (e.g., Stenson and Hammill 2014). Stenson and Hammill (2014) found that if no sea ice was present at the beginning of the pupping period, females moved away from their traditional whelping areas to find suitable ice. However, if small amounts of ice were present, females gave birth even if the ice was too thin to sustain the pups, resulting in high pup mortality. There was no evidence to indicate that harp seals pupped on land, even in areas where ice was absent. If the predicted warming trends continue, ice-breeding harp seals will encounter more years with poor ice conditions in the Atlantic and may eventually adapt by moving north. Until then, they will continue to have increased levels of mortality that could result in the disappearance of the most southern breeding component in the Gulf of St. Lawrence. In contrast, grey seals in the Gulf of St. Lawrence breed on pack ice if available, but pup on land if ice is not present (e.g., Hammill et al. 2007). In the Gulf of St. Lawrence, almost all pupping was on pack ice during the early 1990s but, as sea ice condition has declined over the past three decades, virtually all grey seals now give birth on land (Hammill et al. 2017b).

The decline in ice in the Gulf of St. Lawrence may also benefit some species. Blue whales occur along the southwest coast of Newfoundland during the early spring where they feed along the ice edge at the mouth of the Gulf of St. Lawrence. Unfortunately, because of the currents and nature of the coastline, they can be trapped there during heavy ice years and pushed onto shore (Stenson et al. 2003). In 2014, nine mature blue whales were killed along the southwest coast of Newfoundland (Stenson and Lawson, unpublished data). Such high levels of mortality may be having an impact on recovery of the population, so declining sea ice in the Gulf of St. Lawrence (Johnston et al. 2005; Bajzak et al. 2011) may lessen this source of mortality and potentially allow the population to increase.

In addition to implications for direct mortality, declines in sea ice can also have indirect impacts on marine mammals. Long-term fluctuations in reproductive rates and declines in body condition have been observed in Northwest Atlantic harp seals over the past 40 years. Since the early 1980s, late-term pregnancy rates (ranging from 0.2 to 0.86) among mature females have declined while interannual variability has increased. Stenson et al (2016) found that while the general decline in pregnancy is associated with increased population size, the interannual variability could be explained by variation in the abortion rates. Changes in abortion rates were described by a model that incorporated capelin biomass and mid-winter ice cover (likely a proxy for ecosystem changes in overall prey abundance).

A key gap in our understanding of the status of marine mammals and their ecological role in the Northwest Atlantic is the lack of data on the abundance of many species, particularly small cetaceans, and trends in these data. Recent large-scale surveys will provide a better understanding of changes in abundance, but such surveys will need to be repeated before trends can be determined. Long-term studies of some species (e.g., harp seals, St. Lawrence Estuary beluga whales, and grey seals) are now providing sufficient data to explore hypotheses about how vital rates change as abundance and prey availability change. New technologies, such as satellite telemetry that gathers data on oceanographic conditions and animal movement and behaviour, along with improved modelling of habitat use will increase our understanding of the factors that influence marine mammal habitat use, prey selection, and response to their environment. As highly visible components, marine mammals provide us with an excellent means to monitor their ecosystem and indicators of how physical changes in their environment impact ecological functioning.

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3.6 SEA TURTLES

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There are seven extant species of sea turtle, four of which occur in Atlantic Canadian waters. These are the leatherback turtle (*Dermochelys coriacea*), the loggerhead turtle (*Caretta caretta*), the green turtle (*Chelonia mydas*), and the Kemp's ridley turtle (*Lepidochelys kempii*).

Both leatherback and loggerhead turtles are listed as endangered under Canada's *Species at Risk Act* (COSEWIC 2010). Under the United States *Endangered Species Act*, leatherback turtles are classified as endangered throughout their range (Tiwari et al. 2013), whereas the Northwest Atlantic distinct population segment of loggerhead turtles is classified as threatened (Ceriani and Meylan 2017). Green turtles and Kemp's ridley turtles are not currently listed under the *Species at Risk Act.* Globally, green turtles are classified as endangered and Kemp's ridley turtles are listed as critically endangered under the IUCN Red List (Seminoff 2004; Marine Turtle Specialist Group 1996).

As the sole member of the family Dermochelyidae, leatherback turtles diverge markedly from cheloniid (hard shell) sea turtles in both morphology and behaviour. Leatherbacks have a teardrop-shaped carapace with seven longitudinal ridges (Eckert et al. 2009); the entire body—including the shell—is covered in skin; and individuals in Canadian waters can attain a curved carapace length of 175 cm and body mass of 640 kg (James et al. 2007). The species is counted among the deepest diving air-breathing vertebrates, reaching depths greater than 1200 m; however, behaviour in Canadian waters is normally characterized by relatively short (<12 min) and shallow (<50 m, photic zone) dives (Wallace et al. 2015).

Among the three species of cheloniid sea turtle found in Atlantic Canadian waters, the loggerhead is the most regularly encountered (Bleakney 1965; Witzell 1999; McAlpine et al. 2007), with large juveniles principally represented among pelagic longline fisheries bycatch (Brazner and McMillan 2008). Loggerheads in Atlantic Canada inhabit the epipelagic zone, spending most of their time in near-surface waters, with behaviour characterized by extended surfacing intervals. Records of green and Kemp's ridley turtles in Atlantic Canada are relatively rare and largely limited to animals found stranded along the coast (James et al. 2004; McAlpine et al. 2007). Most strandings have occurred in late autumn and were linked to cooling ambient ocean temperature and onset of hypothermia.

Leatherback turtles are highly migratory, with adults and subadults undertaking annual migrations between foraging and reproductive areas in the tropical and subtropical Atlantic and high latitude temperate foraging habitat (James et al. 2007; Bond and James 2017). DNA analysis and passive identification tagging have confirmed that leatherbacks found in Atlantic Canadian waters originate from nesting assemblages in over a dozen countries in the Caribbean, South America, and Florida (James et al. 2007; Stewart et al. 2013; Roden et al. 2017). Leatherbacks seasonally inhabit both continental shelf and offshore waters of Atlantic Canada, arriving as early as June and departing as late as December (Figure 3.6-1).

The distribution of juvenile loggerhead sea turtles in the Northwest Atlantic is constrained by ocean temperature, with most sightings concentrated during the summer and fall in warm, offshore waters, especially those influenced by the northern edge of the Gulf Stream (Witzell

1999; Brazner and McMillan 2008). Preliminary genetic studies indicate that nesting beaches in the southeastern United States, including those in Florida and the Carolinas, are the principal source populations for loggerheads in Canadian waters (K.R. Stewart, NOAA, and M.C. James, DFO Maritimes, unpublished data).

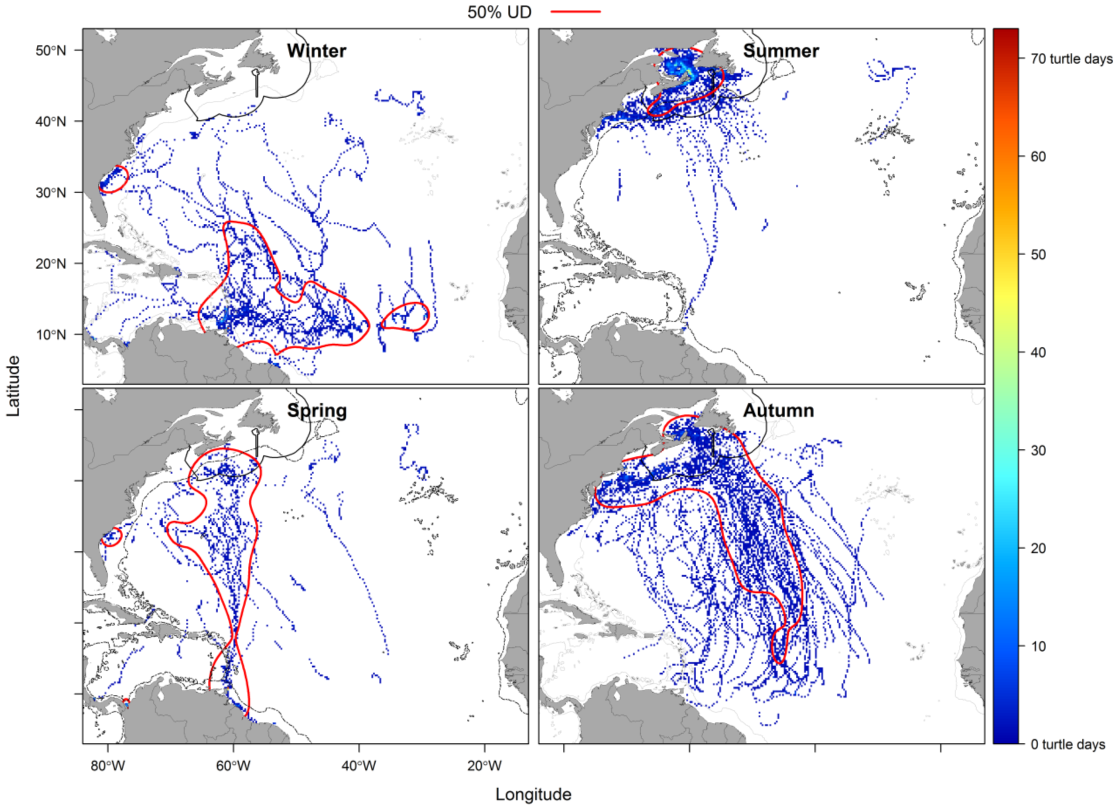

Figure 3.6-1. Leatherback sea turtle annual movements acquired through satellite tag deployments in Canadian waters from 1999 to 2016. Tracking data were reduced to the single best daily location (based on the highest quality Argos-derived position classification) and summed over 0.25 x 0.25 cells within the Northwest Atlantic. High-use areas are defined as 50% volume contours overlaid in red for each season: Winter (January, February, and March); Spring (April, May, and June); Summer (July, August, and September); and Autumn (October, November, and December). Data source: M.C. James, DFO.

Atlantic sea turtles occupy various habitats during different life stages, including beaches, nearshore coastal waters, and the open ocean. The majority of their lives are spent at sea, with mature female turtles returning to nest at two- to three-year remigration intervals. Sea turtles are exploited by a broad suite of marine predators, including birds and finfish, and sea turtle eggs and hatchlings experience high levels of predation in the terrestrial environment. As such, sea turtles transport nutrients and energy between marine and terrestrial ecosystems (Bouchard and Bjorndal 2000).

Leatherback turtles are believed to be one of the few marine species that rely solely on a relatively low-energy diet of gelatinous zooplankton, including jellyfish, ctenophores, and salps. The principal prey for leatherbacks in shelf waters of Atlantic Canada are lion’s mane jellyfish (*Cyanea capillata*) and moon jellyfish, *Aurelia aurita* (James and Herman 2001; Heaslip et al.

2012; Wallace et al. 2015). Jellyfish are an efficient predator of zooplankton and larval fish (Acuña et al. 2011), thus leatherbacks in some areas may play an important role in limiting the prey clearance potential of jellyfish aggregations, thereby contributing to ecosystem balance.

Loggerhead turtles are carnivores that feed on various crustaceans, jellyfish, squid, and fish. The offshore distribution of juvenile loggerheads in Atlantic Canada suggests opportunistic foraging—including scavenging—on a variety of epipelagic prey. However, larger size classes of loggerheads target benthic shellfish, including scallops, horseshoe crabs and mussels, and other invertebrates (Bjorndal 1997).

Leatherback turtles have been opportunistically surveyed annually in high-use foraging areas off the coast of Nova Scotia since 2002. Analysis of sightings per unit effort over a 14-year time period suggests that this population is likely stable (Archibald and James 2016). Cheloniid sea turtles are reported in Atlantic Canadian waters on an annual basis; however, dedicated in-water sampling effort was initiated in 2012 and surveys have proven impractical, thus population size and trends in Canadian waters remain unclear.

The primary threat to sea turtles in Atlantic Canadian waters is incidental capture in fisheries. Fixed-gear fisheries have been identified as a key threat to leatherbacks foraging in shelf waters of Atlantic Canada (James et al. 2005; Hamelin et al. 2017), and pelagic longline fisheries regularly interact with both leatherback and loggerhead turtles (James et al. 2006; Brazner and McMillan 2008). Pelagic longline fisheries have been identified as a threat to juvenile loggerheads in particular, as their foraging habitats overlap with productive fishing areas and their opportunistic, carnivorous diet leads them to target baited hooks used in these fisheries. For the period of 1999 to 2006, it was estimated that 9,592 juvenile loggerhead turtles were incidentally captured by Atlantic Canada’s large pelagic longline fleet (Brazner and McMillan 2008).

Beyond Canadian waters and throughout their life cycles, all sea turtle species are vulnerable to a variety of anthropogenic threats. These include, but are not limited to, illegal harvesting of nesting females and eggs (Tomillo et al. 2008), beach development and habitat loss (Witherington and Martin 2000), oil and gas exploration (Lutcavage et al. 1995), and ingestion of marine debris (i.e., plastic) which may resemble natural prey such as jellyfish (Carr 1987; Mrosovsky et al. 2009).

While in-water sampling, application of identification tags, and telemetry studies have provided insight into population characteristics, movements, foraging behaviour, and habitat use of leatherback and loggerhead turtles, the relationships between physical and biological oceanographic variables and turtle habitat remain unclear. Understanding why and how sea turtles interact with different types of fishing gear, assessing associated survival outcomes, and identifying how best to mitigate turtle and fishery interactions remain largely unresolved themes. Seasonal sea turtle population density in Canadian waters remains unknown for all species.

Atlantic Canadian waters provide important sea turtle habitat for approximately six months of the year. International collaboration involving governments, scientists, and conservation organizations is essential to the management and recovery of sea turtle populations that use Atlantic Canadian waters. Knowledge of sea turtles in Atlantic Canada has strongly benefitted from the contributions of commercial fishers (e.g., Goff and Lien 1988; Martin and James 2005), and their continued participation in all aspects of sea turtle research and conservation is critical.

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3.7 SEABIRDS

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Seabirds are among the most visible organisms in the marine landscape. As top predators and excellent samplers of the marine environment, seabirds can be used as indicators of the general health of the ocean environment. The eastern Canadian coastlines bordering the Atlantic Ocean and Gulf of St. Lawrence are host to approximately 10 million breeding seabirds of over 20 different species. Colonies of national and international importance for several species are found in this region. The productive waters of the Northwest Atlantic also attract millions of non-breeding seabirds of over 60 different species, with many migrants coming from the Arctic, Europe, and even South America. A recent assessment of the conservation outlook for all seabirds and ocean-associated species, including those that rely on marine and coastal habitats during the non-breeding season, showed that most species that occur in the Canadian Atlantic are of moderate conservation concern (NABCI 2016). This report provides an overview of the overall population trend of seabirds breeding in the Northwest Atlantic and discusses findings in light of threats faced by seabirds breeding in this region.

Systematic population monitoring of the major seabird colonies in Canada’s Northwest Atlantic has been ongoing since the 1970s with results showing that the breeding population of seabirds in eastern Canada has increased over this time period (NABCI 2012; Figure 3.7-1). In particular, species of the Alcidae family, such as common murres (*Uria aalge*) and Atlantic puffins (*Fratercula arctica*) (Figure 3.7-2), have experienced moderate to large population growth as a result of fewer gillnets being placed in inshore waters since the closure of the large-scale groundfish fishery in 1992, which had been responsible for high levels of seabird mortality (Regular et al. 2013). Alcids are also particularly vulnerable to oil pollution as they spend much of their lives on the surface of the ocean. Fortunately, the practice by ocean-going vessels of illegally discharging oil along the Atlantic coast has declined over the past 15 years. This is evidenced through fewer oiled birds found along the beaches of Newfoundland and Nova Scotia (Wilhelm et al. 2009; Lucas et al. 2012). Northern gannets (*Morus bassanus*) have also been experiencing population growth since the 1970s by restricting the use of pesticides in North America (Chardine et al. 2013). Prior to restrictions imposed in the 1970s, northern gannets were exposed to DDT in the marine environment, which negatively impacted their ability to successfully hatch chicks (Chapdelaine et al. 1987).

In contrast, surface-feeding species, such as herring gulls (*Larus argentatus*) and black-legged kittiwakes (*Rissa tridactyla*), have shown moderate to large population declines across the region since the early 1990s. This is a result of large-scale changes in oceanographic conditions that affect the availability of prey fish as well as reduced availability of fish discards since the groundfish moratorium (Wilhelm et al. 2016; Descamps et al. 2017).

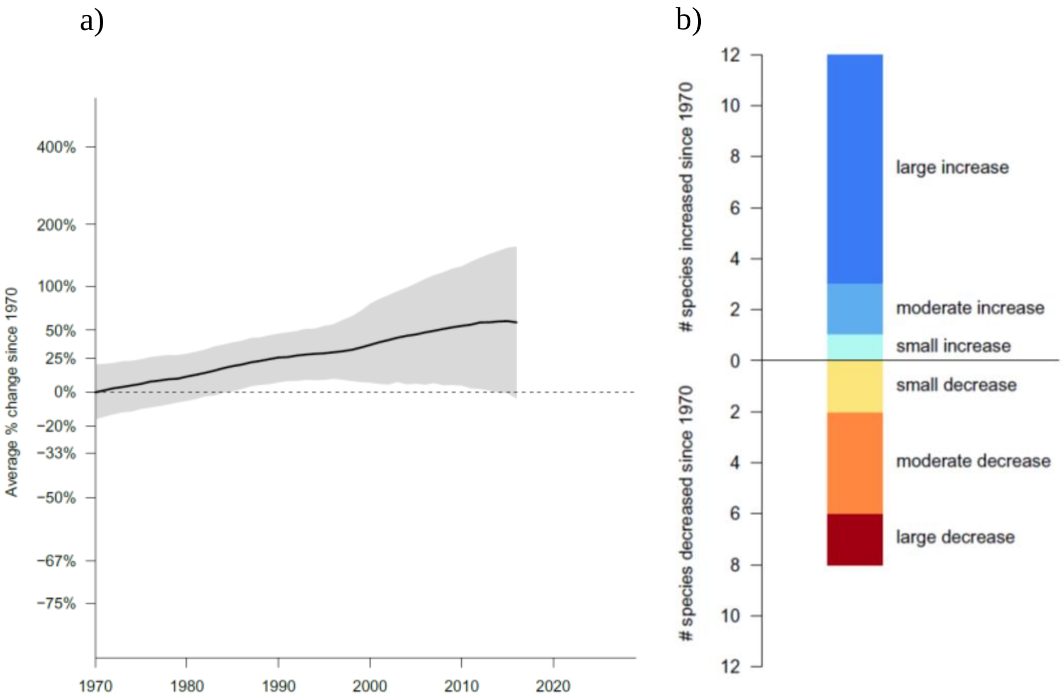

Figure 3.7-1. a) Average percent change in population size since 1970 of 20 breeding seabirds in eastern Canada and b) the number of those 20 species that have increased or decreased since 1970. Data are included for 20 of the species of seabirds that regularly breed in Atlantic Canada, and for which long-term monitoring data are available. There are an additional 17 species of seabirds that breed in Atlantic, but for which monitoring data are not available.

Figure 3.7-2. An Atlantic puffin holding a capelin, the main prey for many seabirds breeding in the Atlantic zone (Photo: S.I. Wilhelm, ECCC).

Although activities that previously led to high seabird mortalities have been greatly reduced in this region, recoveries of seabird populations experienced by many species since the 1970s have been levelling off over the past 10–15 years. This is in part due to declines in abundance and changes in distribution of high-quality prey fish (e.g., Breton and Diamond 2014; Chapdelaine and Rail 2014; Fitzsimmons et al. 2017). In addition, ongoing activities associated with commercial fisheries and oil and gas exploration and production continue to pose risks to seabirds frequenting Atlantic Canadian waters (Ellis et al. 2013; Ronconi et al. 2015).

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4.0 CASE STUDIES

4.1 MULTISPECIES MASS MORTALITY OF MARINE FAUNA LINKED TO A TOXIC DINOFLAGELLATE BLOOM

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Following heavy precipitation and high river runoff in August 2008, an intense algal bloom occurred in the St. Lawrence Estuary (Figures 4.1-1 and 4.1-2), coinciding with an unusually high mortality of several species of marine fish, birds, and mammals, including species designated at risk (Starr et al. 2017). The algal species was identified as *Alexandrium tamarense* and was determined to contain a potent mixture of paralytic shellfish toxins (PST). Filter-feeding aquatic organisms, such as bivalves and zooplankton, appear relatively tolerant to PST and can accumulate high levels of these toxins by directly feeding on algae (Doucette et al. 2006; Dam et al. 2011). This has been identified as a mechanism by which toxins may be transferred through the food web to higher trophic levels. This mechanism was likely responsible for the significant levels of PST found in the liver and/or gastrointestinal contents of several animal carcasses and in live planktivorous fish, molluscs, and plankton samples collected during the bloom. This provided strong evidence for the trophic transfer of PST resulting in mortalities of multiple wildlife species (Starr et al. 2017).

High concentrations of *A. tamarense* cysts were retrieved in the sediments of the St. Lawrence Estuary (Gracia et al. 2013). High river runoff could induce resuspension and germination of these cysts into vegetative cells, which could potentially initiate a new bloom under favorable environmental conditions. High river runoff creates optimal growth conditions for *A. tamarense* due to the beneficial effects of low salinity and high temperature on cellular growth rate, the riverine input of terrestrially derived dissolved organic matter or nutrients that can serve as growth stimulants, and/or the increased water column stability that favours the proliferation and retention of cells (Weise et al. 2002). A recent multi-model study suggested that the balance between precipitation and evaporation (an indicator of river runoff) over the Atlantic watershed would increase by approximately 5% to 10% before the end of the century (Chassé et al. 2013). Another model study that focused on a set of 21 river basins located in the Quebec/Labrador peninsula also suggested an increased freshwater runoff in the future (2041–2070) relative to the 1961–1990 period (Frigon et al. 2010). The frequency, intensity, and geographic extent of toxic algal blooms are apparently increasing worldwide in response to climate change, coastal eutrophication, and other environmental perturbations (Van Dolah 2000; Gulland and Hall 2007). The frequency of mortality events associated with toxic algae might also increase within the St. Lawrence Estuary in the near future considering these water budget models and the association between *A. tamarense* and river runoff.

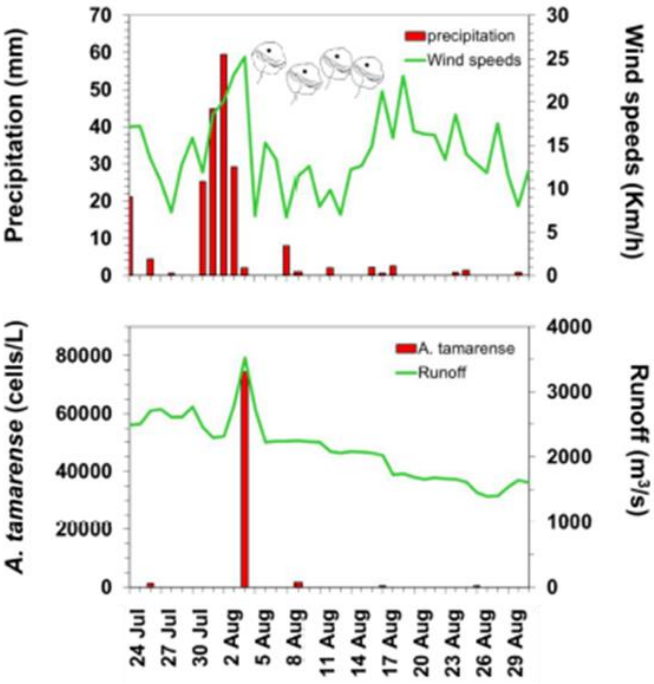

Figure 4.1-1. Environmental conditions associated with *Alexandrium tamarense* bloom in the St. Lawrence Estuary. (Top) Daily Tadoussac rainfall (mm) (bars) and Mont-Joli airport wind speeds (solid line). (Bottom) *Alexandrium tamarense* cell abundances at Tadoussac (cells l^{-1}) (bars) and Saguenay River runoff (m^3s^{-1}) (solid line). *Alexandrium tamarense* cell symbols indicate the period of the bloom. (Edited from Starr et al. 2017)

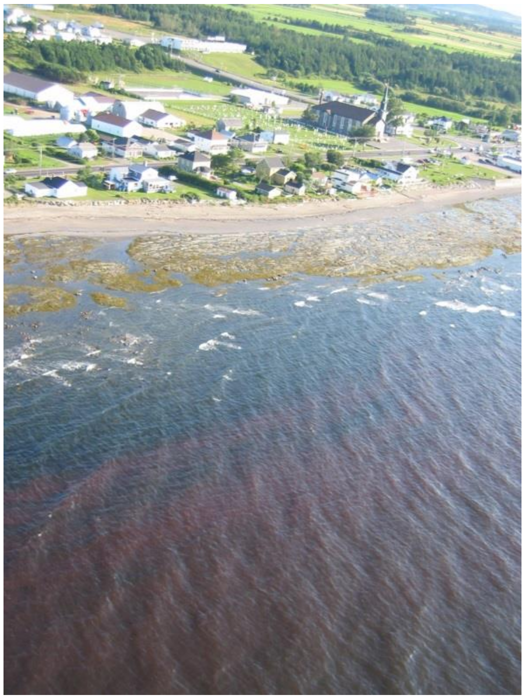

Figure 4.1-2. A large toxic algae bloom in the St. Lawrence Estuary, noticeable by its red colour (foreground), killed 10 beluga whales, about 100 seals and thousands of birds and fish in August 2008. (Photo: M. Starr, DFO)

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4.2 HYPOXIA AND ACIDIFICATION OF LOWER ST. LAWRENCE ESTUARY BOTTOM WATERS: LINKAGE WITH CARBON, NITROGEN, AND PHOSPHORUS FLUX FROM THE ST. LAWRENCE RIVER

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The ocean is the largest sink of anthropogenic CO_2 released to the atmosphere (Sabine et al. 2004). Over the last century, uptake of CO_2 from the atmosphere has decreased the pH of the ocean surface by an estimated 0.1 units (Caldeira and Wickett 2005). CO_2 is also added to the ocean by respiration of organic matter. Accumulation of metabolic CO_2 through respiration can acidify marine waters above and beyond the levels due to ongoing acidification of the ocean by anthropogenic CO_2. The impact of respiration on carbonate chemistry and pH is most acute in isolated or poorly ventilated water masses, where metabolic CO_2 accumulates to high concentrations and hypoxic conditions develop. The bottom waters of the Lower St. Lawrence Estuary, where persistently severe hypoxia has developed and pH has decreased by a full 0.2–0.3 units over the last 80 years, is one such case (Figures 4.2-1 and 4.2-2) (Mucci et al. 2011).

Annual flux of carbon, nitrogen, and phosphorus from the St. Lawrence River likely contributes significantly to hypoxia and acidification of the Lower St. Lawrence Estuary through two major processes: (1) the direct consumption of O_2 for decomposition of riverine organic carbon and (2) the stimulation of estuarine carbon production through the injection of riverine nitrogen and phosphorus. Between 5.42 and 7.09 million tonnes of O_2 are potentially consumed annually (producing a similar amount of CO_2 through respiration) in the estuary for the degradation of organic carbon exported from the St. Lawrence River (Hudon et al. 2017). Moreover, tidal mixing of carbon-, nitrogen-, and phosphorus-rich freshwater with saltwater downstream from Quebec stimulates microbial production and induces the flocculation of terrigenous organic matter that eventually settles in the deep Laurentian Channel (Annane et al. 2015), contributing to estuarine acidification. Recent estimates of nitrogen influx to the Lower St. Lawrence Estuary are larger than they were a few decades ago (134×10^3 t $year^{-1}$ versus approximately 70×10^3 t $year^{-1}$) (Hudon et al. 2017). Any further increase in the delivery of metabolizable organic matter to the deep waters and sediments of the Laurentian Channel will translate into a greater oxygen demand and will alter carbonate chemistry and pH.

The increased acidity in these hypoxic conditions will lower the saturation state of ocean waters with respect to calcite and aragonite, and likely affect the ecology of carbonate-secreting organisms, such as molluscs, bivalves, benthic foraminifera, crustaceans, echinoderms, cnidarians, and gastropods (Fabry et al. 2008; Ries et al. 2009), which are abundant in the St. Lawrence Estuary. Many of these bottom-dwelling calcifiers are of direct economic importance (e.g., snow crab); others provide food for fish and marine mammals or contribute to the maintenance of the ecosystem.

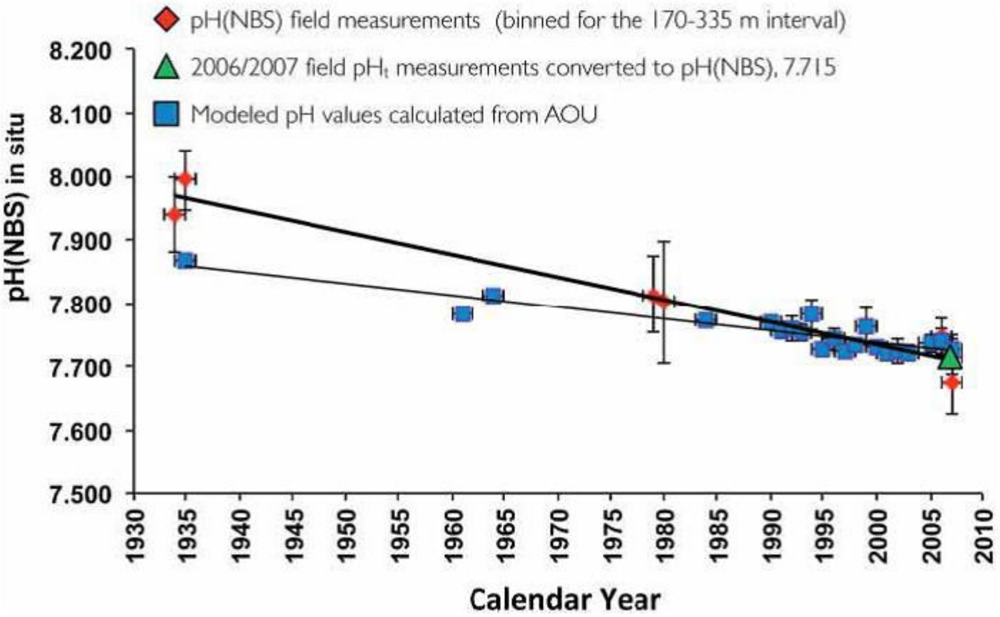

Figure 4.2-1. Measured and modelled pH (NBS) in the bottom waters of the Lower St. Lawrence Estuary over the past 75 years based on pre-selected historical data (Gilbert et al. 2005, electronic supplement). Error bars represent standard deviations on either the field measurements or the average of hindcast pH values computed from the time series data in a given year. (From Mucci et al. 2011)

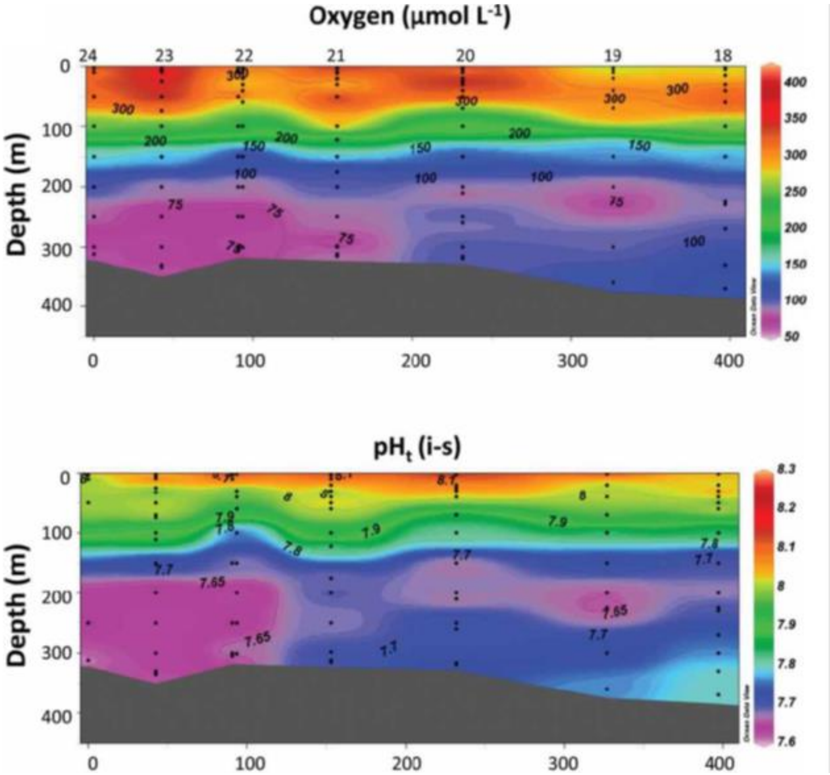

Figure 4.2-2. Measurements from the August 2006 and July 2007 ship surveys of in situ dissolved oxygen concentrations (top panel) and in situ pH on the total proton scale (pHt(i-s)) (bottom panel) throughout the Lower St. Lawrence Estuary and western Gulf of St. Lawrence. Units for the x-axis are defined as distance in kilometres (edited from Mucci et al. 2011).

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4.3 PREY-PREDATOR DYNAMICS: THE IMPACT OF GREY AND HARP SEALS ON ATLANTIC COD

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In the early 1990s, there was a widespread collapse of Atlantic cod (*Gadus morhua*) stocks in Atlantic Canada (Shelton et al. 2006). The suspected reasons were varied and included non-reporting of catches, declines in productivity, increases in natural mortality due to poor oceanographic conditions, and increased predation. In spite of strict management measures limiting fishing effort since then, some stocks have recovered very slowly or have resumed their decline.

While groundfish stocks in general (and Atlantic cod stocks in particular) declined, harp seal (*Pagophilus groenlandicus*) and grey seal (*Halichoerus grypus*) populations have shown strong signs of recovery, to levels not seen over the last 50 years (Figure 4.3-1). This has led to the suggestion that the lack of recovery is due to high levels of predation by the "over-abundant" seal populations on severely depleted groundfish populations. Although marine mammals play an important role in structuring marine ecosystems, factors affecting Atlantic cod recovery are quite complex. A series of studies examining the factors influencing cod population dynamics have shown that the role of seal predation differs between ecosystems.

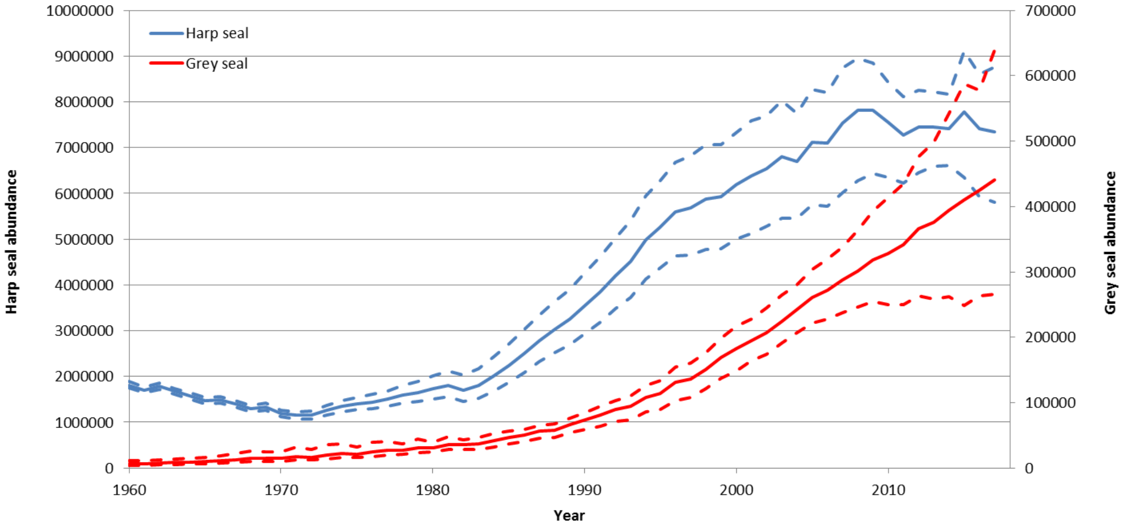

Figure 4.3-1. Abundance of harp seals and grey seals in Atlantic Canada (based on Hammill et al. 2015, 2016).

There are seven Atlantic cod stocks in Atlantic Canada (Figure 4.3-2). Some appear to be recovering slowly, whereas others remain at low levels or continue to decline. Here we examine three stocks, all which appear to have different ecosystem factors (including seals) affecting the dynamics of the stocks. The northern cod stock (2J3KL) and the northern Gulf of St. Lawrence cod stock (4RS/3Pn) are showing signs of recovery, while the southern Gulf of St. Lawrence stock (4T) continues to decline.

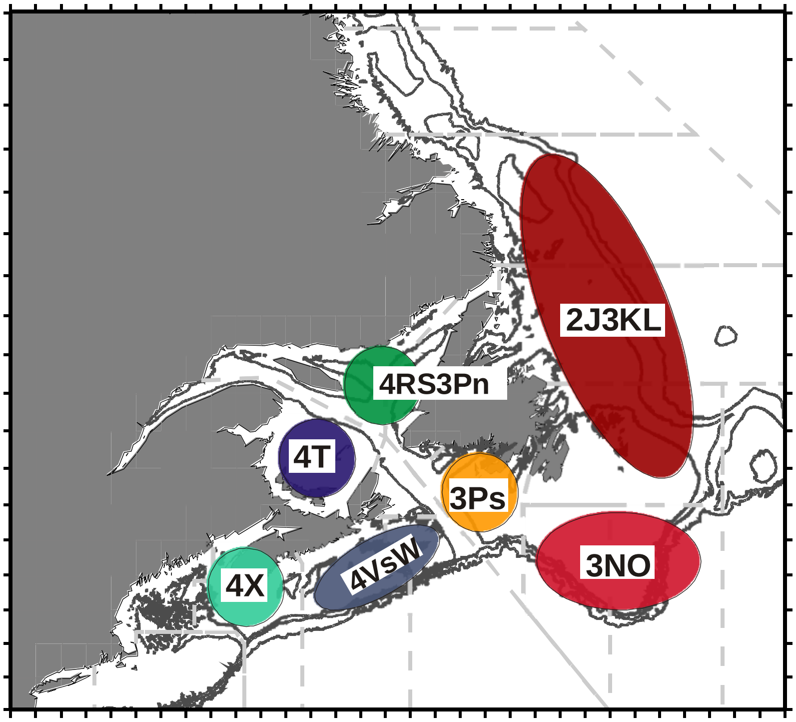

Figure 4.3-2. Location of cod stocks in Atlantic Canada showing NAFO division names.

Northern cod stock 2J3KL

The 2J3KL stock has increased considerably over the past decade but remains quite low compared to historical levels and compared to conservation objective levels as well. The delay in recovery appears to be due to a combination of high levels of mortality, arising from both fishing and natural mortality, and low levels of recruitment. Since 2010, natural mortality rates have declined and recruitment has improved (DFO 2016a).

Predation by harp seal has been repeatedly proposed as an explanation for the lack of recovery of 2J3KL cod, but other hypotheses include reduced prey availability and/or food quality (i.e., lack of capelin (*Mallotus villosus*)), fisheries catches, and environmental effects. In a recent study, the relative contributions of these drivers to the lack of recovery and dynamics of the northern cod stock were examined. The biomass dynamics were best explained by a combination of fisheries removals and capelin availability, whereas seal consumption was found not to be an important driver of the northern cod stock. A decline in body condition and abundance of capelin during the 1990s and early 2000s was associated with a regime shift and ice conditions, which resulted in a reduction in prey availability to cod (Buren et al. 2014a, 2014b). These findings point to the recovery of cod being controlled by bottom-up mechanisms (i.e., availability of food) rather than by top-down control (i.e., predation) and that a depressed capelin stock could be a serious impediment for cod rebuilding.

Northern Gulf cod stock 4RS/3Pn

The northern Gulf of St. Lawrence cod stock summers in the northern Gulf of St. Lawrence and overwinters off southwestern and southern Newfoundland (DFO 2017). Although this cod stock shows signs of recovery, continued fishing and recent increases in natural mortality appear to be slowing the recovery. Increased seal predation has been proposed as a contributing factor to higher observed natural mortality rates, but body condition indices, although acceptable, have been below the long-term average. Lack of recovery in this stock has been examined to assess the relative contribution of environmental conditions (using water temperature as a proxy), fishing, and predation by the northwest Atlantic harp seal on the decline and recovery of this stock. Model results show that the collapse of the northern Gulf of St. Lawrence cod stock was mainly due to the combination of high fishing mortality rates and low water temperatures in the early to mid-1990s (Lambert and Dutil 1997; Dutil and Lambert 2000). The increase in harp seal abundance during 1984 to 2006 resulted in an increase in predation mortality for the young cod age groups targeted by seals. Although predation mortality was identified as an important factor affecting cod spawning biomass, the lack of recovery of the northern Gulf of St. Lawrence cod stock seems to be due mainly to continued fishing (Lambert 2011). In a subsequent study, water temperature was identified as a key factor affecting the rebuilding of the stock. Under cooler water temperatures, no recovery could be expected. However, under warmer water temperature conditions, fishing and predation by harp seals were identified as the major factors affecting recovery (Chassot et al. 2009; Bousquet et al. 2014).

Southern Gulf cod stock 4T

Southern Gulf cod are widely distributed throughout the southern Gulf of St. Lawrence (south of the Laurentian Channel) in the summer. The fall migration begins in late October as they move into the overwintering grounds along the southern edge of the Laurentian Channel in the eastern Gulf, Cabot Strait, and in some years further east off northwestern Cape Breton Island. Although the commercial fishery has been closed since 2009, abundance indices, particularly for large cod, have continued to decline. The lack of recovery in this stock is due to extremely high mortality among mature fish (Swain and Benoît 2015; DFO 2016b). Under the current high rates of mortality, extirpation is estimated to be likely within approximately 40 years if rates of recruitment and individual growth remain near recent levels (Swain and Chouinard 2008). Several hypotheses have been examined as potential causes for lack of recovery of this cod stock including unreported catch, emigration, disease, contaminants, poor fish condition, life history changes (i.e., early maturation or senescence), parasites, and predation by seals (Chouinard et al. 2005; DFO 2011; Swain and Benoît 2015). While unreported catch and poor cod condition may have contributed to the estimates of elevated natural mortality in the 1980s and early 1990s, predation by grey seals appears to be the most likely explanation since then, especially given the large increase in natural mortality of cod that coincided with the increase in grey seal abundance, the high proportion of cod in the grey seal diet at some times of the year, and strong seasonal overlap between the two species, particularly in winter (Chouinard et al. 2005; Harvey et al. 2012; Hammill et al. 2014; Swain and Benoît 2015). Estimating the portion of mortality of cod that can be attributed to grey seal predation is difficult due to uncertainties in distribution, diet composition, and abundance, but some scenarios indicate that grey seal predation can account for 50% of the natural mortality, particularly among mature fish (Benoît et al. 2011; DFO 2011). The current lack of recovery of southern Gulf cod in the absence of fishing suggests a predator pit effect, with predation by grey seals preventing cod recovery (Swain and Benoît 2015). In addition to high predation rates by grey seals on cod, indirect effects are also evident. Between 1971 and 2012, the spatial distribution of some important fish species eaten by grey seals shifted into lower risk areas as predation risk increased. These include Atlantic cod, white hake (*Urophycis tenuis*), and thorny skate (*Amblyraja radiate*). In contrast, non-prey species did not show similar changes in habitat use. Spatial variation in fish condition suggests that these low-risk areas are also less profitable for Atlantic cod and thorny skate in terms of food availability, which may be restricting growth of these populations. The effects of fish population size and water temperature were also important but did not account for the changes in habitat use as the risk of predation increased (Swain et al. 2015).

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4.4 THE INFLUENCE OF CHANGING ICE ON THE POPULATION DYNAMICS OF NORTHWEST ATLANTIC HARP SEALS

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As the northern hemisphere continues to warm, declines in sea ice seriously impact species that rely on ice for reproduction and/or feeding. Northwest Atlantic harp seals (*Pagophilus groenlandicus*) give birth on ice and feed along the southern edge of the seasonal pack ice. They require ice of sufficient quantity and thickness to withstand winter storms until the pups are weaned and capable of feeding on their own. If the ice breaks up before then, young seals can drown (Stenson and Hammill 2014). However, climate change will also impact ice-breeding seals indirectly through changes in prey and subsequent changes in reproductive rates. Since the early 1980s, the proportion of females that give birth in a given year has declined (from an average of around 85% to 50%), become highly variable (ranging from 20% to 86%), and since 1987, there have been signs of abortions. During the same period, harp seals have also undergone a large change in abundance, increasing from fewer than 1.5 million seals in the early 1970s to approximately 7.4 million seals today (Hammill et al. 2015). A combination of biological and environmental factors influence reproduction, pregnancy, and abortion rates of harp seals (Stenson et al. 2016). The overall decline in pregnancy is associated with increased population size, through density-dependent effects, probably operating through changes in body size and energy acquisition (Hammill and Sauvé 2017). The interannual variability is due to changes in the number of late-term abortions. The likelihood that a female would abort a foetus depends upon the amount of prey available, body condition, and mid-winter ice cover.

Changes in ice influence the population dynamics of capelin (*Mallotus villosus*) off Newfoundland (Buren et al. 2014). The spring melt triggers the phytoplankton bloom which is consumed by zooplankton such as *Calanus* copepods and, in turn, by capelin. If the bloom occurs at the usual time of year (match), it is available for the zooplankton which results in a high abundance of capelin. If the timing is off (mismatch), there would be no phytoplankton for the zooplankton to eat and as a result, no food for capelin. As capelin is the main prey of harp seals, without them, harp seals are not able to build up the energy they need to continue a pregnancy or nurse a pup and so may spontaneously abort (Figure 4.4-1). Thus, mid-winter ice appears to be a proxy for ecosystem changes in overall prey abundance. Harp seals appear to respond to relatively small variations in environmental conditions when they are at high population levels. These negative impacts of changing climate will likely increase if the general warming trend and associated reduction in ice conditions continue.

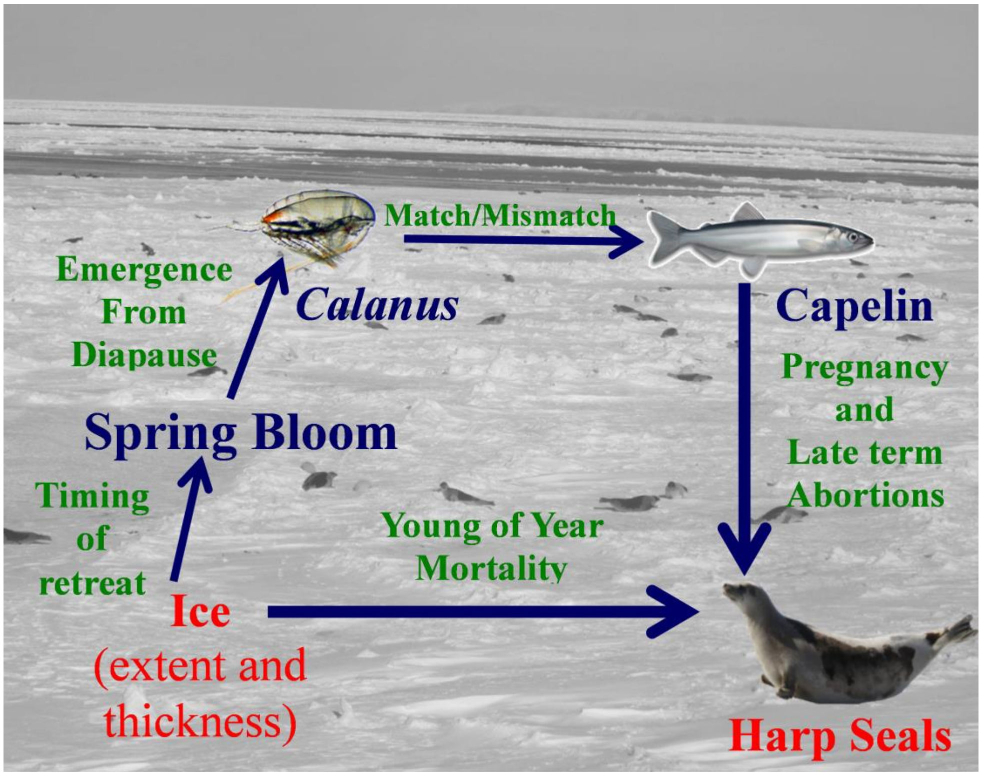

Figure 4.4-1. The direct and indirect impacts of changes in ice on Northwest Atlantic harp seals (*Pagophilus groenlandicus*).

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4.5 EUTROPHICATION IN ESTUARIES OF THE SOUTHERN GULF OF ST. LAWRENCE

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The addition of nutrients to aquatic systems stimulates primary production. Although an increase in productivity generally has a positive connotation, too much production leading to accumulation of plants and algal biomass can have negative consequences for the community (Paerl et al. 2014). Indeed, nutrient pollution (eutrophication) has been considered a major threat to coastal systems since at least the 1970s (Howarth and Marino 2006). Nutrients naturally enter coastal systems in various ways, but can be problematic at high loadings, which generally come from human-related activities such as over-application of fertilizer in agriculture and lawn maintenance, discharge of sewage and other industrial effluents, and urban runoff. Although not always the case, phosphorus is generally considered the limiting nutrient in fresh water and nitrogen the limiting nutrient in salt water (Rosenberg et al. 1990; Schindler et al. 2008). Consequently, fresh water entering coastal systems has a higher proportion of nitrogen than ocean water, which creates a gradient of productivity that begins, and is highest, in the upper estuary (Valiela 1995).

Eelgrass (*Zostera marina*) is the dominant vegetation in shallow estuaries of the North Atlantic and has been declared as an Ecologically Significant Sepcies by DFO (DFO 2009). It is a vascular seagrass that can efficiently fix atmospheric nitrogen via a symbiotic relationship with bacteria associated with its rhizome. As such, it is generally accepted that eelgrass is more limited by light than by nutrients (Burkholder et al. 2007). While increased nutrient availability increases eelgrass production, this occurs at a much slower rate than faster growing algal species, such as sea lettuce (*Ulva* spp.) and phytoplankton (Valiela et al. 1997). Unfortunately for eelgrass health and distribution, as algae become more abundant they block light from reaching the eelgrass below and eventually displace it (Figure 4.5-1).

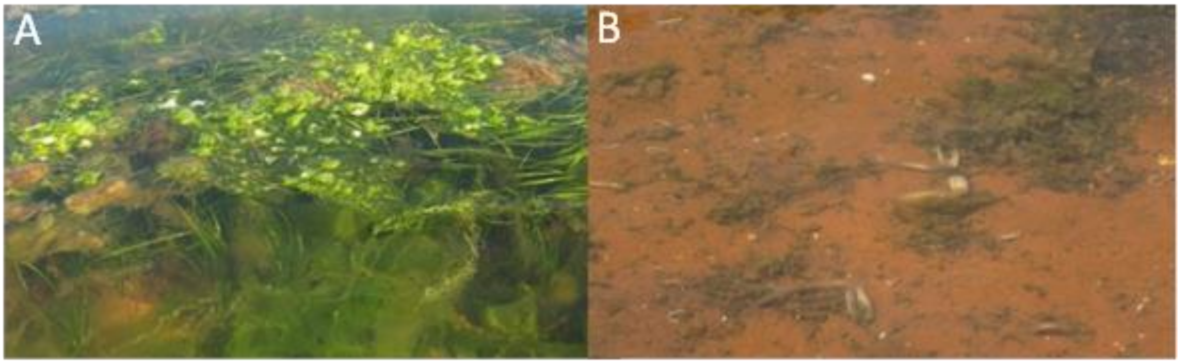

Figure 4.5-1. A) Sea lettuce (*Ulva* spp.) smothering eelgrass (*Zostera marina*). B) Example of mortality of benthic invertebrates (i.e., clams, polychaete worms) after an anoxic event in Prince Edward Island. (Photos: M.R.S. Coffin, DFO).

The replacement of eelgrass with algae has two notable negative consequences. First, the change in habitat from eelgrass to algae means that the physical structure, food type, and food availability also change, which favours some species (Pearson and Rosenberg 1978) and is detrimental to others, especially those adapted specifically to eelgrass (Deegan 2002). Second, water quality conditions can change dramatically and rapidly in a phytoplankton-dominated water body, going from a system that is nearly always saturated with dissolved oxygen to one where water can be supersaturated (more than 100% oxygen) and hypoxic or anoxic (low or no oxygen) over a short period of time (Vaquer-Sunyer and Duarte 2008; Coffin et al. 2017). In severe cases, a net consumption of oxygen from community respiration and algal decomposition can lead to anoxia persisting for long periods (Coffin et al. 2018a), which can lead to high mortality of fish and invertebrates (Middelburg and Levin 2009; Figure 4.5-1).

Eelgrass is in decline in the southern Gulf of St. Lawrence (DFO 2009). There are many potential reasons for this decline (DFO 2009; Vandermeulen et al. 2012), but in Prince Edward Island, nutrient impacts in the upper estuary seem to be negatively impacting eelgrass coverage (Hitchcock et al. 2017). In certain estuaries with high agricultural land use (Jiang et al. 2015), anoxic events caused by the decomposition of algae have become a chronic problem (Coffin et al. 2018a). Overall, monitoring information for coastal systems is scarce, so most long-term information is anecdotal and/or related to public reports based on common symptoms of anoxia, such as discoloured water and a rotten egg or sulphuric smell (Figure 4.5-2).

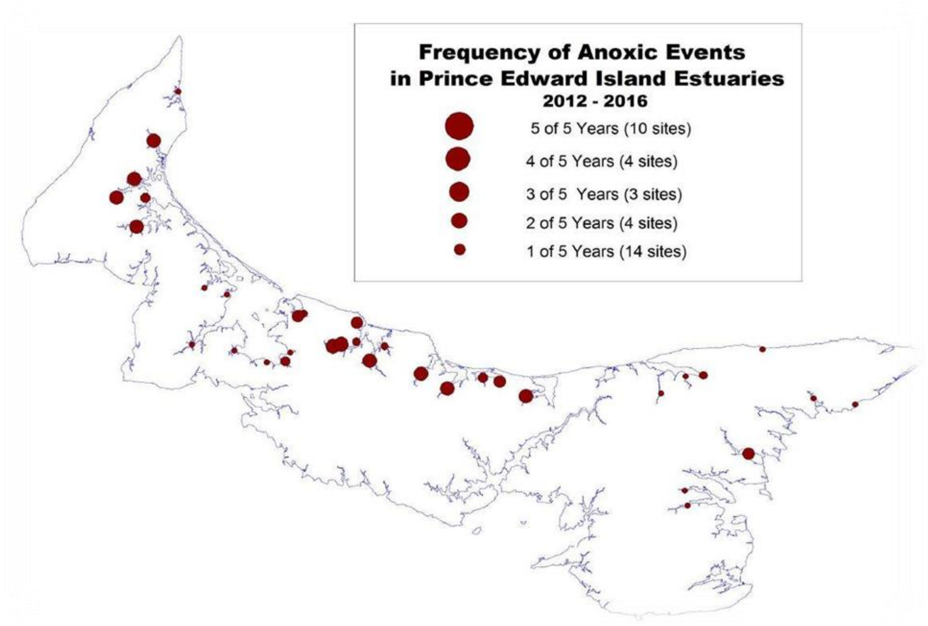

Figure 4.5-2. Estuarine anoxic events in Prince Edward Island from 2012 to 2016. (Government of PEI 2017).

The replacement of eelgrass with algae generally results in an overall loss of diversity but with increased abundance of certain species as was the case in estuaries of the Gulf of St. Lawrence (Coll et al. 2011; Schein et al. 2012; Coffin et al. 2018b). In severely impacted estuaries of Prince Edward Island, dramatic declines in mobile invertebrates were correlated with sustained anoxia (Coffin et al. 2017; Figure 4.5-3) and mortality of benthic animals has been observed (Figure 4.5-3).

Eutrophication reduces the availability and quality of habitat for many species, including economically important bivalves, and results in increased mortality of some fish species during anoxic periods (Chaput et al. 2014).

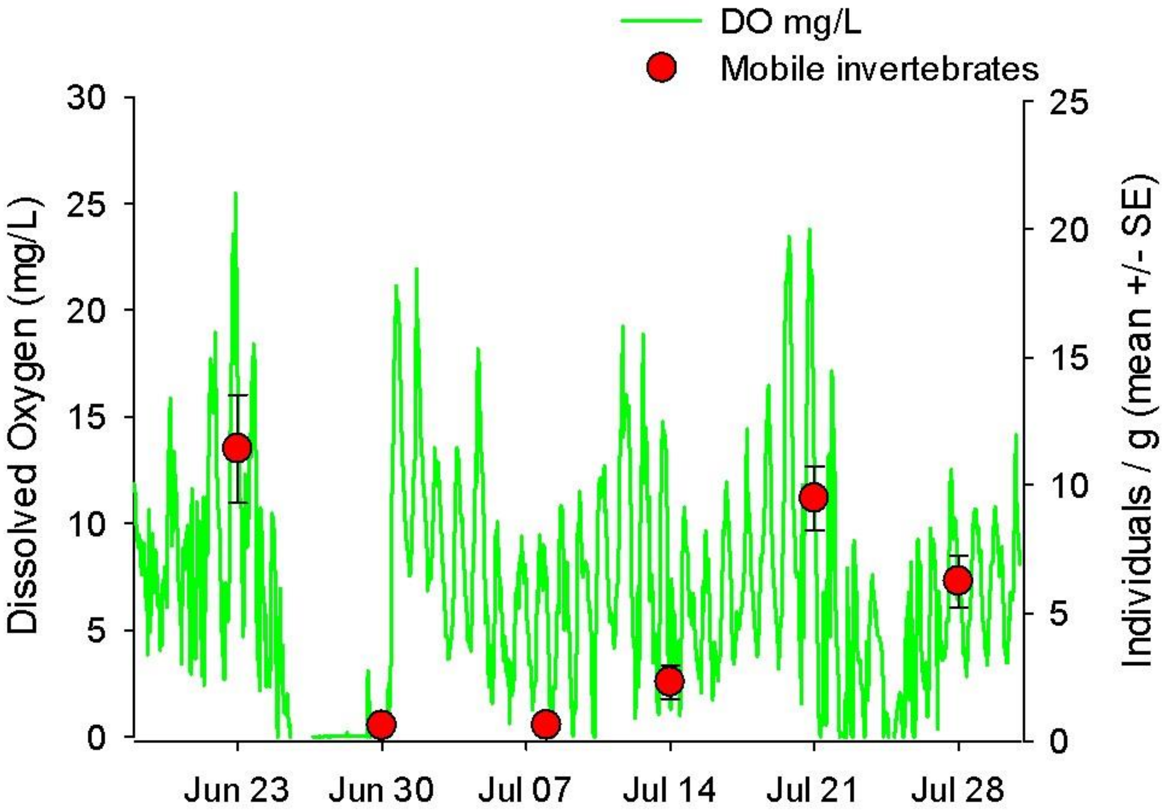

Figure 4.5-3. Hourly dissolved oxygen concentration (mg l^{-1}) overlaid with the average abundance (+/- 1 standard error (SE) of mobile invertebrates on submerged *Ulva* spp. mats (Figure adapted from Coffin et al. 2017).

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4.6 RECENT WARMING EVENTS IN MARITIME CANADA

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In 2012, 2014, and 2015 anomalous warm events were observed in the subsurface waters in the Scotian Shelf and Gulf of St. Lawrence regions of eastern Canada. Monthly output from a high-resolution numerical ocean model simulation of the North Atlantic Ocean from 1990 to 2015 was used to investigate this phenomenon (Brickman et al. 2016, 2018; see also Wang et al. 2016).

A model simulating the anomaly fields derived from the Atlantic Zone Monitoring Program (AZMP) and the July Research Vessel (RV) survey data demonstrates the observed warming trend over the last decade (Figures 4.6-1 and 4.6-2). The zooplankton communities changed with ocean temperature, with an increase in warm-water zooplankton species reported on the Scotian Shelf and in the Gulf of St. Lawrence (Devine et al. 2017; Johnson et al. 2017; see also Figure 3.2-12 in this document).

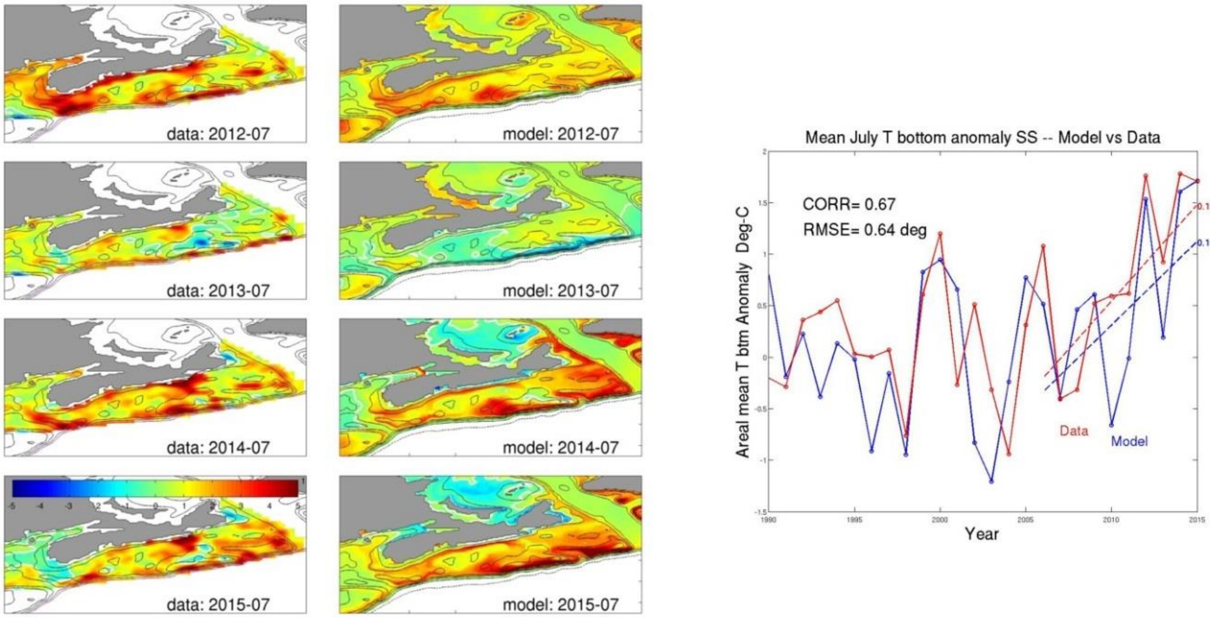

Figure 4.6-1. (Left) Bottom temperature anomalies from the July RV survey for 2012–2015, data and model. (Right) Spatially averaged July RV survey bottom temperature anomalies for 1990–2015: data (red), model simulation (blue). Slopes from 2006–2015 are 0.19ºC yr^{-1} for the data and 0.16ºC yr^{-1}for the model.

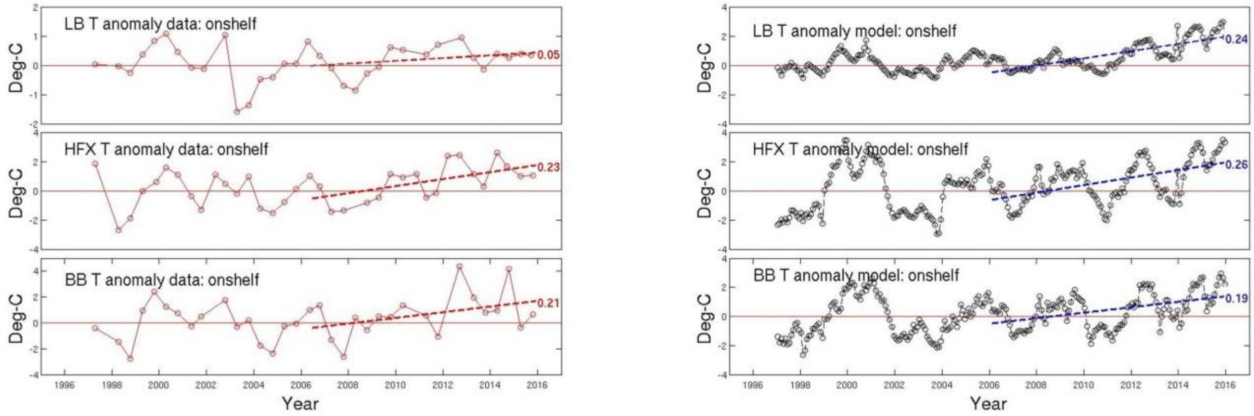

Figure 4.6-2. Average on-shelf temperature anomalies for the three Scotian Shelf sections (Louisbourg, Halifax, Browns Bank) from 1996 to 2016 (averaged from 50 m to bottom): Left, data from biannual surveys; Right, monthly model output. Slopes from 2006 to 2016 are annotated.

From analysis of the model run, anomalies originate from the interaction between the Gulf Stream and the Labrador Current at the tail of the Grand Banks (south of Newfoundland) (Figure 4.6-3). This interaction results in the creation of anomalous warm/salty (or cold/fresh) eddies that travel east to west along the shelf break. These anomalies penetrate into the Gulf of St. Lawrence, onto the Scotian Shelf, and into the Gulf of Maine via deep channels along the shelf break. The observed warming trend can be attributed to an increase in the frequency of creation of warm anomalies during the last decade. These strong anomalous events are commonly observed in the data and model, and thus should be considered as part of the natural variability of the coupled atmosphere–ocean system as opposed to an effect of climate change.

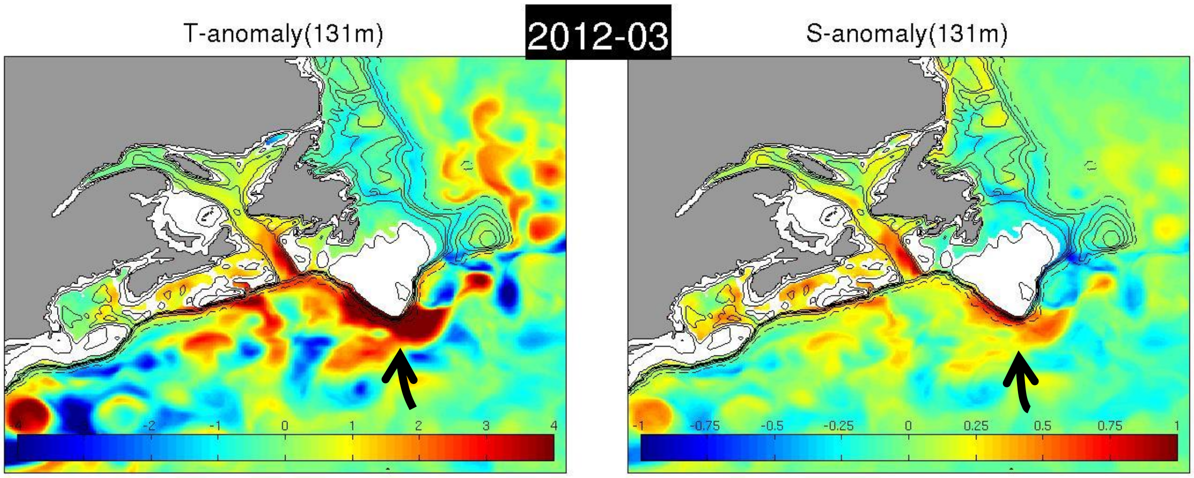

Figure 4.6-3. Warm (T-), salty (S-) anomalies (indicated by black arrows) originate from the interaction between the Gulf Stream and Labrador Current at the Tail of the Grand Banks, and propagate east to west. An animation of this process is available as supplementary material in Brickman et al. (2018).

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4.7 HOW CLIMATE CAN AFFECT THE PRODUCTIVITY OF CANADA'S ATLANTIC MARINE ECOSYSTEMS: THE ECOLOGICAL ROLE OF FORAGE FISH

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Small pelagic fish like Atlantic herring (*Clupea harengus*) and capelin (*Mallotus villosus*) fulfill a key role in ecosystem functioning and are often referred to as forage species (Buren et al. 2014a). These species are energy rich, feed on zooplankton, and are a core prey for larger marine predators, including fish like Atlantic cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*), marine mammals, and seabirds. Since the adult stage of most of these larger predators do not feed on zooplankton directly, these forage species are the main avenue through which productivity generated by microscopic organisms at the base of the marine food chain (plants like phytoplankton and animals like zooplankton) gets transferred to large animals at the top of the food chain. Without sufficient forage fish in the ecosystem, many species that the fisheries rely upon would decline due to lack of food.

Populations of forage fish are well known for having large fluctuations in their abundance due to changing environmental conditions. They can reach very high numbers when the environmental conditions are good and crash to very low numbers when they are not. Understanding what regulates their populations is key to understanding what drives changes in the productivity of the larger predators that depend on them.

Recent studies for the Newfoundland and Labrador Shelves provide us with insight into how changes in climate can influence the population of capelin, and through it, the potential productivity of the whole ecosystem. In this region, a very important physical feature that influences many biological processes is the sea ice cycle. During the winter time a vast sea ice sheet develops from north to south over most of northern and central areas. During the spring, as temperature rises, this ice sheet begins to melt from south to north. The melting associated with this annual ice retreat generates the ocean conditions that trigger the spring bloom, a rapid and intense growth of phytoplankton. This boon of plant production is fed upon by zooplankton, which experiences its own population growth spurt. The ability of capelin, which are preparing for spawning, to feed on this zooplankton will affect how many capelin will survive until spawning and when they will be ready to spawn (Figure 4.7-1).

However, for these connections to work well, all these processes have to happen within the right window of time. Depending on how the climate conditions have been during the winter and spring, the ice can retreat at different times. In general, warmer conditions will favour an early retreat of the sea ice, and an early spring bloom. Conversely, cold conditions will favour a late spring bloom. If the bloom is too early, the zooplankton may not be ready yet to feed upon the rapidly growing phytoplankton, and they will not fully utilize the food available. If the bloom is too late, some zooplankton may have already died by the time the big pulse of food becomes available. The timing of these events has to be just right ('match') as the wrong timing ('mismatch') can mean poor zooplankton availability, which in turn, means bad news for capelin.

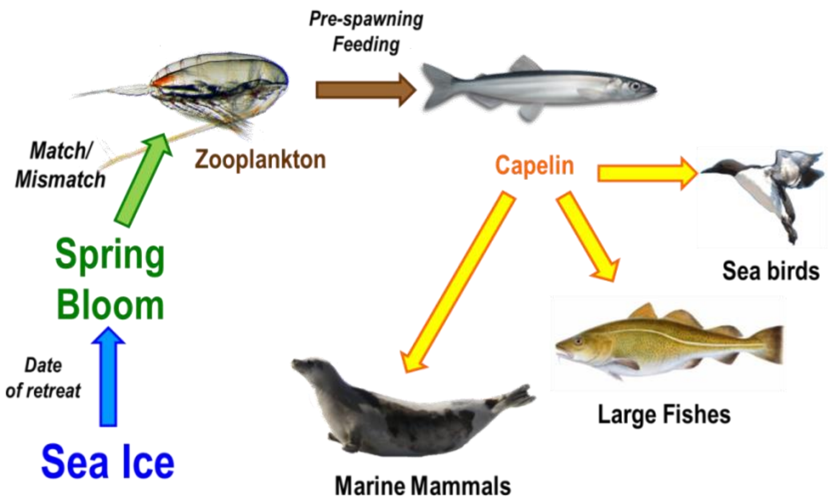

Figure 4.7-1. Schematic representation of the environmental regulation of capelin in the Newfoundland and Labrador Shelves and its role as key forage species in this bioregion.

Using mathematical models that incorporate the dates of the beginning of the sea ice retreat, and a rapid ecosystem change that occurred in the early 1990s during which the capelin stock collapsed, a great portion of the inter-annual variability in capelin stock size can be explained (Figure 4.7-2).

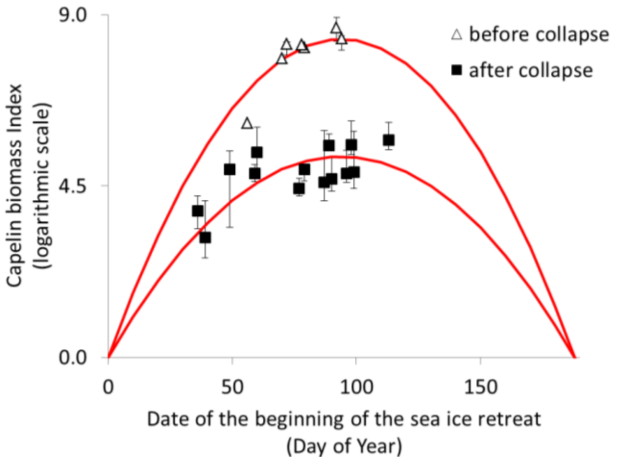

Figure 4.7-2. Capelin biomass as a function of the date of the beginning of the sea ice retreat, distinguishing estimates before and after the collapse of the stock. The red lines indicate the predictions from a mathematical model that considers the rapid ecosystem change that took place in early 1990s, and the timing of the sea ice retreat (which is an indicator of the timing of the phytoplankton spring bloom). The vertical lines on the capelin biomass index indicate the variability around each annual estimate (figure from Buren et al. 2014a).

This indicates that capelin availability in this ecosystem is mainly regulated by bottom-up processes like environmental conditions and availability of food. Other studies have shown that capelin availability is an important driver of the iconic northern cod stock, and some of the build-up that has been observed in that stock in recent years has been associated with modest improvements in capelin (Buren et al. 2014b). When we connect all these dots, the picture starts to become clear. The productivity of the Newfoundland and Labrador marine ecosystem depends on healthy forage fish stocks, where climate conditions play a big role by influencing the degree of temporal overlap between the spring bloom and zooplankton feeding.

These bottom-up ecological processes connecting the spring bloom, zooplankton, and the performance of forage fish stocks is not exclusive to the Newfoundland and Labrador ecosystem. Other marine ecosystems in Canada's Atlantic zone are likely to have similar regulatory mechanisms, although some of the pieces in the puzzle can be different. On the western Scotian Shelf, Atlantic herring is a major forage species that, like capelin in Newfoundland and Labrador, has experienced important declines in stock size in the late 1980s and early 1990s. Since 2004, the herring spawning stock biomass in southwest Nova Scotia and the Bay of Fundy has oscillated around very low values and has been trending downwards for the last two years. This trend is a cause for concern and indicates that current management measures may be insufficient to promote the rebuilding of this stock. In this case, the reasons for the decline and lack of rebuilding remain unclear, but DFO is actively researching the bottom-up hypothesis by looking into the links between the spring bloom timing and intensity, zooplankton availability, and herring stock dynamics.

Current science findings are indicating how tight and critical the connections among environmental conditions, spring bloom, and zooplankton are in defining the productivity of forage species, and through them, the marine ecosystem as a whole. Since fisheries management measures cannot control environmental conditions, sustainable fisheries management needs to pay close attention to these ecosystem processes that can impact the productivity of commercially important stocks and their ability to rebuild.

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4.8 EELGRASS AND ATLANTIC COD RECRUITMENT

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A working principle among fisheries ecologists is that young fish produced in nursery habitats support commercially important fisheries in proportion to their abundance (Fogarty and Botsford 2007). As straightforward and appealing as this idea is, it has proven difficult to study, especially among years. Young fish typically occur in different locations in time and space than adults, even in the same species, such as Atlantic cod (*Gadus morhua*). As small juveniles, cod are found in high densities in vegetated habitats (e.g., seagrass and algal species) in the shallow coastal zone (Figure 4.8-1). In contrast, adults are typically more widespread, living throughout various coastal and offshore habitats. The fact that juvenile and adult cod may use different habitats during their life cycle makes it difficult to use juvenile abundance and growth data collected in coastal nurseries to assess offshore fisheries of adult cod (DFO 2006; Laurel et al. 2017). Habitat and environmental change can also mediate the role of coastal nurseries in production of offshore fish by inducing changes in habitat-specific growth (Renkawitz et al. 2011) and density-dependent survival (Laurel et al. 2004) in coastal nurseries. Environmental factors are often variable among years. Therefore, applying these principles has long been a challenge in fisheries science (e.g., Anderson and Gregory 2000).

As nursery habitats go, eelgrass beds (*Zostera marina*) are among the most productive in the world (Hemminga and Duarte 2000). Eelgrass provides protective cover (Linehan et al. 2001; Laurel et al. 2003) and food (Renkawitz et al. 2011) for early life stages of fish (Cote et al. 2013), increasing vital rates (abundance, survival, and growth) which vary most in the first year of life (Knutsen et al. 2007; Gorman et al. 2009; Shapiera et al. 2014). Atlantic cod occupy progressively deeper water and substrates with less vegetation as they grow from habitat-dependent juveniles through to adults (Gregory and Anderson 1997; Anderson and Gregory 2000). The contribution of coastal habitats to offshore commercial capture fisheries requires assumptions of natural mortality and growth in early life. However, direct measurements of vital rates for early juveniles have been rare.

The density of 1-year old Atlantic cod in Newman Sound, Bonavista Bay, Newfoundland, is strongly correlated with pre-adult cod just prior to attaining commercial size, linking adult abundance to early juvenile abundance in the marine environment. As the abundance of 1-year old cod increases, adult cod abundance follows. Similarly, as the abundance of 1-year old juvenile cod declines, adult abundance decreases years later (Gregory et al. 2016). Given the strong link between coastal zone habitat and juvenile fish growth and survival rates, and hence abundance, it is clear that better habitat produces more juveniles, which in turn improves the abundance of adults offshore. Although, the strength of this association varies across years, the importance of eelgrass ecosystems to cod abundance is clear (Gotceitas et al. 1997; Warren et al. 2010), suggesting that factors which negatively affect eelgrass (e.g., green crab, see Matheson et al. 2016) also adversely affect cod recruitment.

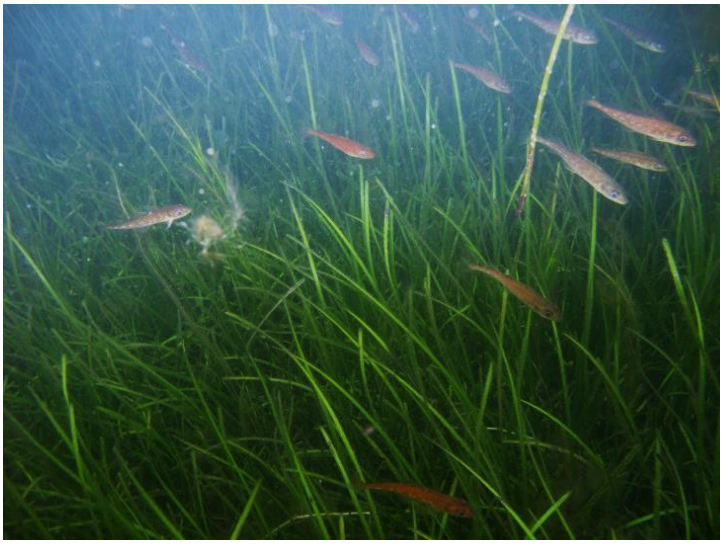

Figure 4.8-1. One year old Atlantic cod over eelgrass habitat in Newman Sound, September 2014. (Photo: DFO diving group)

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4.9 COASTAL BIODIVERSITY IN THE PASSAMAQUODDY BAY

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Total biodiversity surveys are labour intensive and subject to limited spatial coverage. A coastal biodiversity trawl survey was conducted within the Passamaquoddy Bay area of New Brunswick from July to October in 2009 and 2011 to 2014 (Figure 4.9-1).

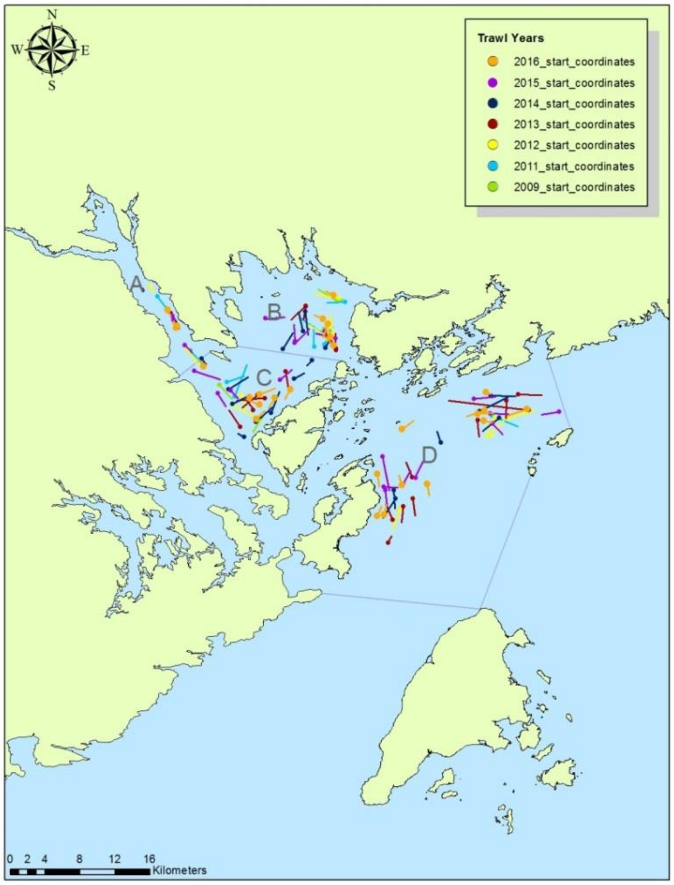

Figure 4.9-1. Passamaquoddy Bay area map illustrating sampling zones and trawl transects that were conducted from 2009 to 2014 (excluding 2010). Zone A: St. Croix Estuary, Zone B: Upper Bay, Zone C: Lower Bay, Zone D: Outer Bay.

All species captured were identified and enumerated (see Cooper and Blanchard 2016 for methodology). Annual changes in the composition of the most abundant species were observed in part due to variable catchability of the trawl when encountering congregations of numerous small species in the water column, such as northern shrimp (*Pandalus borealis*), moon jellyfish (*Aurelia aurita*), Atlantic herring (*Clupea harengus*), or silver hake (*Merluccius bilinearis*). Despite this variability, several dominant species, such as American lobster (*Homarus americanus*), winter flounder (*Pseudopleuronectes americanus*), and longhorn sculpin (*Myoxocephalus octodecemspinosus*) were consistently observed from year to year due to a more even distribution throughout the area. A diversity profile of three indices (Shannon-Weiner, Simpson's, and Fisher's Alpha) was advocated to capture changes in dominant taxa, sample variability, and species richness. Changes in indices were compared against historical environmental trends for temperature, salinity, and chlorophyll (Figure 4.9-2).

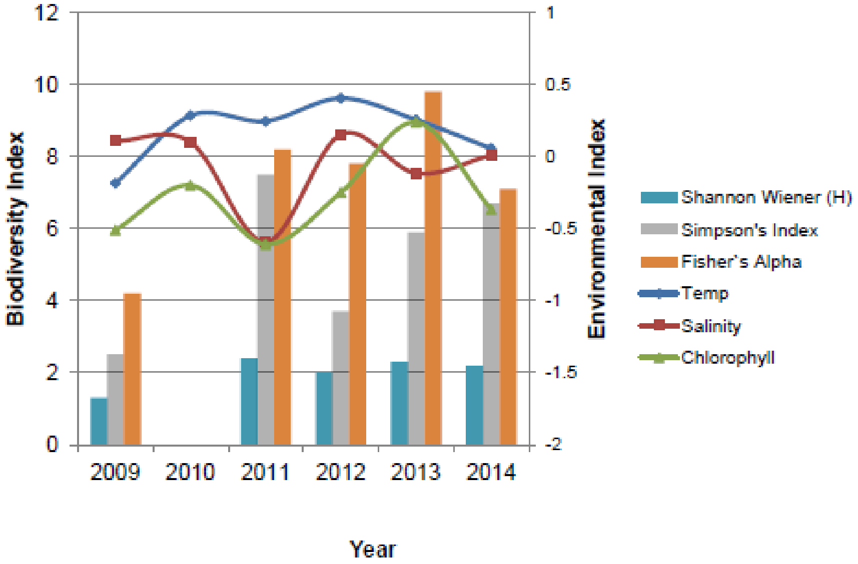

Figure 4.9-2. Biodiversity indices compared against the standardized March–October environmental anomaly for temperature (Temp) and salinity (from 1990–2014), and for chlorophyll (from 2001–2014).

A relationship between biodiversity and the environment was not observed due to the limited time series. Further sampling and a species-by-species examination were recommended as future considerations for this project. Size-frequency distribution and condition factor (fish only) were calculated for commonly caught species, such as alewife (*Alosa pseudoharengus*), Atlantic herring, longhorn sculpin, silver hake, winter flounder, and American lobster. Catch size-frequency and condition were compared to known sizes at maturity and against a 15-year average condition for the Scotian Shelf and Bay of Fundy to assess the role of the Passamaquoddy Bay area in the life history of these organisms. This information established a baseline for biodiversity in this area to support monitoring of long-term change. There could be some broader application using target species indices if similar data from other surveys was used (e.g., species condition factors).

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4.10 OCCURRENCE OF NOVEL SPECIES IN SCOTIAN SHELF TRAWL SURVEYS

Donald Clark (Study from DFO 2018)

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Standardized monitoring surveys, such as the Summer Ecosystem Survey in the Maritimes Region, have a number of objectives. They are used to provide indices of abundance-at-age for some species; to monitor trends in abundance for a broad suite of species; and to collect biological information such as fish condition and stomach contents. DFO Maritimes Region surveys have also been used to monitor environmental conditions at all sampling stations. In addition, these surveys provide information on species distribution and changes in species assemblages. Particularly noticeable in the last decade has been the increase in prevalence of warm-water species. This includes species that have been regularly observed on Georges Bank and are now becoming common on the Scotian Shelf. Even more noticeable to those who take part in the surveys has been the increased frequency of species that had rarely or never before been caught in the area (Figure 4.10-1).

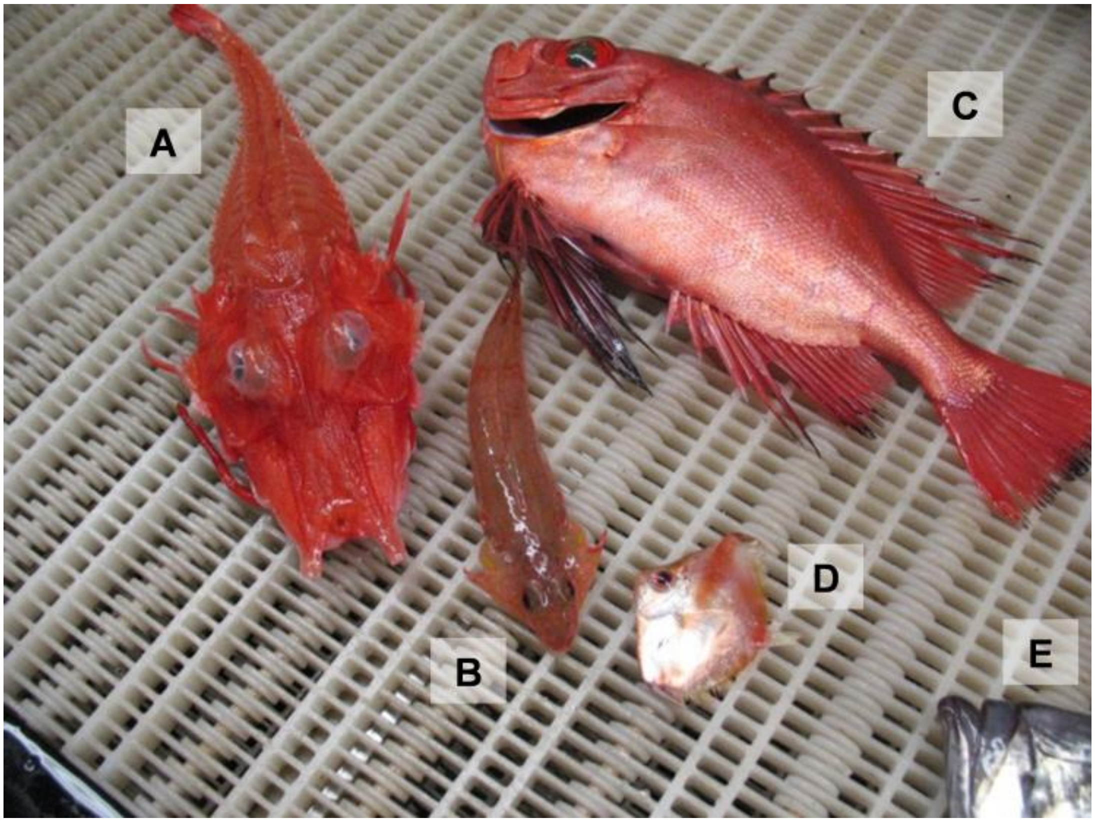

Figure 4.10-1. A variety of “exotic” fish captured in a set on the Scotian Shelf: (A) armored searobin (*Peristedion miniatum*), (B) spotfin dragonet (*Foetorepus agassizii*), (C) glasseye snapper (*Heteropriacanthus cruentatus*), (D) deep-bodied boarfish (*Antigonia capros*), (E) American John Dory (*Zenopsis ocellata*) (partial). (Photo: W. Joyce, DFO).

Bottom trawl catches from the annual DFO summer survey of the Scotian Shelf and Bay of Fundy are showing an increasing prevalence of warm-water species more commonly found to the south. The average bottom temperature recorded during the summer survey time series is

6.8ºC. This varies annually, with the warmest average temperatures experienced in the last six years (Figure 4.10-2).

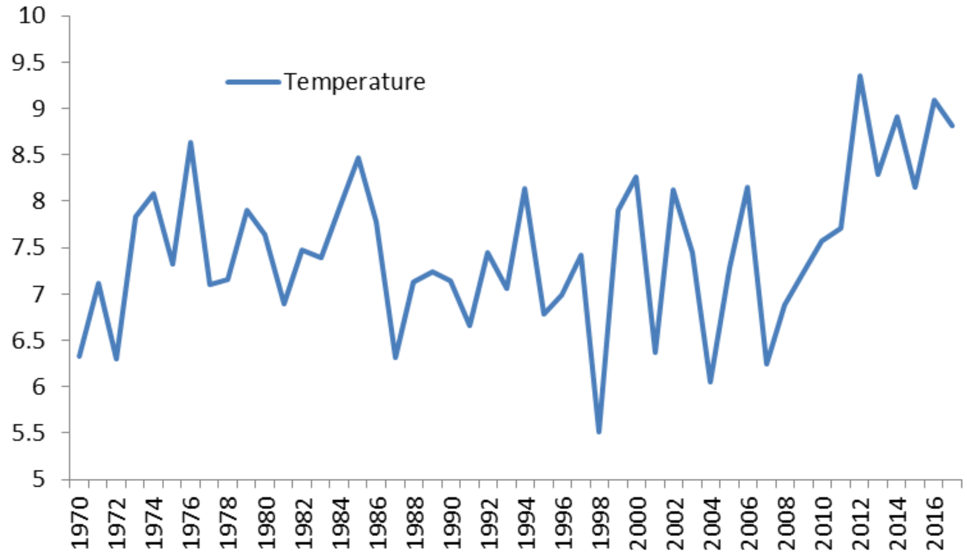

Figure 4.10-2. Average annual bottom temperature (°C) from the Scotia Shelf Summer Ecosystem Survey in NAFO Divisions 4VWX.

Over the geographic range covered, bottom temperature ranges from below 2ºC to above 11ºC, and there are changes in species encountered in relation to bottom temperature. The warmest waters for the summer survey are found in the Fundian Channel, along the edge of the Scotian Shelf, in the central Scotian Shelf, and in shallow waters around Sable Island.

There are 33 species of fish for which the average temperature of capture is >8.5ºC; most of these have not been consistently captured over time during the survey (22 species in NAFO Division 4X and 26 in NAFO Divisions 4VW). There are some species that are regularly caught in the survey, like barndoor skate (*Dipturus laevis*), for which the average temperature of capture exceeds this. There are also a variety of warm-water species which are only occasionally captured during the summer survey, although they may be common further south where ocean bottom temperatures are higher. Some, like the blackbelly rosefish (*Helicolenus dactylopterus*), appear to have colonized the Scotian Shelf and are now captured every year (Figure 4.10-3). Blackbelly rosefish are found within the warmer parts of the survey area and their distribution has expanded along the Scotian Shelf edge.

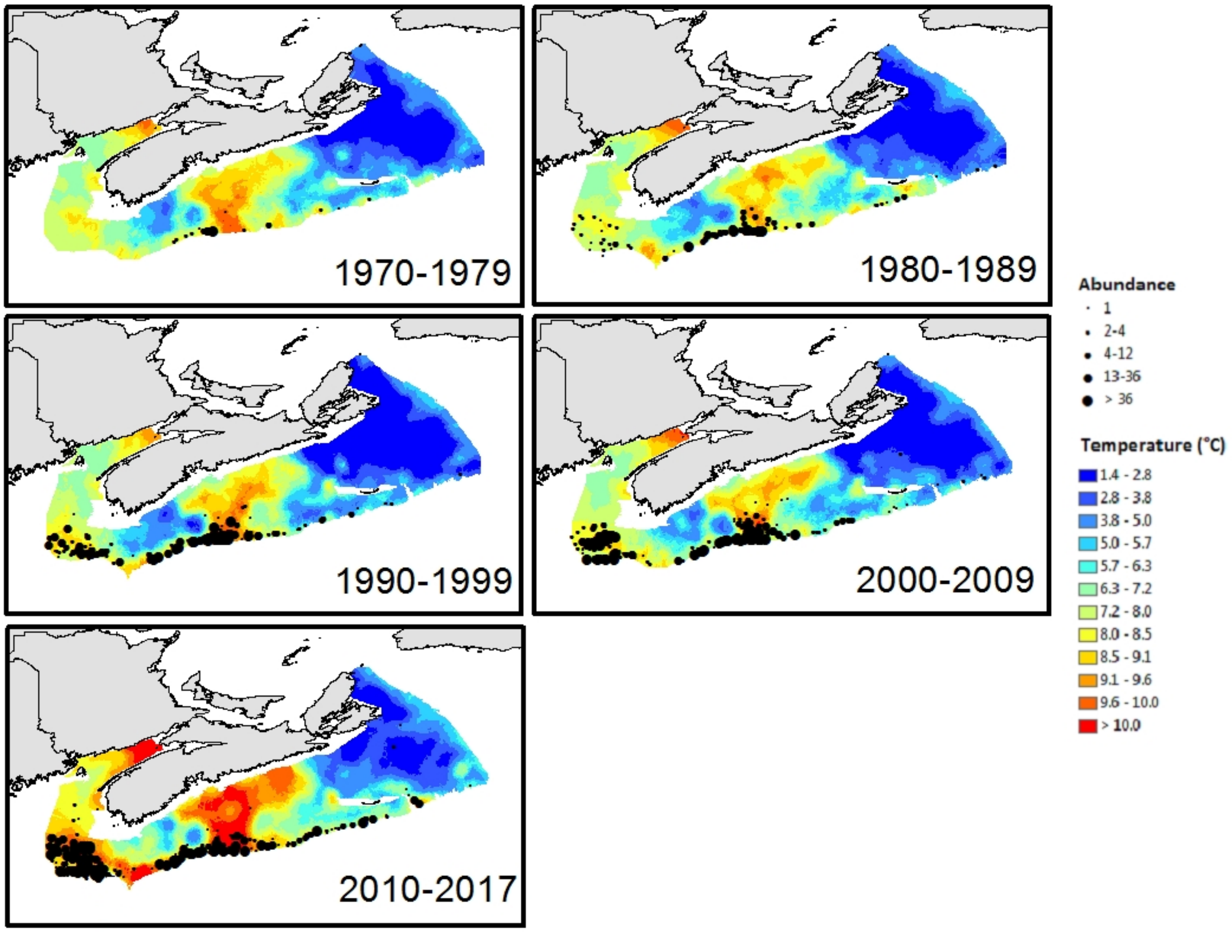

Figure 4.10-3. Decadal distribution of abundance of blackbelly rosefish overlain on the average temperature for each time period.

The number of warm-water species captured has been increasing as has the frequency with which they are captured. In the last five years, the number of warm-water species has increased markedly in 4VW, with catches of species such as American John Dory, armored sea robin, spotted tinselfish (*Xenolepidichthys dalgleishi*) and deep-bodied boarfish becoming much more common. The distribution of capture for these species is clearly associated with areas of warm water in all time periods and the distribution has expanded along with the expansion of warm bottom temperatures (Figure 4.10-4).

While the biomass associated with these species remains fairly small relative to the overall groundfish biomass, their prevalence has clearly increased and more species seem to be following the blackbelly rosefish in becoming part of the regular fauna of the Scotian Shelf.

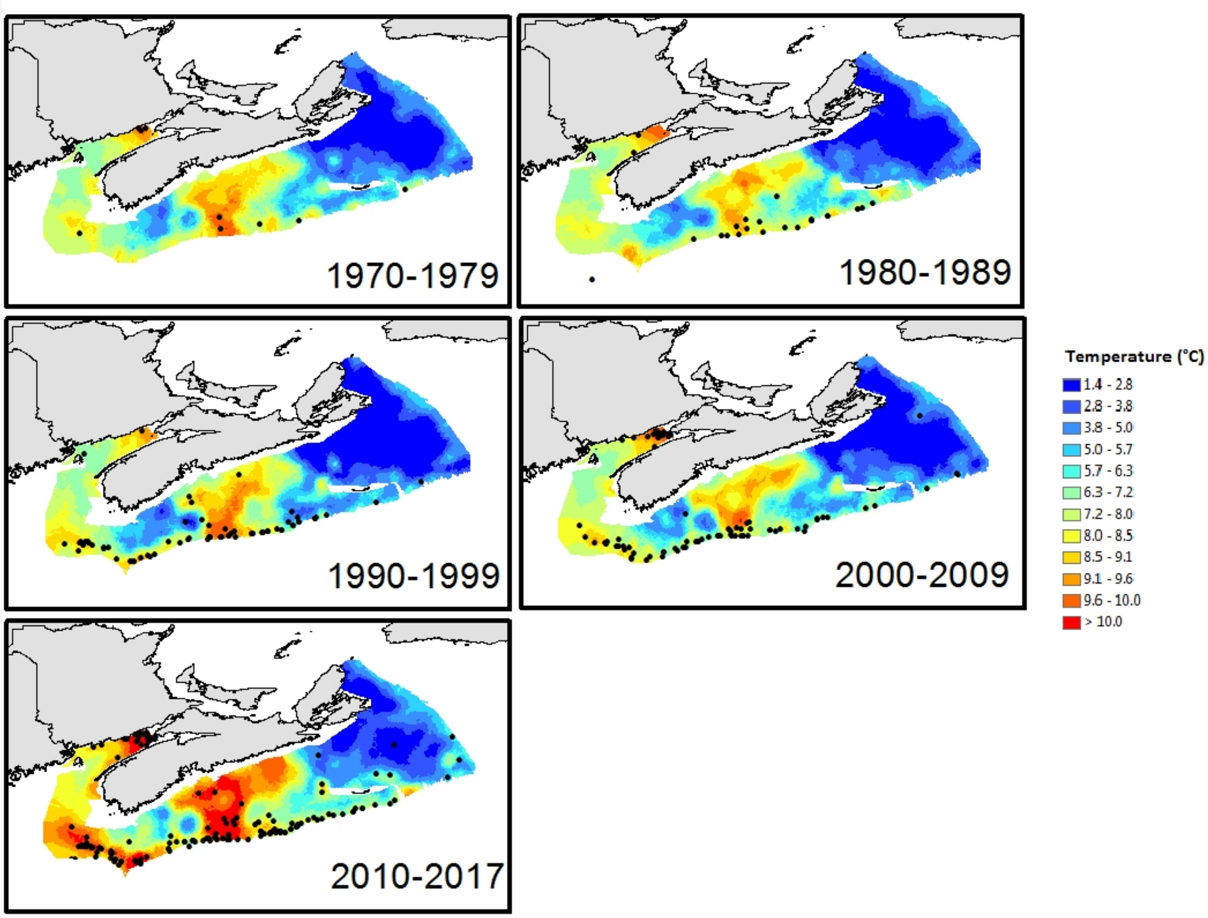

Figure 4.10-4. Decadal distribution of captures of warm-water fish species overlain on the average temperature for each time period. Black dots (•) represent a set in which at least one warm-water fish species was present.

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4.11 SEABIRD POPULATIONS RESPOND TO REDUCED FORAGE FISH AVAILABILITY

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[2] Environment and Climate Change Canada, Canadian Wildlife Service Quebec Region

As top predators, seabirds are integral parts of healthy ecosystems and serve as important indicators of changes in the abundance and distribution of the forage fish on which they rely (Davoren and Montevecchi 2003; Gaston et al. 2003). For example, northern gannet (*Morus bassanus*) chicks reared on Bonaventure Island, the largest gannet colony in North America, obtain most of their nutritional energy from Atlantic mackerel (*Scomber scombrus* L.) (Rail et al. 2013). Gannets (Figure 4.11-1) have been experiencing low reproductive success since 2009, far below the level required to maintain a stable population, marking the end of a period of population growth (Chapdelaine and Rail 2014). Poor breeding conditions are attributed to low food availability linked to recent stock declines and distributional change of mackerel in the Gulf of St. Lawrence (Grégoire et al. 2013; DFO 2017).

Figure 4.11-1. Juvenile (left) and adult (right) northern gannet (*Morus bassanus*). (Photo: J.-F. Rail, ECCC)

Further south in the Bay of Fundy, declining Atlantic herring (*Clupea harengus*) stocks are affecting the most important seabird breeding colony in the Gulf of Maine, Machias Seal Island. Alcids and terns at this site rely on herring to successfully raise their young, and since the early 2000s have shifted their diets to lower quality prey leading to reduced breeding success (Gaston et al. 2009). Consequently, the number of breeding terns at the largest tern colony in the Gulf of

Maine has been near zero since 2006 (Gaston et al. 2009; Scopel and Diamond 2017). Further, decline in herring abundance has been linked to reduced adult survival in Atlantic puffins (*Fratercula arctica*), causing general concern for the sustainability of puffins breeding in the Gulf of Maine (Breton and Diamond 2014). While rising water temperatures in the Bay of Fundy are raising alarm for the long-term persistence of spawning herring populations, so are some levels of allowable catch (Melvin et al. 2009). No-take zones around important seabird colonies can be effective in reducing forage-fish competition between seabirds and commercial fisheries (Pichegru et al. 2012; Bogdanova et al. 2014). However, it has been proposed that long-term population benefits may only be achieved by limiting regional catch quotas to maintain forage fish stocks above one-third of the biomass on record (Cury et al. 2011; Pichegru et al. 2012).

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4.12 BENTHIC NURSERIES: ROLES OF CORALS AND SPONGES AS NURSERIES IN THE DEEP SEA

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The functional role that benthic megafauna like corals and sponges play in deep-sea ecosystems, especially pertaining to their three-dimensional structures, has been well documented (Bell 2008; Buhl-Mortensen et al. 2010). It includes protection from predators (Wulff 2006), areas in which to rest from currents (Zedel and Fowler 2009), forage areas for food (Buhl-Mortensen and Mortensen 2004), and enhanced biodiversity through habitat provision for other bottom-dwelling animals (Cerrano et al. 2010). The complexity created by corals and sponges, whether between colonies (macrohabitat), between branches (microhabitats), or even within tissue (nanohabitats), provides habitat for smaller animals at various life history stages. Such habitats can be used in many ways, the most interesting of which is as nurseries—corals and sponges are like benthic babysitters of the deep sea.

There are many examples illustrating the diversity of this relationship. Large, branching sponges have been observed with bobtail squid eggs injected within the tissue (Aldrich and Lu 1968; Mercer 1968; Nesis 2003; Frandsen and Wieland 2004; Okutani and Sasaki 2007) (Figure 4.12-1). Eggs were at various stages of development suggesting repeated deposits, although whether by one adult squid or many is still unknown.

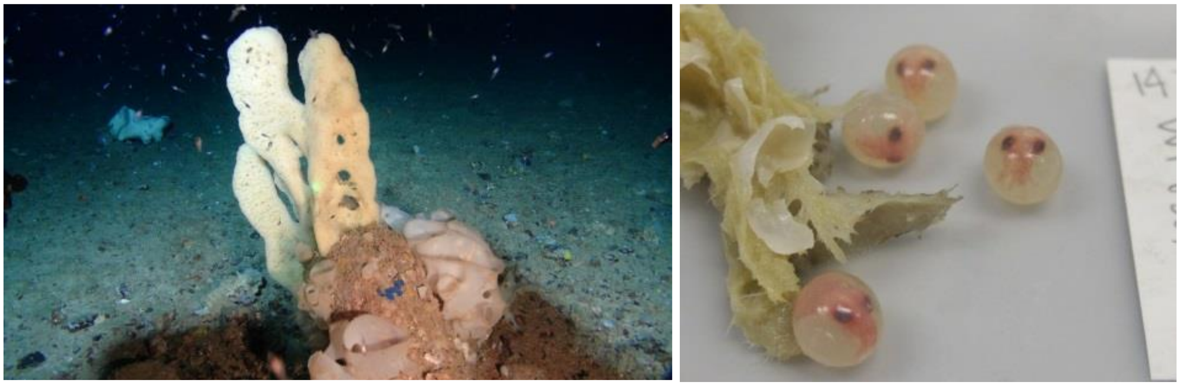

Figure 4.12-1. Left: In situ image of *Mycale* (*Mycale*) *lingua* sponge. (Photo: ArcticNet 2016) Right: *Mycale* (*Mycale*) *lingua* specimen with bobtail squid eggs. (Photo: V.E. Wareham Hayes)

Tree-like gorgonian corals have been found with multiple shark egg cases, called mermaid purses, entangled in the colony, some with up to 17 purses on one coral (Etnoyer and Warrenchuk 2007; Fuller et al. 2008) (Figure 4.12-2). Other gorgonian bamboo corals off southern Newfoundland were covered with numerous juvenile scallops when caught on longline gear. One was a 180-year-old bamboo coral (Sherwood and Edinger 2009), and the scallops along with many other animals were using the large skeleton structure as a substrate to enhance feeding opportunities higher up in the water column (Wareham and Edinger 2007) (Figure 4.12-3). Even small soft corals play a role. Baby basket stars, commonly called tangle foot by fishers, spend their infant years clinging to the branches of soft corals (Patent 1970) (Figure 4.12-4).

Figure 4.12-2. Egg case attached to *Acanthogorgia armata* coral. (Photo: V.E. Wareham Hayes)

Figure 4.12-3. Close-up view of a bamboo coral (*Keratoisis grayi*) with juvenile scallops attached. (Photo: V.E. Wareham Hayes)

Figure 4.12-4. Soft coral called the sea strawberry (*Gersemia rubiformis*) attached to shell with juvenile basket star. (Photo: V.E. Wareham Hayes)

Sea pens do not have the height or girth of tree-like corals (Figure 4.12-5), nonetheless they play an important nursery role, especially in soft mud environments where they can be the only three-dimensional structure around. In the Laurentian Channel and on the continental slope of the Grand Banks of Newfoundland, such areas exist. Large fields of sea pens were observed with juvenile grenadier rat-tail fish and redfish (Baker et al. 2012) (Figures 4.12-5 and 4.12-6). Redfish are slow-growing long-lived ovoviviparous, meaning they bear live young, and have extremely low natural mortality (NOAA 1999). Fish larvae were found closely associated with five species of sea pens, and three species of soft corals (Baillon et al. 2012). Larvae appeared to be at the end of yolk sac phase (Figure 4.12-7). Based on DNA tests, the majority of the larvae were redfish, commercially valuable but endangered (COSEWIC 2010). Others included lantern fish and eelpouts, not commercially valuable species but ecologically important as dominant food sources in marine food webs (Tsarin 1997).

Figure 4.12-5. Left: Sea pen field with grenadier fish. (Photo: ROPOS 2007) Right: Bamboo coral thickets with redfish. (Photo from Baker et al. 2012)

Figure 4.12-6. Sea pen (*Anthoptilum grandiflorum*) with redfish. (Photo: DFO)

Figure 4.12-7. Redfish larvae with yolk sac still present. (Photo: Baillon et al. 2012)

Corals are simple animals, referred to individually as polyps. Corals can be solitary, (one animal = one polyp; Figure 4.12-8), or colonial with many genetically identical polyps (see Figure 4.12-9). Sea pens are unique in the coral world because they can be found in many habitats at different depths, and because they have differentiated polyps, meaning some polyps are for feeding and others are for reproduction or support (Bayer 1956). They have a central rod (rachis) running from colony tip to base, with the latter referred to as the peduncle or foot (Figure 4.12-9). The peduncle is almost always buried and highly sensitive to vibrations in soft sediments.

Figure 4.12-8. Solitary cup corals. (Photo: ROPOS 2007)

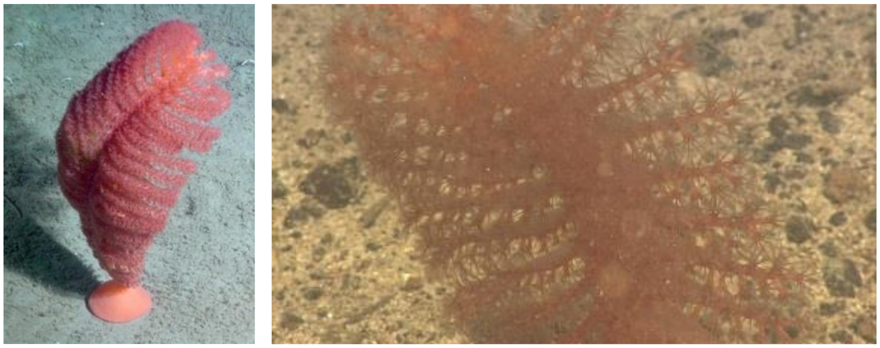

Figure 4.12-9. Left: Sea pen (*Pennatula* sp.) with peduncle swollen and buried. (Photo: ROPOS 2007) Right: Close up sea pen with extended leaves with polyps. (Photo: ROPOS 2007)

Some sea pens have the ability to completely retract into the seafloor, but speeds vary from seconds to minutes (Langton et al. 1990; Greathead et al. 2007). For non-retractable sea pens, defense movements are limited and restricted to the polyp and/or polyp leaf (Figure 4.12-9), which can house many animals. When a colony senses danger, such as vibrations in the mud, or is disturbed, water is expelled from within the tissue walls causing the polyps or leaves to collapse upon themselves and draw tight to the main body (Figure 4.12-10). Fish larvae that use these animals for shelter become trapped between the leaves as the colony is disturbed; in the laboratory, removal of larvae from specimen is difficult due to the strong contractions of the sea pen tissue (Baillon et al. 2012).

Soft corals do the same but to a greater extent because they lack an internal spine. They maintain their shape through hydrostatic pressure, whereby the fluid enclosed within the tissue walls and the resulting pressure maintains the erect branching shape of the colony (Fabricius and Alderslade 2001; Kier 2012) (Figure 4.12-11). They also possess the ability to expel this water if disturbed and can deflate their branches and trunk to a fraction of the original colony size. As the fish larvae linger between the branches for rest and/or protection, they too get trapped, with 244 larvae documented on one soft coral specimen (Baillon et al. 2012). Even though these examples illustrate only a part-time role, seasonal or by life stage, as babysitters of the deep sea, it is an essential role nonetheless.

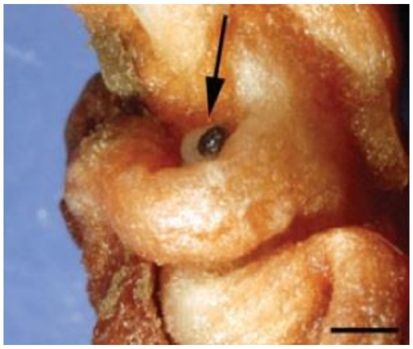

Figure 4.12-10. Deflated sea pen with trapped fish larvae. (Photo: Baillon et al. 2012)

Figure 4.12-11. In situ photo of a soft coral illustrating its hydroskeleton. (Photo: ArcticNet 2015)

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5.0 ACKNOWLEDGEMENTS

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APPENDIX 1 – AGENDA

State of the Oceans—Atlantic Synthesis Workshop Agenda

Location:	Crowne Plaza Moncton Downtown
Date:	December 5–7, 2017
Facilitator:	Marc Lanteigne

Workshop Objectives

1) To describe the status and trends in the Atlantic Ocean
2) To identify key messages about the state of the Atlantic Ocean
3) To inform the public report

Day 1

Welcome and Introduction

0900 — 0910	Opening Remarks	Doug Bliss
0910 — 0920	Introductions	Marc Lanteigne
0920 — 0930	Background and purpose of workshop	Leads
0930 — 0945	Public Reporting	Tara Donaghy
0945 — 1000	Questions	

Theme Group Presentations

1000 — 1030	Oceanography–Physical/Chemical	
	Break	
1045 — 1115	Habitat/Coastal/Significant Benthic Areas	
1115 — 1145	Oceanography–Lower Trophic Levels	
1145 — 1215	Fish and Invertebrate Communities	
	Lunch (not provided)	
1315 — 1345	Marine Mammals	

1345 — 1415	Seabirds	
1415 — 1445	Sea Turtles	

Break

1500 — 1630	Theme Groups Discussion	
1630 — 1700	Key messages from the day Discussion items for Day 2	

Day 2

Recap from Day 1

0900 — 0915		Marc Lanteigne

Case Study Presentations

0915 — 0930	Selection criteria	Leads
0930 — 1030	Case study presentations	

Break

State of the Atlantic Ocean Discussion

1045 — 1230	Linkages, status, trends, stressors, and gaps	

Lunch (not provided)

1330 — 1600	Key messages Primary case studies	

Break

1600 — 1645	Proposal and feedback on public report	Anton Holland
1645 — 1700	Wrap-up	

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APPENDIX 3 – WORKSHOP DISCUSSION

3.1 REPORTING

Day 1

- There was clarification that the theme group reports could be updated based on the workshop discussions.
- Participants wondered if there are methods that could be used to track the impact of the report on the Canadian public. It would be good to know how people are receiving and responding to the report. There could be mechanisms to track this such as surveys, monitoring of web visits (e.g., Google Analytics), or other feedback mechanisms. Would pre- and post-report surveys be possible to gauge the influence on public knowledge? DFO might be able to seek help from outside experts to design a survey or other options (e.g., Dalhousie University's work on public feedback from fisheries management decisions). The Canadian Network for Ocean Education (CaNOE) might have expertise to help. This process will also include follow-up with those who participated in the SOTO process to gather input to inform future reports. This is the first time for this reporting format and we are learning as we go.
- It was indicated that the timeline for the public reporting would have the communications products ready by the end of the fiscal year. The aim would be to have the synthesis report report out at approximately the same time. Material could be added based on public feedback.
- How will emerging issues be dealt with? Should this be done by DFO Science? Usually Communications deals with these issues because they have a national perspective.
- The consultant was given time to review what had been presented thus far on Day 1. It was felt that the key messages were there and generally things were moving in the needed direction. There would have to be more thought given to the units used in the report and how the information could be condensed to fit into 16 pages.
- Additional discussion would be needed on the key messages and their relative significance. Can messages be generalized and are there good news and bad news messages?
- How should uncertainty in the data be presented so it is transparent? The public may see uncertainty differently than scientists and may require education on how science works. The integrity of the science needs to be maintained so the stories are backed up with facts.
- The regional leads will need to look at issues around the time scales used in figures and how they are normalized. Is it necessary to include all the historical data?

Day 2

- The facilitator reviewed the discussions from Day 1. From this discussion it was evident that feedback from both the public and participants would be important to help guide future State of the Oceans reporting. This would be discussed with the Steering Committee following the workshop.

- From the perspective of public reporting, it would be important to further discuss key messages and identify which would apply across theme groups. More discussion would be helpful on how to explain uncertainty to the public. There was also still some question about how to maintain uniformity of report materials (e.g., figures) among theme groups.
- For the synthesis report, it would be useful to include a bioregion overview at the beginning; there could be further discussion of including EBSAs in the report.
- There was still the question of how aquatic invasive species (AIS) would be addressed within the report and if sea turtles and seabirds should be grouped or treated as separate theme groups.
- There was discussion about adding a human component to the report. However, it was pointed out that there wouldn't really be the expertise within DFO Science to address this. This was considered to be more of an Oceans Management issue rather than something to be addressed by Science. The report will be circulated within the Department for use by other groups. Perhaps they can contribute to future reporting.
- It was agreed that the bioregions used by the Fish and Invertebrate Communities group would be used throughout.
- The time scale under consideration was addressed. It was felt that 5 to 7 years might be too short a time for some changes. There has been unprecedented/rapid change over the last 5 to 7 years, but there have also been rapid changes in the past. More data are now available to understand these changes. It should be pointed out that a number of record highs have been observed recently.
- It was noted that MPAs have not been discussed in the report. The website could link to the Marine Conservation storyboard. There could be a map with layers that could be turned on and off.
- It was indicated that the consultant would revise the scientific language for the public report. There would be feedback between the consultant and the group to ensure that the language is being translated to maintain the key messages.

Post workshop

- After the workshop, the DFO National Ecosystem Reporting Steering Committee identified aquatic invasive species (AIS) as a significant gap in the report. Regional leads pursued discussions with members of DFO's national AIS program to produce key messages and a short background text for inclusion in both this synthesis document and the public report.
- Key messages are included in Section 2.0, background text is included here:

  "As of 2017, 11 marine AIS are recognized as having various levels of negative impact on marine ecosystems in Atlantic Canadian waters (DFO Atlantic Zone AIS monitoring program). Ballast water and biofouling via commercial shipping (international and national) and recreational boating, aquaculture and fishing activities, as well as live animal and aquarium trades, remain the most important vectors of AIS introduction and spread. Negative impacts of AIS on Atlantic Canadian marine ecosystems include declines in abundance and biomass of coastal fish communities, eelgrass and macroalgae biomass, shifts in benthic invertebrate communities, as well as negative economic impacts on commercial fishing and aquaculture."

3.2 THEME GROUPS

Oceanography – Physical/Chemical

- It might be helpful to have a figure which illustrates the seasonal cycling of the water layers. Currently this is only expressed in the text. Could have similar figures for Maritimes and Newfoundland.
- Three methods for illustrating the data trends were discussed. One would be score cards (normalized anomalies since the 1980s). Showing the mean and standard deviation would not be necessary in the public report. The score card method makes it easier to see changes in the data. Another method would be stacked anomalies which is a format used in the Lower Trophic Levels summary. Anomalies on the same side of the line show coherence of change. Another method would be line graphs.
- NAFO Divisions in the figures are cut off at the shelf break and not extended. These boundaries are well known by the fishing public and should be extended. Figures in the Fish and Invertebrate Communities report would have the full boxes, and these should be included in an introductory section to the synthesis report. These maps could be used for the Lower Trophic Levels theme group summary as well.
- This section has a very integrated approach, but this was not the case for other theme groups such as Fish and Invertebrate Communities. The synthesis report should have a biogeography/ section up front to provide a general introduction to the theme group reports which might help keep some sections shorter.
- A description of circulation in the area should be added to show how things are connected. This would help give context for connections in other theme groups.
- Clarification was requested on the time series used to calculate anomalies. The standard 30-year time period (1981–2010) has been used in the report. It would be possible to go back further, but would need to rescale the figures. The box colours would change as well. All the time series have data back into the 1980s, so that is why this standard has been chosen.
- Would changing the time series change the perspective on the data? It would not change the interpretation because the same climatology is used as a reference. There has been discussion previously on how best to present the trends. Cumulative plots might be better to illustrate inter-decadal variability. Context might be needed for longer time series.
- For the cold intermediate layer it needs to be clear to the public that more = cold and less = warm.
- Labrador Sea data were not included as it was agreed that these data would not be considered in this report.

- Runoff data could be presented with a running mean to show a smoother line.
- Ocean acidification is a data gap. Data are currently being collected by research through the Aquatic Climate Change Adaptation Program (ACCASP). This data will hopefully be available for the next report.
- Data on sea level rise (SLR), transport, and currents could be added to the report.

Habitat, Coastal, and Significant Benthic Areas

- This section is not as integrative as some of the others. There is also a lack of monitoring for temporal changes in status for this theme.
- The inclusion of sand dollars as a keystone species was questioned. The subject matter expert for the sand dollar section, although not able to be present, clarified by email that because sand dollars can reach very high population densities, they can play a major role in structuring the benthic community; therefore, due to their dominance they can be classified as a keystone species. This is supported by a citation in the text.
- This led to a general discussion on how species/habitats were selected for inclusion in this section. Several factors played a role including selecting habitats for which published information exists, and also habitats which are under pressure from human activities which would be important for public education. The list of species was also limited to the most important based on the space available for the theme group report. Not all could be included, but the list could be expanded in future reports. It was also noted that this section is somewhat skewed towards nearshore habitats. This context should be included in the text.
- In the report, authors should be careful when using “critical” or “essential” habitat terminology as these have particular meaning with respect to SARA species.
- If possible, a map for corals and sponges which covers areas outside of the EEZ (e.g., the Flemish Cap) should be included to give more context.
- The threat of eutrophication to eelgrass comes from increased algal growth which can lead to reduced light levels impeding growth. Vegetative growth may be favoured over root development causing the eelgrass to be more easily dislodged.
- Why is it that in contrast to other habitats, eelgrass in Newfoundland is increasing? In this case climate change is having a positive impact because the waters off Newfoundland are generally warming leading to a longer growing season. This allows plants to put more energy into storage and provides an opportunity to expand to other areas, including northward, through vegetative and seed reproduction.
- A key gap within this section is knowledge of the distribution of these habitats. For example, not all occurrences of eelgrass have been found yet. Distribution maps could be included but would be incomplete.
- Knowledge of potential sea level rise could be added to the oceanography section of the report to add to discussion of this threat to coastal habitats.

- Trends were mentioned in the presentation for some habitats, but no figures were presented. Could maps comparing, for example, the 1980s to the present be included? There is not a lot of data available on trends for these species. Most is presence/absence data, and these species are still being located today. Have some limited data for small regions which might be useful as case studies but not on a bioregional scale. There are also issues with comparability of data collected by different methods.
- Are data available to support statements on threats to habitats? This is available in some cases such as Placentia Bay showing the link between eelgrass and green crab, but the impact of aquaculture on eelgrass is still being studied. Oil and gas activity could be mapped overlying coral and sponge areas. The scale of various threats should be considered.

Oceanography: Lower Trophic Levels

- This section used cumulative anomalies to display the data which they felt would be more legible to the public.
- The relative transfer of energy from the benthic and pelagic systems is very important and may not have been highlighted in the report.
- Are invasive species seen in the lower trophic levels? The sampling protocol is not able to detect them, and a genetic approach might need to be used. Not much effort has been put into this to date.
- The representation of high-energy versus low-energy species would be more intuitive if reported as biomass, but abundance was used in the report. Biomass is measured, and could be reported, although there may be data gaps. Work is being done on *Calanus* energy density which could be included.
- Are harmful algal blooms an issue? Not much work is presently being done on this subject and there is limited capacity to address it. There is some limited monitoring being done in Quebec region where HABs had been an issue, and some work had been done at St. Andrews Biological Station developing remote sensing algorithms.
- *Calanus* might be an interesting story for a case study because of the strong link with capelin in Newfoundland which would be important from a public perspective. There are also three publications being prepared for three species of *Calanus* in the context of the right whale that could be used in the next round of reporting.
- There was a discussion of the standardization of graphs across themes. Should there be a common look and feel, for example the colour palette? Red might be seen by the public to indicate negative information. The consultant indicated that they would have the ability to manipulate the data to produce figures for the public report, and they will consider colours and accessibility. Standardization is not as important for the reports to be included in the synthesis document.

Seabirds

There were no questions on this theme group.

Sea Turtles

- What does critically endangered mean according to the international classification system versus the Canadian system?
- Can other observation data that have been collected since the late 1980s such as in Quebec region be included? Yes, this information has been peer reviewed and published.
- There was discussion about the relative balance and emphasis between species in the report. Sea turtles have a section while larger groups of species such as fish have been grouped for discussion. This is the first year for State of the Ocean reporting in this format, and this will be part of the learning process. Will need to work to find the right balance. Sea turtles are iconic and important from a public perspective, but ecosystem components should be kept in perspective.
- Are there any data on the importance of sea turtles to energy transfer and abundance?

Marine Mammals

There were no questions on this theme group.

Fish and Invertebrate Communities

- It was stated that the increase in redfish was driven by the 2011, 2012, and 2013 year classes. Hake is dominant now in parts of Newfoundland and showing up more in Gulf of St. Lawrence surveys.
- It was suggested that it wouldn't be too difficult to produce a zonal picture, and there were common trends between areas. However, the drivers of these signals may differ between regions.
- The approach of presenting data as communities (e.g., demersal, pelagic, invertebrates) was considered to be useful.
- There was a question about consistency of figures between regions. It was suggested that it would not be necessary to have consistent figures for the synthesis document. The overall story and data would be more important.
- The Atlantic cod biomass estimates for the Scotian Shelf were questioned. There hasn't been an assessment since 2011. Other reports were used for these data that were not necessarily stock assessments. Many species in the demersal, pelagic, and invertebrate groupings used in the report are non-commercial and have no assessment data, so unpublished survey data was used. Would need to consult Maritimes Region experts who will be present on day 2 to clarify Scotian Shelf data.
- Scotian Shelf redfish biomass is not a top 10 species but had the highest biomass. This needs to be reviewed.
- Differentiation between data reported as landings and biomass is important. Both were used, and the landings data has a longer time series but normalization to a reference mean has not been done. For sea cucumber it may appear that the abundance is increasing, but it is actually reported as landings.

- There was a question about standardization of data for changes in gear type during the time series for the northern Gulf and Newfoundland and Labrador Region. This has been addressed in Newfoundland and Labrador where it has been roughly scaled.
- Would landings be a good index for pelagics in the southern Gulf of St. Lawrence? It may be useful for some species (e.g., lobster), but it is less reliable for others such as herring. Surveys are needed to cover deeper waters, and schools can cause spikes in the data. There will be an issue of differences in data sources between regions. Landings can also be biased by changes in effort linked to the popularity of particular fisheries (e.g., herring versus lobster). The southern Gulf Research Vessel survey is a more reliable index than catch per unit effort. Survey data would be preferable, but part of reporting to the public should include describing the difficulties associated with studying these ecosystems.
- There was some disagreement about the importance of using consistent units between regions. Some felt that the overall trends were more important for telling the story. The clearest graph should be selected based on the story being told. Others felt that some readers would be interested in abundances. The report could point to stock assessments for this information. Differences in survey methods between regions would make comparisons difficult. It was suggested that one species could be chosen as an index species and compared between regions. A top 3 or top 5 species per region comparison might also be useful. It was pointed out that the number might reflect catchability rather than abundance. Spark plots might be useful to identify common patterns. In the Gulf of St. Lawrence, catch per unit effort is used because the biomass is not known.
- Reporting of one- and two-year spikes in data was discussed. These years need to be verified and noted as anomalous. Survey trawls are not designed to sample pelagic fish or pelagic invertebrates, so these data may be unclear. This limitation needs to be clear for the public, and this type of graph may not be included in the public report.
- Should a key message for the southern Gulf of St. Lawrence be that herring is increasing? The trend in recent years is decreasing. Not clear which it is.

General

- There was discussion on whether Ecologically and Biologically Significant Areas (EBSAs) should be included within the report. This could be included in the biogeographical overview section. These are defined by Science as biological hotspots. Would not have to describe their use in management, but could acknowledge that the work has been done and provide links to that work. It was questioned whether this would be of interest to the public although informed readers might be familiar with the term. It was suggested that caution be used in introducing EBSAs as they may require a lot of context to be understood and this may not be the right platform. They might fit into the habitat theme.
- How are aquatic invasive species (AIS) being incorporated into reporting? These are currently being considered as stressors within theme groups and are not detailed in their own separate section.

- The question of balance between the sections was discussed. It was suggested that the report could have three larger themes and include case studies for those aspects that don’t require a full theme (e.g., sea turtles, AIS and EBSAs). Sea turtles, marine mammals, and seabirds are not simply upper trophic level animals. Functionally they fit throughout the food web (e.g., sea turtles feed on jellyfish and zooplankton). Generally, however, people see these as separate groups. Their spatial distribution is also a common factor. The sections could be balanced based on the amount of information available. For example, sea turtles and seabirds have similar levels of information, but there may be more on marine mammals. The leads clarified that originally sea turtles and seabirds were included with the marine mammals section, but for logistical reasons, they were presented separately at the workshop. Seabirds and sea turtles might be better grouped together.
- Science outreach indicated that areas that need more information can have links on the website to online information. These areas can be addressed as reporting progresses.

3.3 KEY MESSAGES

- For this section, it will be important to consider overarching key messages. What are the commonalities or inconsistencies in the data? What might be missing from the theme groups?
- The discussion began with consideration of a high level statement that we are in a time of change. Ecosystems/oceans are changing in space and time.
- Key messages were drawn up on the overhead screen with input from the group.
- For public reporting it would be important to determine which components of the synthesis report are the most important and why. What are the ramifications if these trends continue?
- The key messages could be divided into two sections: physical and biological. The physical environment (e.g., sea-surface temperature, deep water temperature, nutrients, pH, and hypoxia) change over time. Interactions in the biological components reflect the underlying signals from the physical environment. There are bottom-up and top-down interactions, novel fish species are introduced, changes in plankton productivity, and changes in community composition. Biophysical zones are shifting and communities are shifting and reorganizing to reflect this.
- The public report should include a figure that clearly illustrates how we define an ecosystem including geographic area, the biological and physical components, and their interactions. Ecosystems are dynamic, but at present we are seeing sustained changes, which is a different situation from the past. Some ecosystems haven’t really recovered from their low productivity state from previous years (prior to 2013).
- What should the scope of the messages be? The report deals with a large geographic area. Changes are not the same between the north and the south. The same stressor (e.g., climate change) can have different impacts in different areas. Rates of change are also different between regions.
- It was felt that the warming climate should be an important, overlying key message.

- Discussion could be included in the report on the changes in ecosystem research from a focus on single species to ecosystem monitoring. This would help explain differences in data over time.
- There was some discussion about whether there are enough strong data to say that the ecosystem is at a non-recovery stage for a species or the ecosystem as a whole. Although the system is currently in a warming period, it was suggested that this has still been a relatively short time period (4–5 years) and it is possible the system may flip back to a previous state in the short term. The Atlantic is affected by multi-decadal variability and the stress from fishing in the past is still being felt in the system which hampers recovery. Commenting on non-recovery is probably not wise at this point based on the level of understanding. The public should understand that there is slow change occurring. It was pointed out that change is not slow in the Arctic.
- A suggestion was made that the report could use language on uncertainty such as that in the IPCC reports on climate change.
- Public interest may be focused on smaller geographic areas which they are familiar with. To some extent this will be addressed by the case studies. Local case studies could be added to the website.
- The key messages for each theme group could be organized according to how things are changing over time, space, and magnitude. The public may understand that things are changing but will ask “So what?” This can be taken as an opportunity to educate the public on why these changes are important.
- Guidance from DFO Outreach indicated that they felt the first step was for Science to provide its key messages and information could be drawn from from these key messages without imposing a new organizational structure.
- The important key messages for each theme group were composed along with key messages for linkages, stressors, gaps and uncertainties, and emerging issues.
- It was felt that the focus of the key messages at this point was for the synthesis document and the language did not need to be simplified at this point. If necessary, this could be done later in conjunction with Outreach and the consultant.
- Participants were reminded that only peer-reviewed and published information would be considered in this report.
- There was discussion on how much detail to include in the stressors section. It was felt that the details would be provided by the text and could be omitted from the key messages. It would not be necessary to make a comprehensive list of all stressors here. Some conclusive messages could be included (e.g., expect to see more storm surges, loss of habitat). Climate change would be considered as a separate stressor which overarches the other stresses and links between theme groups.
- For oil and gas activities, it would be necessary to be more descriptive and include particular stressors (e.g., seismic, oil spills, other contaminants). The impact of noise is still not well understood.

- Cumulative impacts could be important but little progress has been made in understanding this area.
- It would be important to remember that coastal areas can exhibit different trends than the open ocean. For example, warming in coastal areas may be different.

3.4 CASE STUDIES

Multispecies mass mortality of marine fauna linked to a toxic dinoflagellate bloom

- It was unknown how many organisms were affected by the toxic bloom.

Hypoxia and acidification of Lower St. Lawrence Estuary bottom waters: its linkage with carbon, nitrogen and phosphorus flux from the St. Lawrence River

- Are long-term biological data available? There is a good correlation between fish and dissolved oxygen levels, but there are no data from when the estuary was less hypoxic. There are 20 years of dissolved oxygen data from Rimouski, but pH has only been measured recently.

Prey-predator dynamics: the impact of grey and harp seals on Atlantic cod

There were no questions on this case study.

The influence of changing ice on the population dynamics of Northwest Atlantic harp seals

There were no questions on this case study.

Eutrophication in estuaries of the southern Gulf of St. Lawrence

- Could this case study be combined with the study of hypoxia in the St. Lawrence Estuary? The mechanisms differ in these two cases, but could be combined because they both discuss river runoff.
- The salinity in this area was approximately 25 and the depth 2–3.5 m. The water is supersaturated and you can see bubbles coming off *Ulva* spp. Eutrophication is episodic when blooms decompose causing oxygen to be depleted.

Recent warming events in Maritime Canada

There were no questions on this case study.

How climate can affect the productivity of Canada's Atlantic marine ecosystems: the ecological role of forage fish

- Why are there differences between capelin on dates with similar ice conditions? This is not known, but it is possibly linked to differences in physiological and biological conditions.
- Work is being done to update this model with recent data.

Eelgrass and Atlantic cod recruitment

- Could this case study be broadened to include the Atlantic region as a whole? Work from the Maritimes could be included.
- Eelgrass is the only Ecologically Significant Species (ESS) in Atlantic Canada.

Coastal biodiversity from Passamaquoddy Bay

There were no questions on this case study.

Occurrence of novel species in Scotian Shelf trawl surveys

There were no questions on this case study.

Seabird populations respond to reduced forage fish availability

- There was discussion on which data should be included in the figure as not all of it appeared to be peer reviewed. The figure will be updated to include only years with published data (up to 2014).
- There was also a question about whether the link between fish stocks and seabirds had been published. This will be checked.

Benthic babysitters: roles of corals and sponges as nurseries in the deep sea

There were no questions on this case study.

General

- The condensed format of the plain language State of the Atlantic Ocean public report necessitates that only a few out of the twelve case studies be featured.
  - Two or three case studies which addressed the Atlantic zone more broadly would be chosen to be highlighted in the public report.
  - Remaining case studies could be showcased as written summaries or in alternative formats (e.g., lecture/slide presentations, short video interview, infographics, or podcasts) and highlighted on the National DFO State of the Ocean website storyboard along with the public report.
  - All case studies will be included in the synthesis technical report as written summaries.
- There was a discussion on which case studies might be combined. The two eelgrass studies might be combined. It would be important to consider how complex the story would be if two were combined.
- Some graphs in the presentations included information that was unpublished. It was decided not to include these data.
- Should more case studies be included in areas of knowledge gaps such as the coastal zone even if they are more local in extent rather than Atlantic wide?

- The selection criteria used to determine which case studies were to be included in the public report consisted of case studies being based on published, peer-reviewed data, their relevancy at the Atlantic zone scale, multiple key messages being represented, and the involvement of multiple theme groups.
- Workshop participants present on Day 2 of the synthesis workshop for the case study presentations were invited to vote for the three case studies that best fit these selection criteria.
- The following four case studies (due to a tie for third place) were selected for inclusion into public report:
    - Prey-predator dynamics: the impact of grey and harp seals on Atlantic cod
    - How climate can affect the productivity of Canada’s Atlantic marine ecosystems: the ecological role of forage fish
    - Eelgrass and Atlantic cod recruitment
    - Occurrence of novel species in Scotian Shelf trawl surveys
- The format for the case studies which were not selected for the public report will be addressed between the authors and DFO Science Outreach and Communications.

APPENDIX 4 – ACRONYMS AND ABBREVIATIONS

Acronym	Description
ACCASP	Aquatic Climate Change Adaptation Services Program
AIS	Aquatic Invasive Species
AOU	Apparent Oxygen Utilization
AZMP	Atlantic Zone Monitoring Program
AZOMP	Atlantic Zone Offshore Monitoring Program
CaNOE	Canadian Network for Ocean Education
CIL	cold intermediate layer
DFO	Department of Fisheries and Oceans Canada
DO	dissolved oxygen
EBSA	Ecologically and Biologically Significant Area
ECCC	Environment and Climate Change Canada
EEZ	Exclusive Economic Zone
eGoM+BoF	eastern Gulf of Maine and Bay of Fundy
ESS	Ecologically Significant Species
GSL	Gulf of St. Lawrence
HABs	harmful algal blooms
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LIDAR	Light Detection and Ranging
MPA	Marine Protected Area
MPO	Ministère des Pêches et Océans
NAFO	Northwest Atlantic Fisheries Organization
NAO	North Atlantic Oscillation
nGSL	northern Gulf of St. Lawrence
PST	paralytic shellfish toxin
QPX	Quahog Parasite X
ROPOS	Remotely Operated Platform for Ocean Science
ROV	remotely operated vehicle
RSL	relative sea level
RV	research vessel
SARA	Species at Risk Act
SD	standard deviation
SE	standard error
sGSL	southern Gulf of St. Lawrence
SiBA	Significant Biological Area
SLE	St. Lawrence Estuary
SLR	sea level rise
S	salinity
SOTO	State of the Ocean
SS	Scotian Shelf
T	temperature
TNASS	Trans North Atlantic Sightings Survey
UD	Utilization Density
VME	Vulnerable Marine Ecosystem