# STATE OF THE ATLANTIC OCEAN SYNTHESIS REPORT

Renée Y. Bernier, Robyn E. Jamieson, Noreen E. Kelly, Caroline Lafleur, and Andrea M. Moore (Eds.)

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## Canadian Technical Report of Fisheries and Aquatic Sciences 3544

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## Canadian Technical Report of Fisheries and Aquatic Sciences

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# ABSTRACT

Bernier, R.Y., Jamieson, R.E., Kelly, N.E., Lafleur, C., and Moore, A.M. (eds.) 2023. State of the Atlantic Ocean Synthesis Report. Can. Tech. Rep. Fish. Aquat. Sci. 3544: v + 219 p.

Fisheries and Oceans Canada (DFO) has committed to informing Canadians on the state of Canada's oceans and aquatic ecosystems. This technical report, prepared by DFO scientists and collaborators at Environment and Climate Change Canada (ECCC), presents a scientific synthesis of the State of the Atlantic Ocean. This report documents the status, trends, and drivers of change across nine themes representing the physical, chemical, and biological components found in Atlantic Canadian waters: physical oceanography; carbonate chemistry, pH, and dissolved oxygen; nutrients and plankton; marine macrophytes; large marine invertebrates; marine and diadromous fish; marine mammals; sea turtles; and seabirds. Summaries were based on published, peer-reviewed, and/or quality-assured/quality-controlled data and integrated over three Atlantic bioregions: the Scotian Shelf, the Gulf of St. Lawrence, and the Newfoundland and Labrador Shelves. A synthesis chapter including complementary case studies was also developed to illustrate ecosystem connections, oceanographic concepts, processes, or impacts and threats of anthropogenic stressors.

Atlantic Canadian marine ecosystems are changing, and in many cases, this change is occurring rapidly or exceeding the past known range of variability. Changes in physical and chemical oceanographic indicators, such as temperature, circulation patterns, sea ice volumes, and pH, are being driven, directly or indirectly, by climate change: in many places, Atlantic Canadian waters are now warmer, more acidic, with weaker cold intermediate layers and smaller sea ice volumes. Superimposed upon the effects of climate change are a multitude of anthropogenic drivers, such as commercial fishing, shipping, nutrient loading, invasive species, and habitat loss, that affect species across trophic levels and over different spatial and temporal scales. The combination of climate change and anthropogenic drivers across the Atlantic Canadian seascape have important consequences for marine life, altering habitat quality and food availability, shifting the distribution of species, changing abundance or biomass, and altering predator–prey interactions. These changes, however, are not uniform nor of the same magnitude across the bioregions.

The ocean is inherently dynamic; limited coverage of Atlantic Canadian waters by current monitoring programs, or spatial biases in the distribution of research effort, leaves much uncertainty around estimates of oceanographic and biological indicators. With the rise of new methods and technologies, our knowledge of Atlantic Canadian marine ecosystems continues to grow. Advances in our understanding of species' ecology, increased availability of relevant environmental data and advanced modelling frameworks will improve our knowledge, leading to more accurate predictions of how species will likely respond to anthropogenic stressors and climate change driven alterations in their ecosystems.

# RÉSUMÉ

Bernier, R.Y., Jamieson, R.E., Kelly, N.E., Lafleur, C., and Moore, A.M. (eds.) 2023. State of the Atlantic Ocean Synthesis Report. Can. Tech. Rep. Fish. Aquat. Sci. 3544: v + 219 p.

Pêches et Océans Canada (MPO) s’est engagé à informer les Canadiens sur l’état des océans et des écosystèmes aquatiques du Canada. Le présent rapport technique, préparé par des scientifiques du MPO et des collaborateurs d’Environnement et Changement climatique Canada (ECCC), est une synthèse scientifique de l’état de l’océan Atlantique. Ce rapport documente l’état, les tendances et les facteurs de changement selon neuf thématiques représentant les composantes physiques, chimiques et biologiques des eaux du Canada atlantique : l’océanographie physique; la chimie des carbonates, le pH et l’oxygène dissous; les éléments nutritifs et le plancton; les macrophytes marins; les gros invertébrés marins; les poissons marins et les poissons diadromes; les mammifères marins; les tortues de mer; les oiseaux de mer. Les conclusions ont été tirées des données publiées, examinées par des pairs ou ayant fait l’objet d’un contrôle ou d’une assurance de la qualité, et intégrées pour trois biorégions de l’Atlantique : le plateau néo-écossais, le golfe du Saint-Laurent et les plateaux de Terre-Neuve et du Labrador. Un chapitre de synthèse comprenant des études de cas complémentaires a également été élaboré pour illustrer la connectivité des écosystèmes, les concepts océanographiques, les processus, ou encore les impacts et les menaces engendrée par les facteurs de stress anthropiques.

Les écosystèmes marins des eaux canadiennes de l’Atlantique sont en train de changer et, dans bien des cas, ce changement se produit rapidement ou dépasse la variabilité antérieure connue. Les changements observés dans les indicateurs océanographiques physiques et chimiques, comme la température, les courants océaniques, les volumes de glace de mer et le pH, sont directement ou indirectement attribuables aux changements climatiques; à de nombreux endroits, les eaux canadiennes de l’Atlantique sont maintenant plus chaudes, plus acides et caractérisées par des couches intermédiaires froides plus faibles et des volumes de glace de mer réduits. Une multitude de facteurs anthropiques, comme la pêche commerciale, la navigation, l’apport en éléments nutritifs, les espèces envahissantes et la perte d’habitat, viennent se superposer aux effets des changements climatiques, agissant sur les espèces dans tous les niveaux trophiques et à différentes échelles spatiales et temporelles. La combinaison des changements climatiques et des facteurs anthropiques dans l’ensemble du paysage marin des eaux canadiennes de l’Atlantique a d’importantes conséquences sur la vie marine, modifiant la qualité de l’habitat et la disponibilité de la nourriture, la répartition des espèces, leur abondance ou leur biomasse et enfin les interactions entre les prédateurs et les proies. Toutefois, ces changements ne sont pas uniformes et n’ont pas la même ampleur à l’échelle des biorégions.

L’océan est intrinsèquement dynamique; la couverture limitée des eaux canadiennes de l’Atlantique par les programmes de monitorage actuels, ou les biais spatiaux dans la répartition des efforts de recherche, laissent beaucoup d’incertitude quant aux estimations des indicateurs océanographiques et biologiques. Avec l’émergence de nouvelles méthodes et technologies, notre connaissance des écosystèmes marins des eaux canadiennes de l’Atlantique ne cesse de progresser. L’approfondissement de notre compréhension de l’écologie des espèces, la disponibilité accrue de données environnementales pertinentes et de cadres de modélisation avancés amélioreront nos connaissances, nous permettant de prévoir avec plus d’exactitude la réaction probable des espèces aux facteurs de stress anthropiques et aux changements climatiques qui modifient leurs écosystèmes.

# 1. ECOSYSTEM REPORTING

## 1.1 Reporting Process and Structure

This report features the status and trends for the physical, chemical, and biological components across Atlantic Canadian waters, building upon the previous State of the Atlantic Ocean Synthesis Report (Bernier et al. 2018). Status and trends are included in a summary table in Appendix 1 and also presented in each chapter with complementary information on drivers of change and avenues for future research. A wider ecological context featuring stressors, interconnections among Atlantic ecosystem components, and scientific innovations is also included with an overall synthesis for the Atlantic zone. This report was used to develop *Canada's Oceans Now: Atlantic Ecosystems 2022*, a public report that inform Canadians about the current status of our marine environment.

## 1.2 Data

Information was provided by DFO scientists from the four Atlantic Regions (Quebec, Gulf, Maritimes, and Newfoundland and Labrador) and Environment and Climate Change Canada (ECCC) using published, peer-reviewed, or quality-assured/quality-controlled data. Data with open access are indicated where available, other data is available upon request. This report contains information available as of 2022. Important gaps continue to be identified and will be considered in future reports. Chapter key messages were developed during a two-day online workshop (February 1–2, 2022) to synthesize information presented by subject matter experts. Post-workshop, modifications were made to presented data to improve clarity and fill gaps. The workshop agenda and participants list are provided in Appendix 2. Acronyms and abbreviations used throughout the report are provided in Appendix 3.

## 1.3 Biogeographic Units

Reporting is at the Atlantic level where possible but is also presented by bioregion or other relevant assessment units. DFO (2009a) delineated three bioregions in Canada's Atlantic waters: the Gulf of St. Lawrence (GSL), the Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS) (Fig. 1.2-1). These bioregions are based primarily on oceanographic and bathymetric differences, with each area having distinct differences in ecological communities and spatial structure. Place names used throughout the report are shown in Figure 1.2-2.The physical, chemical, and biological oceanographic properties on the continental shelves are collected at sampling stations and along section lines (Fig. 1.2-3) as part of the Atlantic Zone Monitoring Program (AZMP). The same data are collected in the Labrador Sea and from the eXtended Halifax Line (XHL) by the Atlantic Zone Off-Shelf Monitoring Program (AZOMP). Different parameters are averaged over various sub-areas including the northern Gulf of St. Lawrence (nGSL), southern Gulf of St. Lawrence (sGSL), St. Lawrence Estuary (SLE), and/or Northwest Atlantic Fisheries Organization (NAFO) Divisions (Fig. 1.2-4).

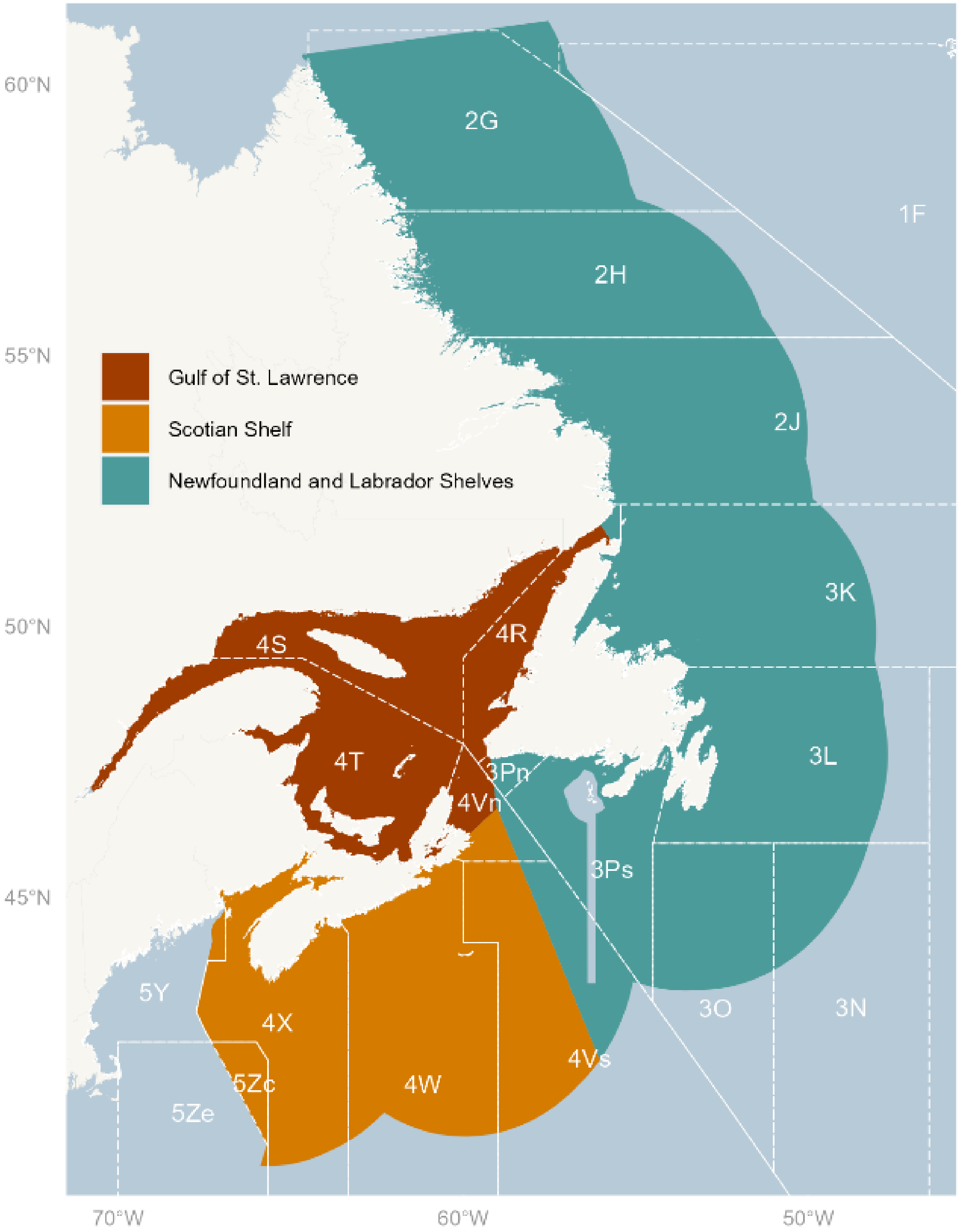

Figure 1.2-1. Map of the Atlantic zone illustrating the three main biogeographic units used in this report (Gulf of St. Lawrence, Scotian Shelf, Newfoundland and Labrador Shelves) and the Northwest Atlantic Fisheries Organization (NAFO) Regulatory Areas. referred to in text. Scientific and statistical NAFO subareas are indicated by numbers, divisions by capital letters and subdivisions by lower case letters.

Figure 1.2-2. Place names in the Atlantic zone used throughout this report.

There are separate research surveys for the nGSL and sGSL so most large marine invertebrates and marine fish are considered at this level. NAFO Divisions are also used to describe many fisheries resources in the GSL, SS, and NLS (Fig. 1.2-1).

Occasionally, the biology and ecology of species or assemblages necessitates use of more meaningful reporting areas than bioregion. Broader assessment areas are more relevant for migratory species of fish, marine mammals, sea turtles, and seabirds, which have ranges that span the Northwest Atlantic (NWA). In contrast, some diadromous fish are monitored at individual rivers and watersheds where they are more easily encountered and are reported on accordingly.

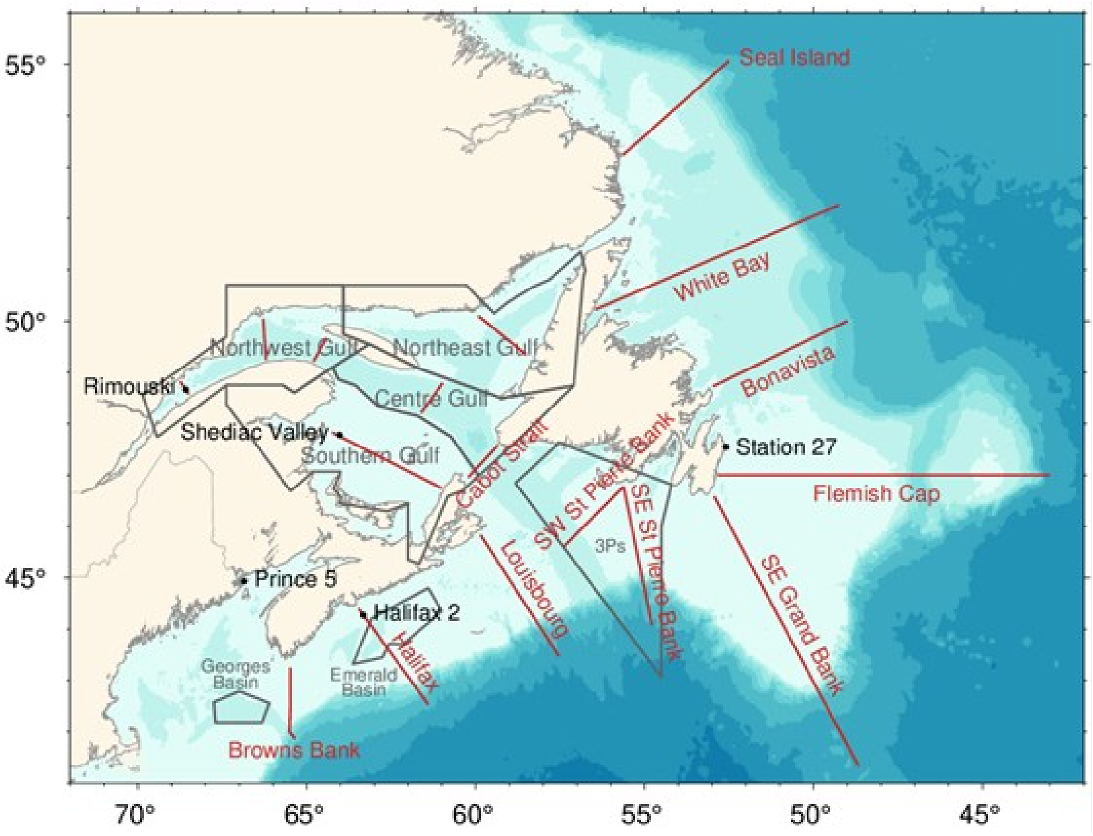

Figure 1.2-3. AZMP high-frequency sampling stations (black circles), selected section lines (red), and bottom temperature averaging areas (gray outlines). AZOMP additional sampling stations not shown.

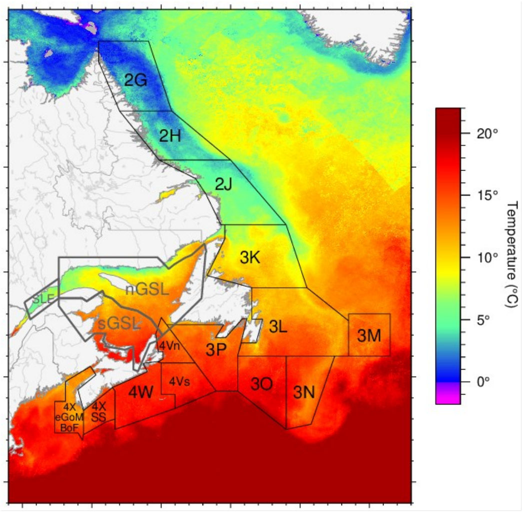

Figure 1.2-4. AZMP sea-surface temperature averaging areas (Data shown is from September 2020). NAFO Divisions are cut off at the shelf break; see Figure 1.2-1 for biogeographical boundaries used in this report.

## 1.4 Legislation and Management

Many species in this report have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an independent advisory panel that reports on the basic biology, population sizes and trends, distribution, habitat availability, and threats for wildlife species suspected of being at risk of extinction or extirpation in Canada (COSEWIC 2021). Species of concern may then be considered for listing on Schedule 1 of the *Species at Risk Act* (SARA), which provides federal legislation to prevent wildlife species in Canada from becoming extinct and to provide for their recovery (GoC 2019). Schedule 1 is the official list of wildlife species at risk and uses the following classifications: Extirpated, Endangered, Threatened, and Special concern. Once listed on Schedule 1, measures to protect and recover a wildlife species are implemented, including the creation of a Recovery Strategy (GoC 2022a, b).

Managing fisheries involves a cycle of data collection and stock assessment which feeds scientific advice to fisheries managers in order to make annual (or multi-year) decisions on various stocks of fish, shellfish, crustacean, and marine mammal species of economic value in accordance with the *Fisheries Act* (DFO 2021). Stock assessments describe what is known about the state of a stock (e.g. abundance, biomass, biology, environmental conditions, natural mortality) to evaluate the expected impacts and benefits of proposed fisheries management measures (e.g. harvest rate, size limits, closures). Fishery-dependent and -independent data are often used as the basis of mathematical models describing past changes in a stock over time to predict how a stock might respond in the future. Stock assessments feed into science advice, from which total allowable catch and opening and closing dates for the season are set by fisheries management (DFO 2021). DFO currently uses a single-species approach for the majority of managed stocks but continues to work towards a more comprehensive ecosystem-based fisheries management approach (e.g. Bundy et al. 2021).

Some harvested stocks have assessments that follow a specific Fisheries Decision-making Framework Incorporating the Precautionary Approach (DFO 2009b). The framework “is about being cautious when scientific knowledge is uncertain and not using the absence of adequate scientific information as a reason to postpone action or failure to take action to avoid serious harm to fish stocks or their ecosystem” (DFO 2009b). As policy, the Precautionary Approach (PA) requires that a harvest strategy be incorporated into fisheries management plans to prevent serious or irreversible harm to the stock. This harvest strategy 1) identifies three stock status zones (healthy, cautious, and critical) delineated by an upper stock reference point (USR) and a limit reference point (LRP); 2) sets the removal rate at which the stock may be harvested within each stock status zone; and 3) adjusts the removal rate according to variations in stock status (i.e. spawning stock biomass or other metric relevant to population productivity) based on pre-agreed harvest control rules (HCRs) (DFO 2006; Marentette et al. 2021). In addition, uncertainty in stock status and biological reference points must be explicitly considered as well as the risk of stock decline associated with a particular management decision (DFO 2009b).

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# 2. PHYSICAL OCEANOGRAPHY

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## 2.1 Key Messages

- Climate change–driven rise in air temperature is leading to warmer sea-surface waters, less sea ice cover, weaker cold intermediate layers, and warmer shallow sea bottom water temperatures in some areas. The latter are associated with the cold intermediate layer such as on the Newfoundland and Labrador Shelves and the Magdalen Shallows.
- 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 last ten years were characterized by smaller than normal cold intermediate layer volumes for both the Gulf of St. Lawrence and the Scotian Shelf, including series records in 2021. Generally, ice conditions in the Gulf of St. Lawrence, on the Scotian Shelf, and on the Newfoundland and Labrador Shelves have been lower than normal reaching a record-low seasonal average volume in the Gulf of St. Lawrence in 2021 and record-low index on the Newfoundland and Labrador Shelves in 2011.
- On average, the Atlantic zone has been experiencing warmer cold intermediate layer and sea ice conditions. Three of the warmest years since 1970 occurred between 2016 and 2021, with 2021 being the warmest year ever recorded.

## 2.2 Background

The Gulf of St. Lawrence (GSL), Scotian Shelf (SS), and Newfoundland and Labrador Shelves (NLS) form an interconnected shelf sea in Atlantic Canada. The circulation in the region is characterized by a general northeast to southwest flow of water from the Labrador and Newfoundland Shelf areas through the GSL, SS, and into the Gulf of Maine (Fig. 2.2-1).

The NLS are dominated by subpolar waters. The cool, fresh Labrador Current flows southward along the NLS 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). The deep waters of the Laurentian Channel are formed by a mixture of these two water sources (DFO 2009).

The GSL is defined by its distinct oceanography as a semi-enclosed inland sea (Loder et al. 1998; DFO 2009). The southern GSL (sGSL) is dominated by the Magdalen Shallows which is an area of high productivity and the northern GSL (nGSL) is dominated by deep channels. Differences can be found in the fish, plankton and benthic communities between the sGSL and nGSL (DFO 2009). Waters in the GSL 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 GSL at depth (Chabot and Gilbert 2013).

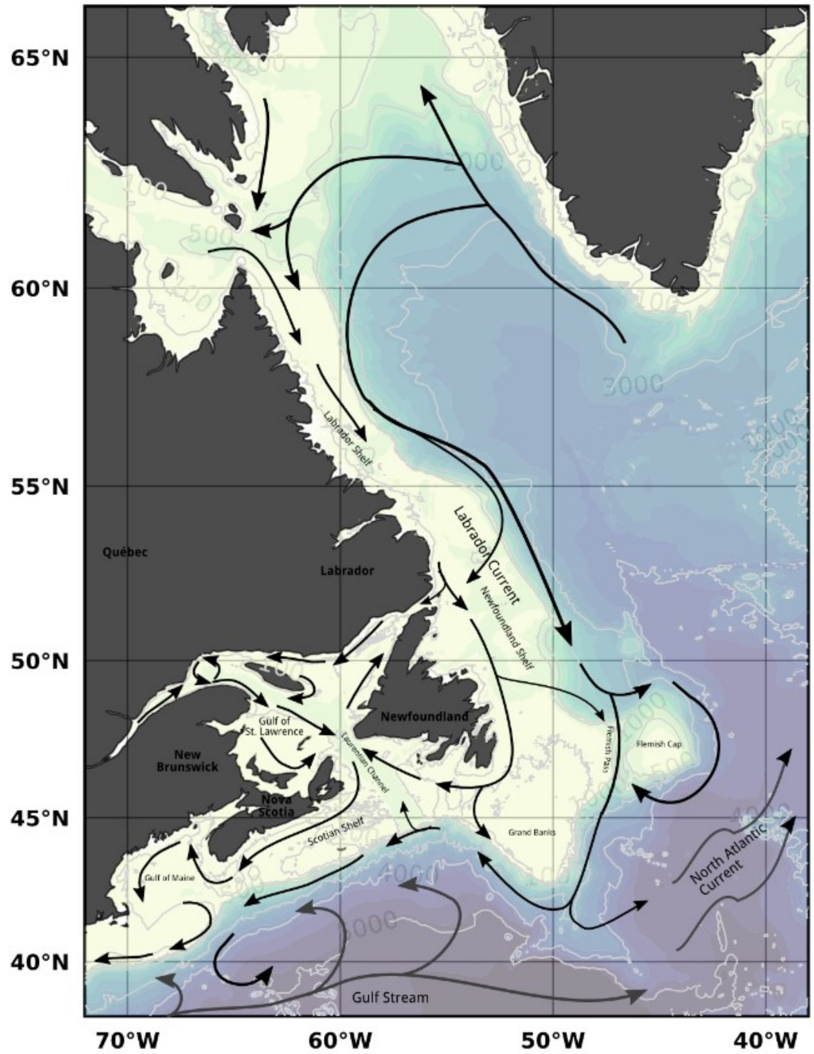

Figure 2.2-1. Schematic diagram of the general circulation patterns in the western North Atlantic Ocean illustrating the two main currents influencing the Canadian Atlantic: the cold Labrador Current from the north and the warm Gulf Stream from the south.

The SS includes the Bay of Fundy and the eastern portion of Georges Bank and is adjacent to the Gulf of Maine to the southwest. It is influenced by the transition between subpolar waters and the Gulf Stream (Loder et al. 1998; DFO 2013). Waters from the GSL flow out through the western side of Cabot Strait with part feeding the Nova Scotia Current and the rest following the western flank of the Laurentian Channel then merging with the current at the SS shelf break.

Seasonal changes in ice, near-surface temperatures, and freshwater runoff are important drivers throughout Canada’s Atlantic zone. The varied direct and indirect impacts of changes to physical oceanographic parameters are discussed for many marine species in Chapter 11 *Ecosystem Perspectives*. In particular, ice cover varies seasonally in the GSL and sea ice moves from northern areas through the Labrador Current over the NLS (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 that live under and on top of the ice.

The vertical structure of waters in the Atlantic zone varies seasonally. In the summer, there are three distinct layers: the warm surface layer, the cold intermediate layer (CIL), and the deeper-water layer. During fall and winter, the surface layer deepens and cools from wind-driven mixing prior to ice formation as well as cooling, reduced runoff, and brine rejection from sea ice formation. Large portions of the Atlantic shelf, including the sGSL and the Grand Banks, only have one layer in winter and two layers in the summer because depths are too shallow to accommodate the deep-water layer. During spring, surface warming, sea ice melt waters, and continental runoff lead to a lower salinity and higher temperature surface layer that stratifies the water column. Below this, cold waters from the previous winter 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).

## 2.3 Status and Trends

Physical oceanographic variables are usually expressed as anomalies—deviations from the long-term means. Here, anomalies are calculated using a reference period of 1991–2020 and normalized (see Section 2.6 *Technical Notes*). Areas over which conditions were averaged are shown in Figures 1.2-3 and 1.2-4. Status and trends are also summarized in Appendix 1.

### *2.3.1 Ocean Temperature*

Sea-surface temperature is obtained from intercalibrated satellite-based datasets that begin in 1982 (Galbraith et al. 2021); water temperatures within the water columns that describe CIL and deep-water conditions are obtained from oceanographic surveys. Sea-surface temperature is averaged over ice-free periods of the year, which may be as short as June to October on the Labrador Shelf or extending to the entire year on the SS (Figs. 2.3-1 and 2.3-2).

Seasonal sea-surface temperature is well correlated with average air temperature (Galbraith et al. 2012, 2021). 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. Deep-water temperature time series are shown in Figures 2.3-1 and 2.3-2 for many sites. Deep waters are defined here as those below the CIL that have only weak seasonal cycles, typically below 200 m in the GSL and SS.

- In the Atlantic zone, sea-surface temperatures during the ice-free period was the third-warmest in 2021, but that was preceded by variable conditions, including two colder-than-normal years: 2018 and 2019 (DFO 2022). The SLE had its warmest ice-free period in 2021.
- In the Atlantic zone, of the 75 annual averages of bottom and deep temperatures between 2016 and 2021, only four were below normal (Fig. 2.3-2).
    - The NLS were characterized by normal to above normal bottom temperatures between 2016 and 2021, including one of the series records in 2021. In between these years, some below normal averages occurred which were associated with colder than normal CIL conditions.
    - All bottom temperature anomalies were normal to above normal on the SS and the nGSL.
    - Series records were observed in the eastern (4V), central (4W), and western (4X) SS as well as 100+ year records in the nGSL and in the Cabot Strait. Deep-water temperatures in Georges Basin, Emerald Basin, and Cabot Strait have been the highest of the time series since 2016.

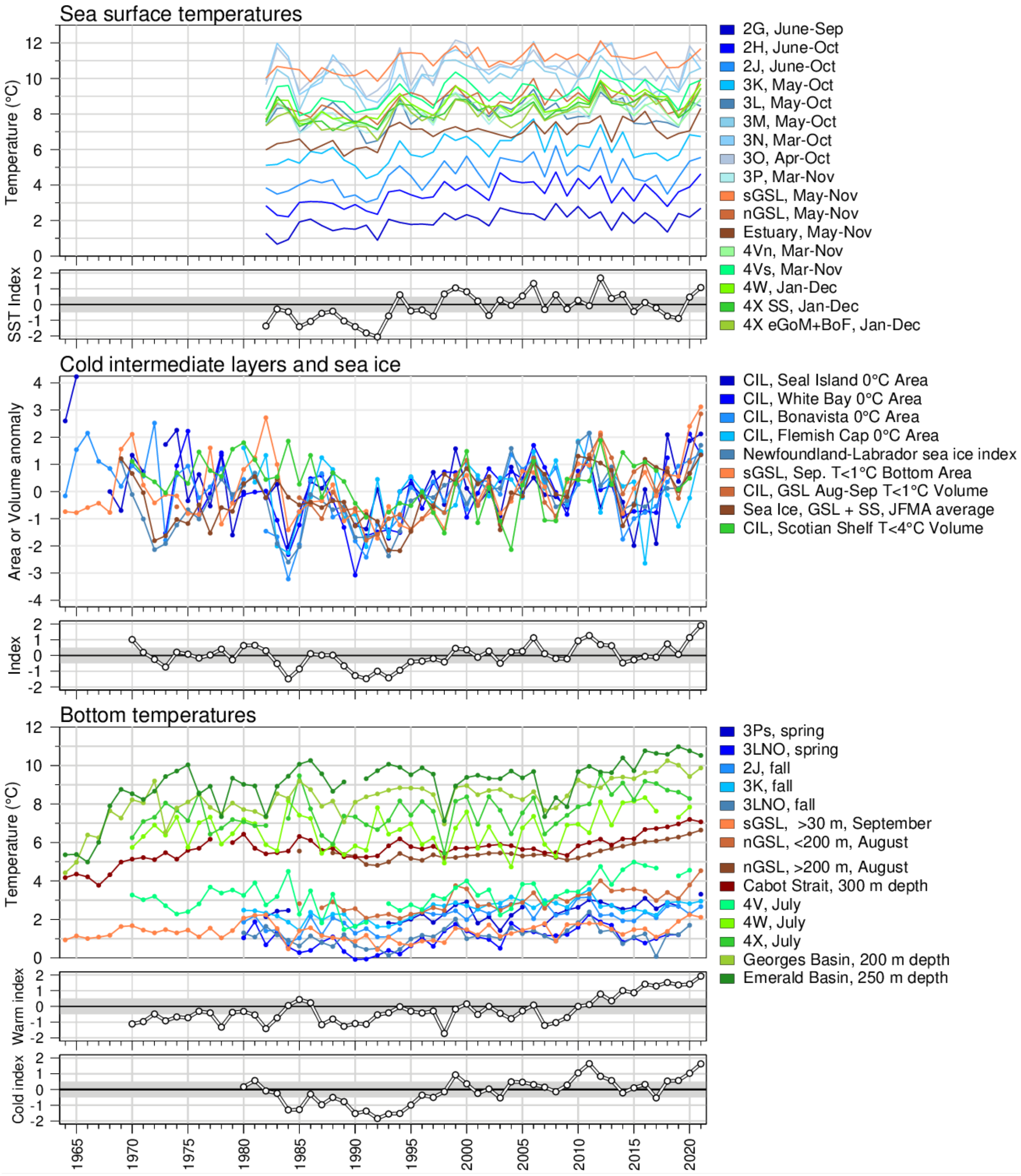

Figure 2.3-1. Time series of oceanographic variables. Anomalies are reversed for sea ice conditions and CIL such that positive anomalies correspond to warmer conditions. See Section 1.2 for biogeographical boundaries. The sea-surface temperature index is an area-weighted average of normalized anomalies. The cold intermediate layer and bottom temperature indices are averages (not area-weighted) of normalized anomalies (see Fig. 2.3-2). Adapted from Hebert et al. (2021), Cyr et al. (2022), DFO (2022), and Galbraith et al. (2022).

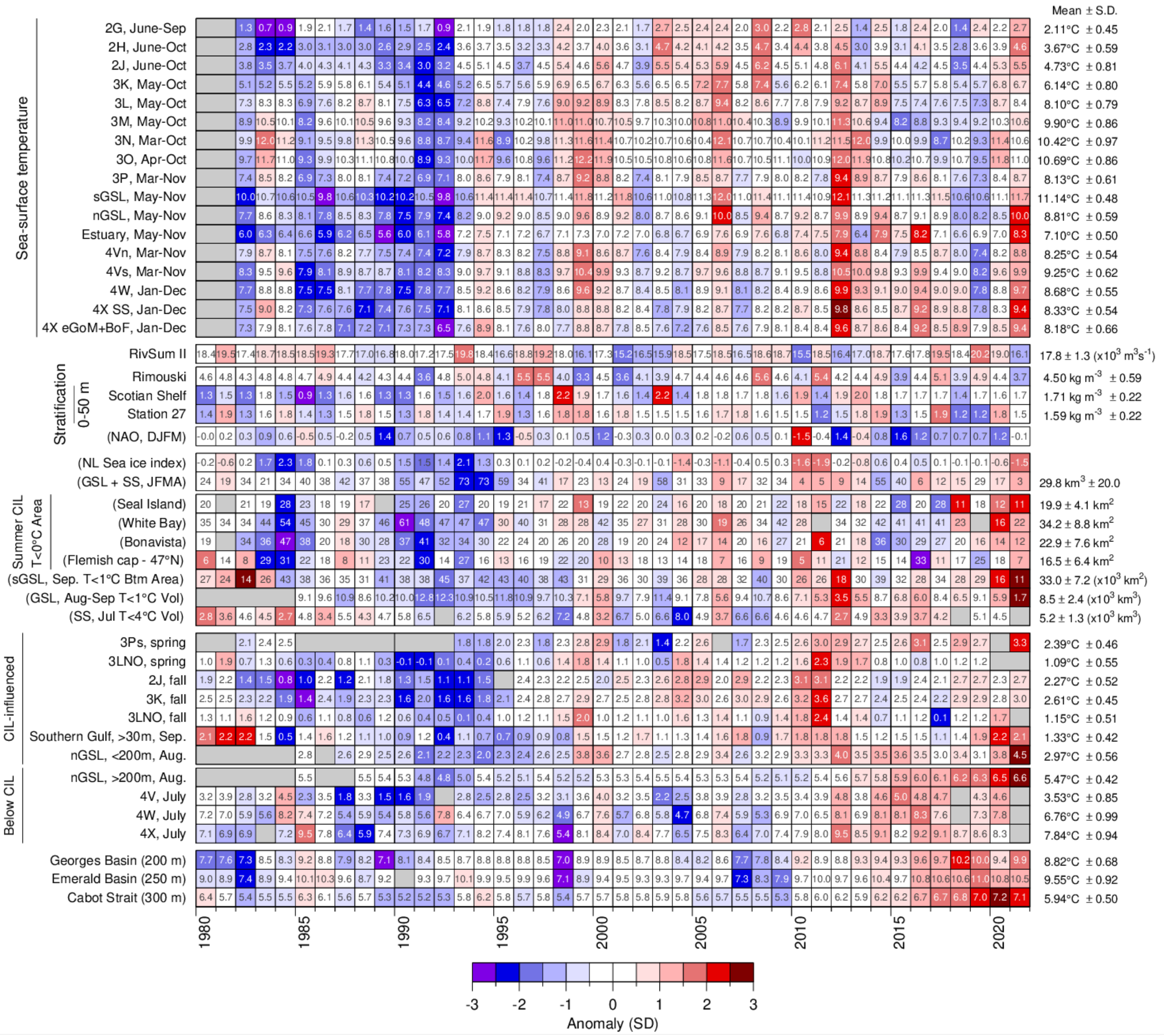

Figure 2.3-2. Time series of oceanographic variables (1980–2021). Gray cells indicate missing data; white cells have a value within 0.5 standard deviation of the long-term mean based on data from 1991 to 2020 when possible; red cells indicate above-normal conditions; and blue cells indicate below-normal conditions. Variables with names in parentheses have reversed sign and therefore colour coding, whereby reds are below-normal values that correspond to warm conditions. Long-term means and standard deviations are shown on the right side of the figure. RivSum II is the sum of runoff measured at Québec City with drainage into the upper and lower St. Lawrence Estuary from a hydrological model. Stratification is expressed as the water density difference between 0 and 50 m; values prior to 1991 for Rimouski station are estimated by a correlation with runoff. See Section 1.2 for biogeographical boundaries. Adapted from Hebert et al. (2021), Cyr et al. (2022), DFO (2022), and Galbraith et al. (2022).

### *2.3.2 Sea Ice*

Sea ice in the GSL and on the SS is quantified by its seasonal average volume (Galbraith et al. 2022). Sea ice conditions in the NLS are summarized by an index that encompasses duration and seasonal maximum area in three regions: the Northern Labrador Shelf, the Southern Labrador Shelf, and the Newfoundland Shelf (Cyr and Galbraith 2021). Sea ice information is presented in Figures 2.3-1 and 2.3-2; note that the signs for sea ice anomalies are reversed such that warm conditions correspond to positive anomalies.

- In recent years, GSL and SS sea ice volumes and the NLS sea ice index have generally been lower than normal.
- Record lows were observed in the GSL and SS in 2021 and the third lowest index on the NLS was observed in 2021.
- Between 2016 and 2021, the GSL and SS seasonal average sea ice volume had three of the seven lowest values of the series and the NLS had two of the eight lowest indices.

### *2.3.3 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 (Fig. 2.3-2). 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 have usually been associated with a positive NAO index, with weaker winds and opposite effects occurring with a negative NAO index (Cyr and Galbraith 2021).

- The positive NAO index observed between 2016 and 2020 did not coincide with conditions as cold as in the previous positive streak of the late 1980s and early 1990s.

### *2.3.4 Cold Intermediate Layer*

The CIL and sea ice cover are well correlated with each other and with winter air temperature because the CIL originates from winter cooling and sea ice cover is formed in winter. For the most part, the CIL is locally formed in winter in separate areas around the Atlantic shelf. Local formation (and not advection from one region to the other) is indicated by the fact that the temperature minimum of the winter mixed layer occurs at about the same time in March on the SS and in the GSL but reaches different minimum temperatures. CIL transport does occur later in the year from the Labrador Shelf to the GSL (Galbraith 2006) and Newfoundland Shelf (Umoh et al. 1995) and from the GSL to the St. Lawrence Estuary (SLE) (Galbraith 2006) and the SS (Umoh and Thompson 1994). The temperature minimum in southern parts of the Newfoundland Shelf (e.g. at Station 27) can occur well after winter—in 2021 it was observed in early June–July.

For the GSL, the CIL volume with water temperature less than 1°C observed in August–September is used (Galbraith et al. 2022). Since the CIL reaches the bottom of the Magdalen Shallows in the sGSL, 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. 2022). For the SS, the CIL volume with water temperature less than 4°C observed in July is used (Hebert et al. 2021). For the NLS, the indices are the cross-sectional areas with water temperature below 0°C during summer along the Seal Island, White Bay, Bonavista, and Flemish Cap AZMP lines (Fig. 1.2-3; Cyr and Galbraith 2021).

The CIL indices reported in Figures 2.3-1 and 2.3-2 are taken at about the same time within their respective annual cycles, although not simultaneously. Note that the signs for CIL anomalies are reversed such that warm conditions correspond to positive anomalies.

- In the GSL, CIL volume was mostly lower than normal in the last six years, reaching a record low in 2021.
- On the SS, CIL volume was lower than normal in 2016–2017 but returned to normal conditions in 2019–2020.

- CIL conditions in the NLS sections were mostly warmer than normal to near-normal in 2016 and 2017, ending with 2021 being the warmest CIL since the 1960s.

### 2.3.5 Runoff

Freshwater runoff in the GSL, particularly within the SLE, strongly influences the circulation, salinity, and stratification (and hence upper water-layer temperatures) in the GSL and, via the Nova Scotia Current, on the SS. The interannual variability of the seasonal (May–October) stratification (0–50 m) at the AZMP Rimouski Station in the SLE is strongly correlated with the seasonally averaged freshwater runoff of the St. Lawrence River (1991–2021; $R^2 = 0.58$). Combined with tidal and wind mixing, runoff drives the estuarine circulation in the SLE and, to a lesser extent, in the whole GSL (Fig. 2.3-2).

- Runoff into the SLE was highly variable from 2016 to 2021.

### 2.3.6 Stratification

Vertical stratification in the water column can affect physical mixing properties and biological processes, such as the sinking of plankton and the upward mixing of nutrients. Long-term stratification indices have been created based on the density difference between the surface and 50 m (Figs. 2.3-2 and 2.3-3). Locations are identified in Figure 1.2-3.

- Stratification in the SLE has followed a similar pattern to seasonal freshwater runoff and has been highly variable over the last decade.
- Stratification on the SS has been mostly normal in recent years.
- At AZMP Station 27 in the NLS, stratification has been variable with no trend between 2016 and 2021.

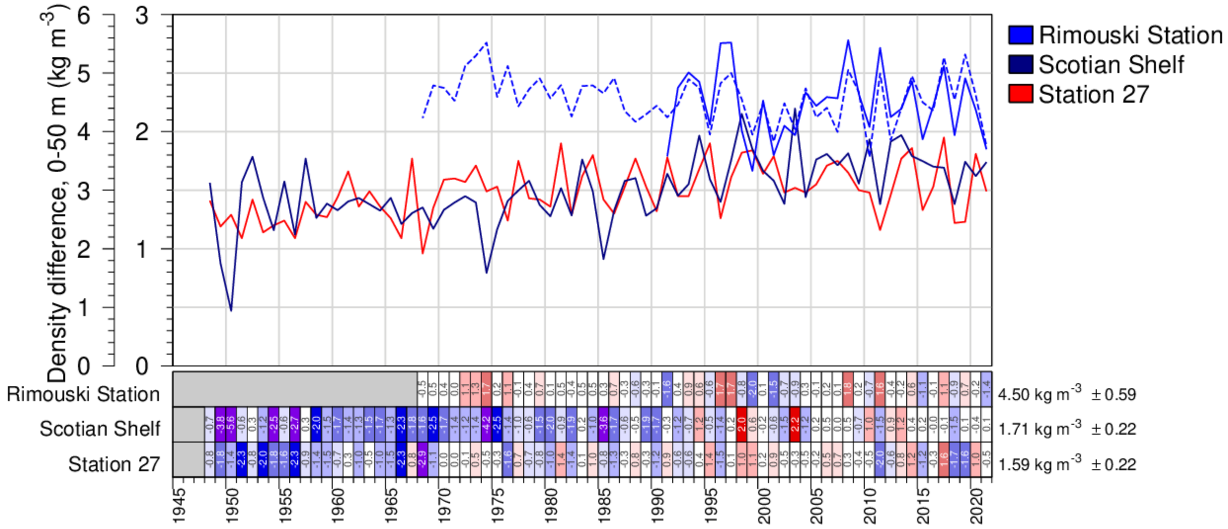

Figure 2.3-3. Stratification trends in the St. Lawrence Estuary (Rimouski Station; outer scale), on the Scotian Shelf (inner scale), and on the southern Newfoundland and Labrador Shelves (at Station 27; inner scale). The dashed line for Rimouski Station is a proxy based on freshwater runoff and is used in the bottom scorecard for values prior to 1991. Adapted from Hebert et al. (2021), Cyr et al. (2022), DFO (2022), and Galbraith et al. (2022).

### *2.3.7 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; Figs. 2.3-4 and 2.3-5).

- Along the nGSL coast, RSL rates change from negative (falling) at Harrington Harbour to positive (rising) at Sept-Îles. Although the rates also change sign at Rimouski and Québec City in the southern SLE, they are not different from zero at the 95% confidence level, suggesting that the magnitude of the historical long-term RSL trend is small along the nGSL and in the SLE.
- To the south of the Atlantic coast, the RSL is rising with rates from 20 to 40 cm/century (22 cm/century at St. John's, 40 cm/century at North Sydney, 33 cm/century at Halifax, 38 cm/century at Yarmouth and 32 cm/century at Charlottetown). In the north it is falling at a rate of 20 cm/century (e.g. Nain; Han et al. 2014).

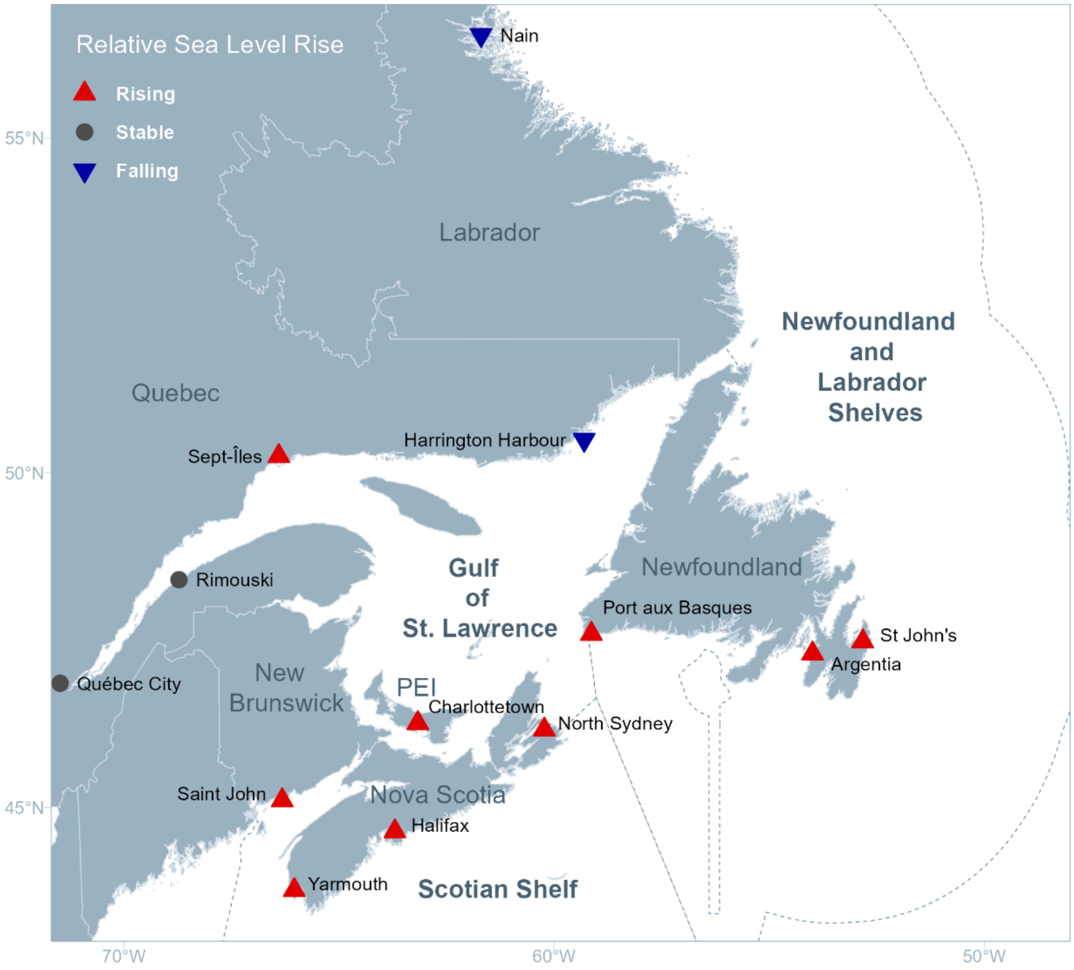

Figure 2.3-4. Map of the Atlantic zone with locations where relative sea level was measured. Data from Han et al. (2014).

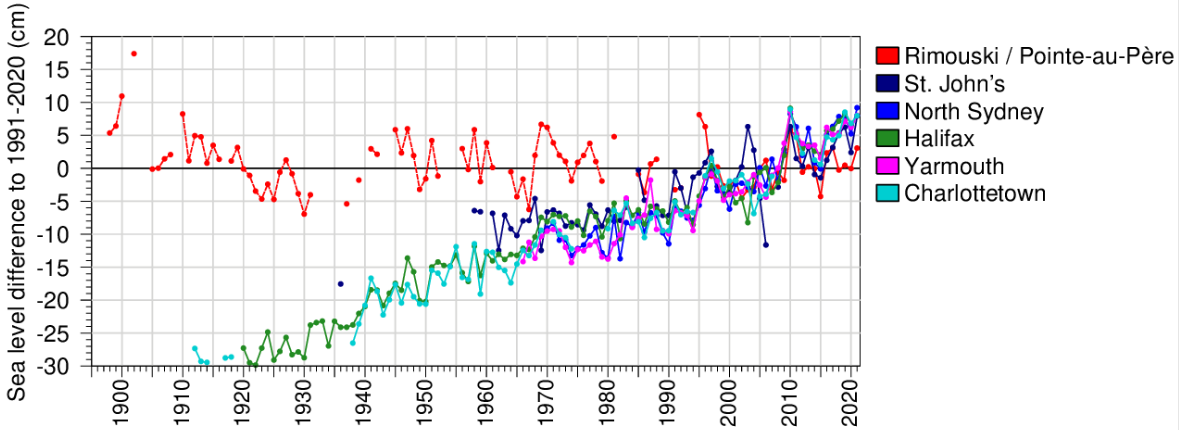

Figure 2.3-5. Annual mean of relative sea level at six sites across the Canadian Atlantic. Values are differences with respect to the 1991–2020 mean for each series. Adapted from Hebert et al. (2021) and DFO Marine Environmental Data Section website https://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/index-eng.htm.

### *2.3.8 Annual Composite Index*

Four annual composite index time series (constructed as the sum of anomalies) are used to assess the overall state of the climate system in the Atlantic zone—a new climate index specific to the NLS is discussed in Section 11.5.4 in *Scientific Innovations to Advance Ecosystem Understanding*. The components of the indices describe sea-surface temperatures; CIL properties and sea ice volume (both formed in winter); cold bottom temperatures (affected by CIL conditions); and warmer bottom and deep temperatures (not affected by seasonal variability). There is strong similarity between the CIL index and the cold bottom temperature index ($R^2 = 0.81$). The indices are shown in Figures 2.3-1 and 2.3-6; positive values represent warm conditions and negative values represent cold conditions.

- During the last six years, sea surface temperature has alternated from cooler-than-normal to warmer-than-normal conditions. CIL, sea ice and cold bottom water anomalies have alternated between near normal and above normal, and warm bottom temperature anomalies have all been positive.
- The highest values of each index have occurred in the last decade.

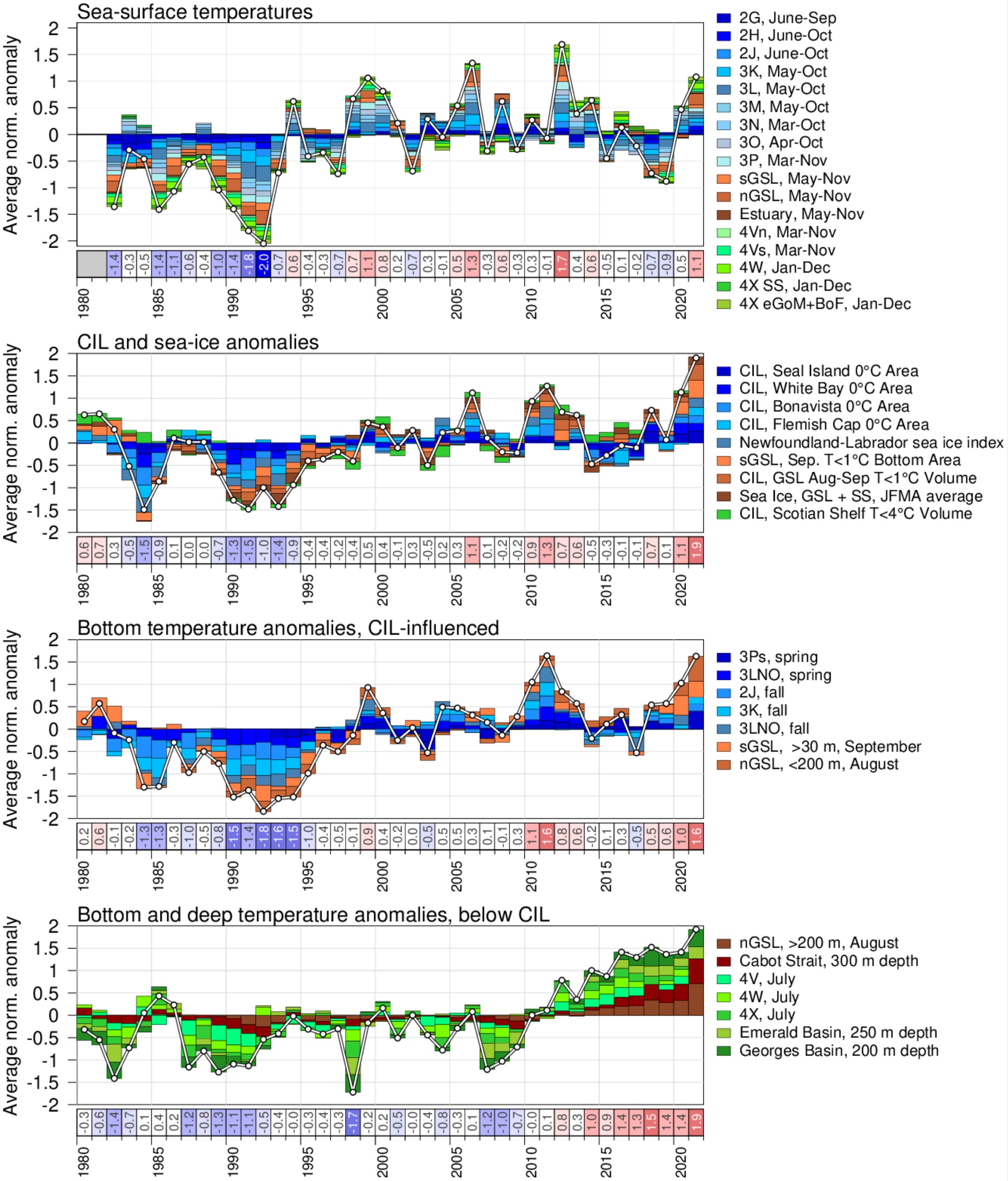

Figure 2.3-6. Composite climate indices (white lines and dots) derived by summing various standardized anomalies from different parts of the environment; coloured boxes stacked above the abscissa are positive anomalies, below are negative. Top panel sums sea-surface temperature anomalies; second panel sums cold intermediate layer and sea ice anomalies with areas and volumes in reversed scale (positive anomalies are warm conditions); and two bottom panel sums bottom temperature anomalies affected by the CIL and deeper warmer conditions that are not. See Section 1.2 for biogeographical boundaries. Adapted from Hebert et al. (2021), Cyr et al. (2022), DFO (2022), and Galbraith et al. (2022).

## 2.4 Drivers of Change

Surface oceanic water temperatures on the Atlantic shelf have been mostly tracking the climate-change driven warming trends observed in the atmosphere during ice-free months. Overall, although the warmest conditions occurred in 2012, only two years (2018 and 2019) have been below normal in the last decade. Warming winters have led to less sea ice cover and weaker CILs.

Interdecadal changes in temperature and salinity of the deep waters of the GSL, SS, and Gulf of Maine are related to the varying influence of their source waters: cold–fresh Labrador Current water and warm–salty Slope Water (McLellan 1957; Lauzier and Trites 1958; Bugden 1991; Gilbert et al. 2005; Brickman et al. 2018).

The thick CIL on the NLS influences its bottom temperature, similar to shallower parts of the SS and GSL such as the Magdalen Shallows. The NLS were characterized by above-normal bottom temperatures at the beginning and end of the last decade (including series records in 2011 and 2021), with some near- and below-normal averages in the middle; whereas anomalies were above normal on the SS and the nGSL during this time period. Bottom temperature series record highs were observed during this period in all regions of the SS, as well as 100+ year records in the nGSL and in the Cabot Strait.

Petrie and Drinkwater (1993) showed that water mass characteristics of the SS deep basins were strongly influenced by variations in the westward transport of Labrador Slope Water from the NLS along the shelf break. Increased transport of Labrador Slope Water through the Flemish Pass was associated with below-normal deep temperatures and salinities on the SS and in the Gulf of Maine. Deep basins (e.g. Emerald Basin, Georges 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 SS (NAFO Divisions 4W and 4Vs, respectively). 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.

Sea ice and winter temperature are highly correlated. Long term trends show winter air temperature over the GSL warming at a rate of 2.1°C per 100 years, forcing a decline in sea ice severity (Galbraith et al. 2022). Sensitivity of the GSL ice cover to climate change can be estimated using past patterns of change in winter air temperature and sea ice features, which indicate losses of 18 $km^3$, 31,000 $km^2$, and 13 days of sea ice season for each 1°C increase in winter air temperature (Galbraith et al. 2022).

## 2.5 Technical Notes

The general spatial and seasonal patterns of physical oceanographic indices in the Northwest Atlantic monitored by AZMP have remained relatively consistent since the start of the program. Although there are seasonal variations in the distribution of water masses, these variations show generally predictable patterns. Physical oceanographic variables are effectively sampled because they exhibit fairly conservative properties that are unlikely to show precipitous changes either spatially or from year to year. In addition, measurements of these variables are made with a good degree of precision.

The climatological reference period changed from 1981–2010 to 1991–2020 for physical variables. This ten-year shift follows the World Meteorological Organization standards and allows, over subsequent decadal shifts, the comparison over the same climatological period of an increasing number of time series. It has the disadvantage of masking long-term trends, including those caused by global warming. In our zone, the effects of the shift are large for sea-surface temperature since it removes the cold 1981–1990 period from the climatological period and adds the warm 2011–2020 period. Previously reported very high anomalies for 2012 are reduced in this report. Similarly, bottom temperatures have been greatly increasing in the last decade, even exceeding the past known range of variability. Therefore, not only has the mean of the climatology changed, but in many cases the variance as well, which also affects normalized anomalies.

After subtraction from its long-term mean, each time series is normalized by dividing by its standard deviation, which is also calculated using data from the reference period. This allows for 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.

In the NLS, seasonal average sea ice volume is correlated with the CIL area along the Bonavista section (1980–2020, $R^2 = 0.70$) whereas Newfoundland Shelf sea ice metrics are correlated with December–March air temperature further North at Cartwright (1969–2021, $R^2 = 0.70–0.74$; Cyr et al. 2022). In the GSL, the correlation between the December–March air temperature averaged over multiple meteorological stations and the annual maximum ice volume reaches $R^2 = 0.74$ (1969–2021; Galbraith et al. 2022). Air temperature is similarly well correlated with sea ice cover area and duration ($R^2 = 0.82–0.83$; Galbraith et al. 2022).

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# 3. CARBONATE CHEMISTRY, PH, AND DISSOLVED OXYGEN

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## 3.1 Key Messages

- The rates of decrease in pH in Atlantic Canadian waters (0.03–0.04 per decade) are generally faster than the global average for surface pH (0.017–0.027 per decade) since the late 1980s.
- Driven by changes in the Northwest Atlantic circulation, the deep waters of the Gulf of St. Lawrence and the St. Lawrence Estuary have been receiving less cold, oxygen-rich Labrador Current Water in favor of warm, oxygen-poor North Atlantic Central Waters in recent years. Near the head of the Laurentian Channel, low pH coincides with an area of severe hypoxia. Oxygen saturation and pH have been declining since 2008, hitting record lows in 2021.

## 3.2 Background

The accumulation of anthropogenic $CO_2$ in the atmosphere and its uptake by the ocean surface has shifted marine carbonate chemistry and altered seawater pH (IPCC 2019). Uptake of $CO_2$ has led to a decrease in carbonate ion concentration in the ocean and a corresponding increase in acidity. Higher acidity (lower pH) makes the water more corrosive to calcium carbonate minerals, a main component of the skeletons and shells of many organisms, including molluscs, crustaceans, corals, and echinoderms.

Oxygen is fundamental to biological and biochemical processes in the ocean; when dissolved oxygen (DO) is low, marine species experience reduced survival, growth, reproduction, and altered behaviour. As a result of anthropogenic climate change, DO has been reduced in the top 1000 m of the world’s oceans (IPCC 2019). This oxygen loss is primarily due to increasing ocean stratification and changes in the ocean’s ventilation and biogeochemistry. Thus, ocean acidification and increasing temperatures are mechanistically linked to the process of deoxygenation (reviewed in Breitburg et al. 2018). Together, ocean acidification and the reduction of DO in the ocean can increase the physiological stress on numerous marine organisms.

## 3.3 Status and Trends

Historical measurements of acidification parameters exist in the Atlantic zone and ocean acidification parameters have been systematically collected by DFO as part of the AZMP since fall 2014. In addition to pH, calcium carbonate saturation states with respect to calcite ($\Omega_{cal}$) and aragonite ($\Omega_{arg}$) are measures of ocean acidity. They indicate the potential to precipitate or dissolve calcium carbonate from the water column—below a threshold of 1, the environment is considered undersaturated and potentially corrosive to organisms that build biogenic carbonate shells. The $\Omega$ typically decreases with depth, thus deep slope waters tend to have lower $\Omega$ than the bottom waters of the shallower shelf waters.

DO measurements have been systematically collected by DFO as part of the AZMP since 1998. Low DO concentrations (<30% saturation or <62.5 µmol $L^{-1}$) are generally considered hypoxic and conditions with very little to no DO (0% saturation or 0–6.25 µmol $L^{-1}$) are considered anoxic. During the three to four years that it takes for deep waters entering the mouth of the Laurentian Channel to travel to the channel heads in the SLE, the DO content progressively declines from respiration and oxidation of organic material sinking to the bottom. Therefore, the lowest levels of dissolved oxygen are found in the deep waters at the head of the Laurentian Channel in the St. Lawrence Estuary (SLE).

Recent status and trends from the Atlantic zone are presented below for the Gulf of St. Lawrence (GSL), the Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS). Recent bottom ocean acidification parameters are shown across the Atlantic in Figure 3.3-1; acidity on the (SS) and in the Labrador Sea are shown in Figure 3.3-2; and acidity, dissolved oxygen, and temperature for the lower SLE are shown in Figure 3.3-3. Status and trends are also summarized in Appendix 1.

- The rates of decrease in pH in Atlantic Canadian waters (0.03–0.04 per decade) are generally faster than the global average for surface pH (0.017–0.027 per decade since the late 1980s (IPCC 2019).
    - The deep waters of the GSL experienced the fastest decrease in pH, at a rate of about 0.04 units per decade since 1934, reaching a record low in 2021 of 7.44.
    - In the SS there has also been a decrease in pH at a rate of about 0.03 pH units per decade since the 1930s.
    - In the Labrador Sea, there has been a near-linear decrease in pH from 1996 to present at a rate of about 0.03 pH units per decade.
- At the surface, pH and $\Omega_{arg}$ (not shown) are lower in the NLS and in the GSL (especially in the lower SLE) compared to the SS, primarily due to lower temperatures and/or salinity.
- pH and Ω values measured in bottom waters are lower in the SLE and GSL compared to the SS and the NLS.
    - Bottom waters of the GSL were undersaturated with respect to aragonite except inflowing waters in the Strait of Belle Isle and the Cabot Strait.
    - The lowest pH and Ω values were observed along the deep Laurentian Channel, especially in the SLE where most of the deep layer (>300 m) was undersaturated with respect to aragonite and calcite and represents increased acidification relative to the conditions in 2019.
    - Bottom pH values were below 7.6 throughout the SLE; for the SS and NLS, values ranged from 7.8 to above 8 and demonstrated considerable spatial variability.
    - In 2020, $\Omega_{arg}$ was slightly undersaturated in the Avalon Channel, on the Grand Banks, in the deepest part of the Newfoundland Shelf slope, and on the eastern SS.
- DO saturation is generally high in Atlantic Canadian waters, except for in the GSL (Fig. 3.3-1, bottom row).
    - Bottom water in the deep channel of the SLE has been below 20% saturation since 2014 and consistently hypoxic since 1984 (Fig. 3.3-3).
    - In 2020, oxygen saturation at many sampling locations in the GSL was well below 20%, even below 15% at some stations. In 2021, a new low oxygen

concentration record was observed for the lower SLE: 44.50 µmol $L^{-1}$ or 14.4% saturation, which corresponds to severe hypoxia.

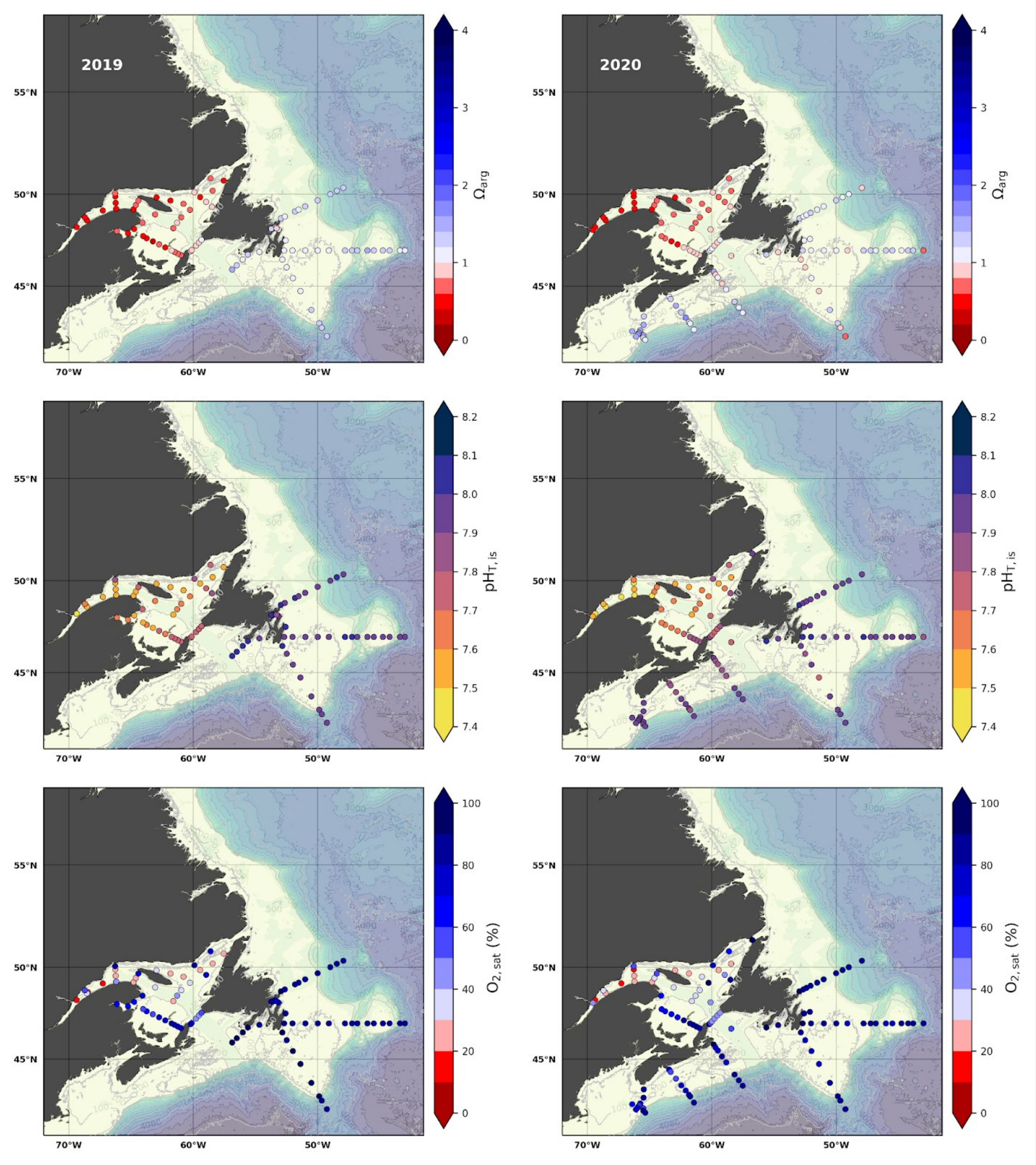

Figure 3.3-1. Bottom ocean acidification parameters during fall 2019 (left) and 2020 (right): aragonite saturation state (top), *in situ* pH using total scale (center) and dissolved oxygen saturation (lower). Undersaturated conditions relative to aragonite and hypoxic oxygen conditions are plotted in red. Adapted from DFO (2021); data available from Cyr et al. (2022).

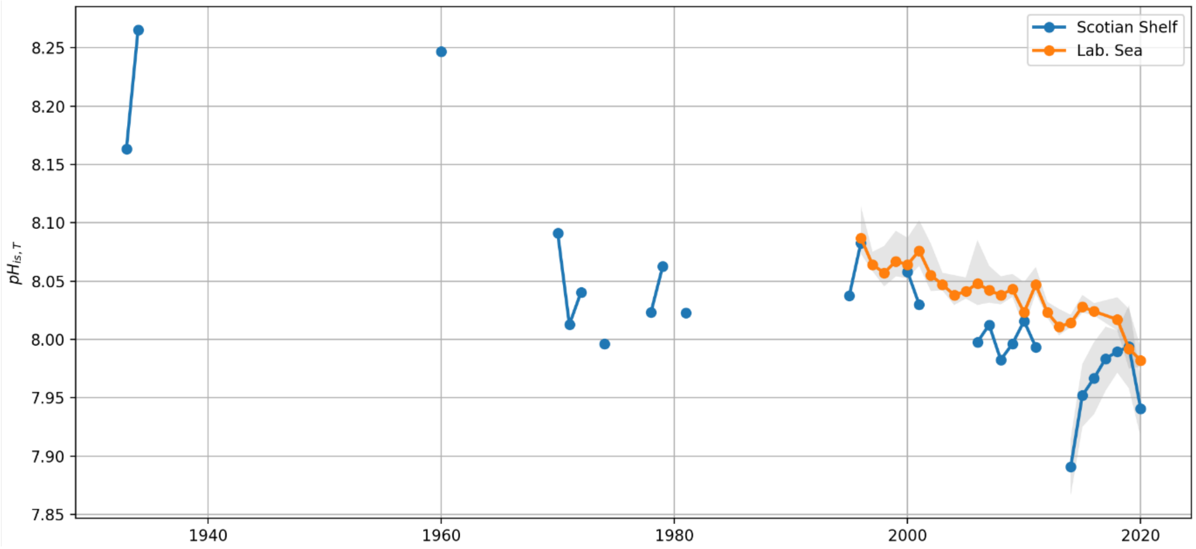

Figure 3.3-2. Acidity (pH; *in situ*, total scale) on the Scotian Shelf 50–200 m (blue) and in the Labrador Sea 150–500 m (orange). Data for the Labrador Sea (1996–2020) and for the Scotian Shelf (2014–2020) are provided with an envelope corresponding to ± 0.5 SD (gray shading).

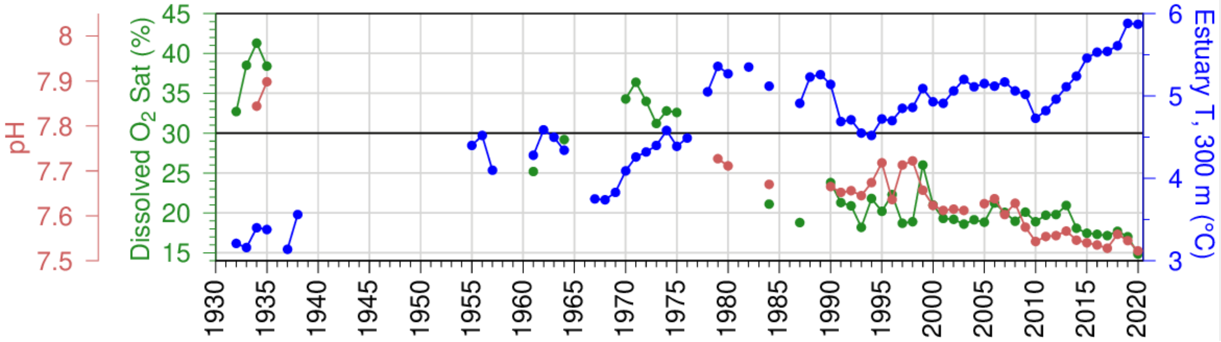

Figure 3.3-3. Acidity (pH), annual mean dissolved oxygen saturation, and bottom temperature in the lower St. Lawrence Estuary between 295 m and bottom in the deep central portion of the estuary. The horizontal line corresponds to 30% saturation in dissolved oxygen and marks the threshold of hypoxic conditions. The mean dissolved oxygen data (Blais et al. 2021) are an update to the time series presented in Gilbert et al. (2005). Temperature data are from Galbraith et al. (2021). The Gulf of St. Lawrence Estuary pH data are updated from Mucci et al. (2011).

## 3.4 Drivers of Change

Ocean acidification and the reduction of DO concentration in the top 1000 m of the world's oceans—which further causes hypoxia—are two important ocean stressors resulting from anthropogenic climate change (IPCC 2019). It is projected that further acidification (*virtually certain*) and oxygen decline (*medium confidence*) will occur over the 21st century (IPCC 2019). Deoxygenation may also occur as a result of eutrophication, particularly in coastal areas close to major centers of agriculture or human sewage inputs, such as in the SLE. Deoxygenation and ocean acidification may also have ecosystem-level effects, including changes in biodiversity and the cycling of nutrients, direct loss of habitat or habitat compression, altered trophic relationships, changes in migration patterns, and a reduction in the productivity of fisheries.

There are multiple drivers of the decadal changes in DO concentration and saturation in the deep waters of the GSL. However, Gilbert et al. (2005) suggested that while oxygen utilization in the SLE in response to warmer temperatures and eutrophication is important to explain the oxygen loss, large-scale circulation changes in the western North Atlantic that vary the proportions of source waters to the GSL dominates. Jutras et al. (2021) suggested that the rapid decline in oxygen concentrations observed since 2008 in the deep GSL resulted from reduced inflow of cold, highly oxygenated Labrador Current Water to the deep waters of the system in favor of warm, low-oxygenated North Atlantic Central Water. These changes are likely also responsible for the rapid increase in deep bottom temperatures in the GSL and SLE (Fig. 3.3-3, see also Section 2.3.1 *Ocean Temperature*).

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# 4. NUTRIENTS AND PLANKTON

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## 4.1 Key Messages

- An important shift in the deep-water nitrate from near-minimum levels observed in 2017–2018 to near-normal levels in 2019–2020 has been driven mainly by increases observed in the Gulf of St. Lawrence and on the Newfoundland and Labrador Shelves.
- Since 2017, phytoplankton biomass has been mainly near or above normal both on the Newfoundland and Labrador Shelves and in the Gulf of St. Lawrence and has remained near or below normal on the Scotian Shelf.
- The initiation and duration of the spring phytoplankton bloom have remained fairly stable since 2017 with near- or later-than-normal initiation timing, and near- or longer-than-normal duration. Bloom magnitude varied between and among sampling locations within subregions since 2017. High values of the bloom magnitude were observed in 2018 and 2019 on the Grand Banks of Newfoundland but magnitude returned to near-normal levels across the Atlantic zone in 2020.
- Total zooplankton biomass, which is largely driven by the abundance of *Calanus finmarchicus* copepods, increased to near-normal levels from 2018 to 2020, following a period of approximately eight years of lower-than-normal biomass.
- Changes in zooplankton community structure in the second half of the 2010s suggest a gradual transition toward increasing abundances of large, energy-rich copepods (*Calanus finmarchicus*) and decreasing abundances of smaller, less-energy rich copepods (*Pseudocalanus* spp.) and non-copepod organisms, with potentially beneficial consequences on the flow of energy toward higher trophic levels.
- Warming surface and deep waters as well as subsequent shifts in ocean circulation are important drivers of change in nutrient and chlorophyll *a* inventories and overall zooplankton biomass. Long-term declines in these lower trophic level indices may be indicative of lower ecosystem production potential compared to previous decades.

## 4.2 Background

Planktonic organisms, primarily phytoplankton and zooplankton, transfer energy to higher trophic level animals. Phytoplankton grow best under optimal conditions of temperature, light availability, and nutrient supply. Zooplankton are the main consumers of phytoplankton and hence, are a critical link between primary producers and larger organisms.

Many plankton species in the Northwest Atlantic (NWA) synchronize critical phases of their life history with the changing seasons in order to maximize survival, growth, and reproduction. As a result, phytoplankton and zooplankton exhibit recurring temporal and spatial distribution patterns. Plankton distribution is also influenced by disturbances in the physical environment and nutrient supply which can have important impacts on the entire ecosystem.

## 4.3 Status and Trends

Nutrients, phytoplankton, and zooplankton in the NWA are described as indices representing key characteristics at the annual scale for the Gulf of St. Lawrence (GSL), the Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS) (Figs. 4.3-1 to 4.3-4). Status and trends are also summarized in Appendix 1. Each index is a time series of annual standardized anomalies calculated as the difference between the annual average for a given year and the long-term mean over a refence period, divided by the standard deviation of that reference period for each oceanographic averaging area. The reference period is from 2003 to 2020 for spring bloom indices and from 1999 to 2020 for nutrients, chlorophyll *a*, and zooplankton indices. Each subregion/section/station is identified based on the Atlantic Zone Monitoring Program (AZMP) survey design (DFO 2021) along with its associated North Atlantic Fisheries Organization (NAFO) subareas (see Figures 1.2-3 and 1.2-4).

### *4.3.1 Nutrients*

The productivity of marine ecosystems largely depends on photosynthesis, the process used by phytoplankton for the synthesis of organic matter from carbon dioxide and dissolved nutrients, fueled by the sun's energy. The growth rate of phytoplankton is dependent on the availability of light and nutrients in the form of nitrogen (nitrate, nitrite, and ammonium), phosphorous (phosphate), and silica (silicate), with the latter being essential for production of diatoms. In continental shelf waters, nitrate is the dominant form of nitrogen and usually the limiting nutrient for phytoplankton growth.

Surface nitrate is highly coupled with phytoplankton growth and thus shows important seasonal variability. In contrast, nitrate in the lower part of the water column provides a good indicator of the resources available to surface waters for phytoplankton growth via vertical mixing and/or upwelling. The amount of nitrate contained in the water column below the surface mixed layer at depths of 50–150 m—the deep-nitrate inventory—is therefore used to assess the status of nutrient availability. Deep-nitrate inventories depend strongly on circulation patterns, which can vary from year to year and which contribute to the source waters making up these deeper waters on continental shelves.

Standardized anomalies of the deep-nitrate inventory are shown in Figure 4.3-1.

- Two of the lowest levels of deep-water nitrate on record were reached in 2017 and 2018, when below-normal levels were recorded over most areas in the Atlantic zone. In 2019 and 2020, deep nitrates rebounded to near-normal levels, driven by increases in the GSL and on the NLS.
    - In the GSL, deep-nitrate levels were mostly below normal in 2017 and 2018 and mostly above normal in 2019 and 2020.
    - On the SS, deep-nitrate levels were predominantly below normal from 2016 to 2020.
    - On the NLS, deep-nitrate levels increased from below normal in 2018 to mostly above normal in 2019 and 2020.
- Since 1999, deep-water nitrate inventories have exhibited large inter-annual variability at the zonal and regional scale. For example, deep-nitrate inventories on the NLS were predominantly above normal from 1999 to 2008 and predominantly below normal from 2009 to 2015. Conditions in the GSL and SS indicated more frequent but moderate variations over those periods.

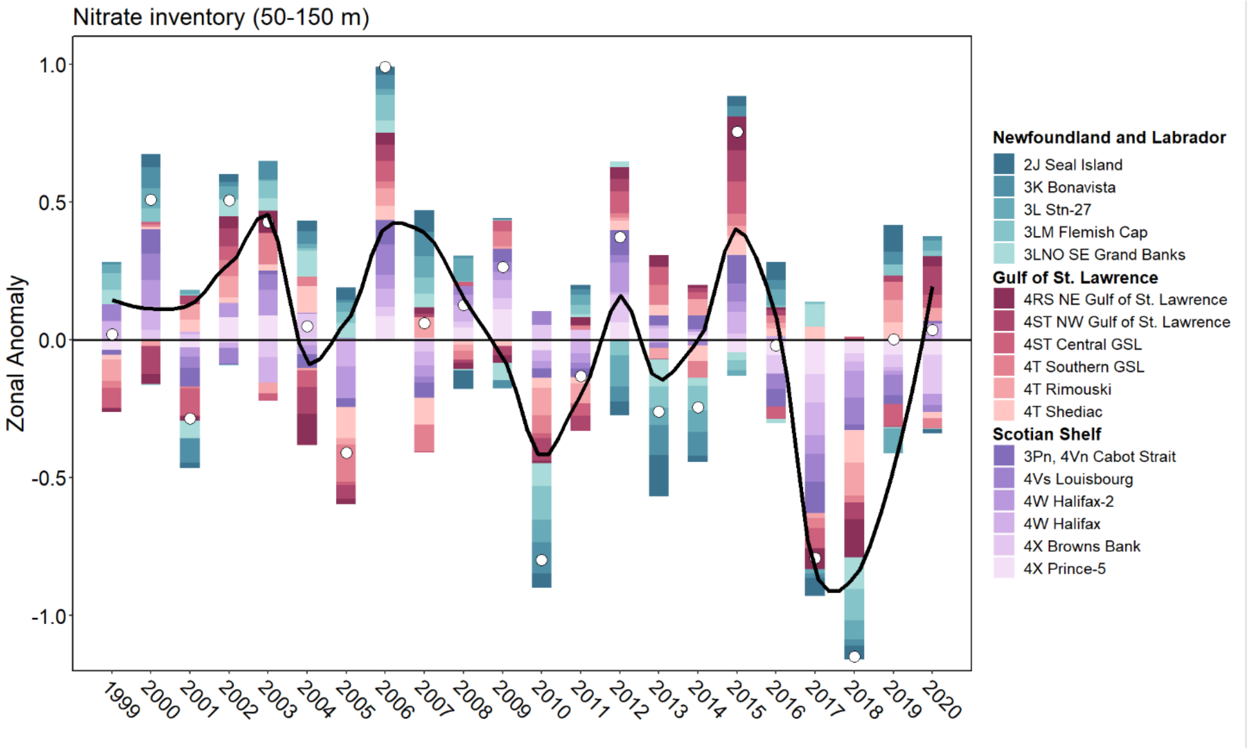

Figure 4.3-1. Standardized anomalies of the deep-nitrate inventory (combined nitrate and nitrite) in the lower water column (50–150 m or bottom if shallower) for different oceanographic sections and fixed stations from the AZMP over the period 1999–2020. Coloured bars indicate the relative contribution of each section/station to the mean zonal anomaly (open circles). The black line (loess regression) indicates the overall temporal trend. See Section 1.2 for biogeographical boundaries and Section 4.3 for interpretation of anomalies.

### *4.3.2 Phytoplankton*

Phytoplankton include photosynthetic bacteria and algae, with chlorophyll *a* being the main pigment used in photosynthesis. As a result, the chlorophyll *a* concentration in seawater is a proxy for the *in situ* phytoplankton biomass. Phytoplankton is usually found in the upper part of the water column where light is sufficiently available (i.e. the euphotic zone) to sustain photosynthesis.

In the NWA, phytoplankton proliferate under favorable conditions of temperature, light availability, and nutrient supply. The spring bloom is a period of intense production near the surface of the ocean during which the phytoplankton biomass and the abundance of large phytoplankton reach peak levels before declining due to nutrient limitation and grazing by zooplankton. The characteristics of the spring bloom (timing, duration, and magnitude) provide important information about regional variations in ecosystem production potential and are linked to the productivity of organisms that depend on lower trophic levels as they can influence the timing and intensity of the secondary production cycle by zooplankton.

The surface water chlorophyll *a* inventory, which represents the amount of chlorophyll *a* contained in the euphotic zone at depths of 0–100 m, is an indicator of total phytoplankton biomass. In addition to *in situ* sampling, near-surface concentration of chlorophyll *a* can be estimated from ocean colour observations measured from satellite remote sensing. These measurements allow the broad-scale tracking of the oceanic phytoplankton seasonal cycle, and the phenological characteristics of the spring phytoplankton bloom.

The surface water chlorophyll *a* inventory and characteristics of the spring bloom are presented here to assess the status of phytoplankton biomass/abundance. The magnitude of the spring bloom is an indicator of total phytoplankton production during the period of the year when phytoplankton abundance is highest. Figure 4.3-2 shows the anomalies of the chlorophyll *a* inventory and Figure 4.3-3 shows the anomalies of the initiation, duration, and magnitude of the spring phytoplankton bloom for the Atlantic zone.

- Across the Atlantic zone, the mean zonal chlorophyll *a* inventory showed an increase from second-lowest levels on record in 2016 to near- and above-normal conditions from 2017 to 2020.
    - In 2016, chlorophyll *a* inventories were below normal for all areas of the SS and NLS but spatially variable within the GSL.
    - Since 2017, chlorophyll *a* inventories have been mainly near or above normal both in the GSL and on the NLS, but have remained near or below normal on the SS.
- The initiation and duration of the spring phytoplankton bloom have remained fairly stable since 2017 following a period of high variability from 2003 to 2016. Initiation has been either near or later than normal and duration either near or longer than normal.
- The magnitude of the spring phytoplankton bloom was mainly lower than normal from 2012 to 2017, reached peak levels in 2018 and 2019, and decreased to near-normal levels in 2020.

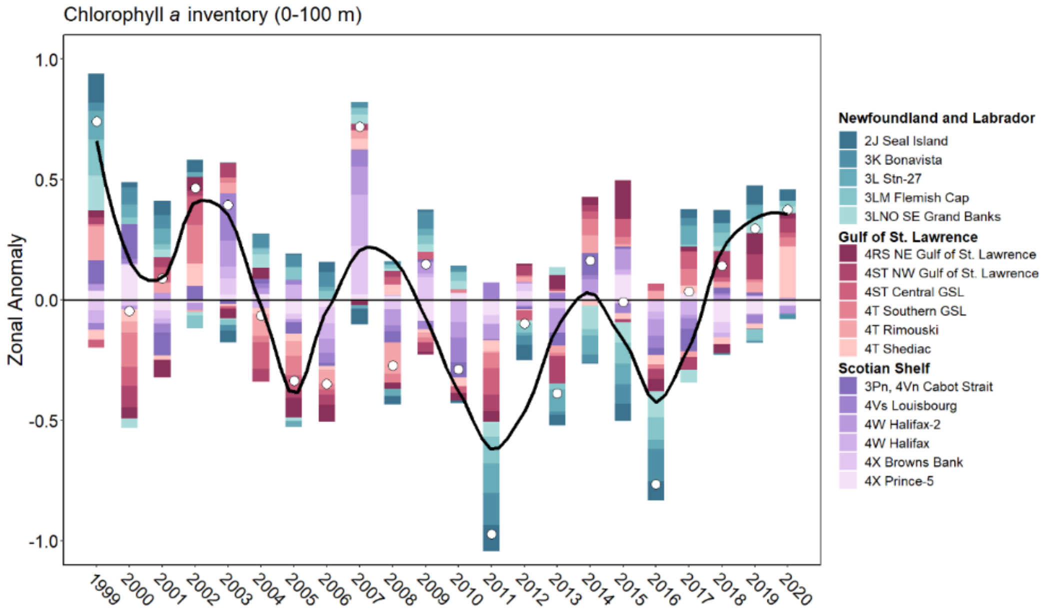

Figure 4.3-2. Standardized anomalies of the chlorophyll *a* inventory (representing phytoplankton biomass) in the upper water column (0–100 m or bottom if shallower) for different oceanographic sections and fixed stations from the AZMP over the period 1999–2020. Coloured bars indicate the relative contribution of each section/station to the mean zonal anomaly (open circles). The black line (loess regression) indicates the overall temporal trend. See Section 1.2 for biogeographical boundaries and Section 4.3 for interpretation of anomalies.

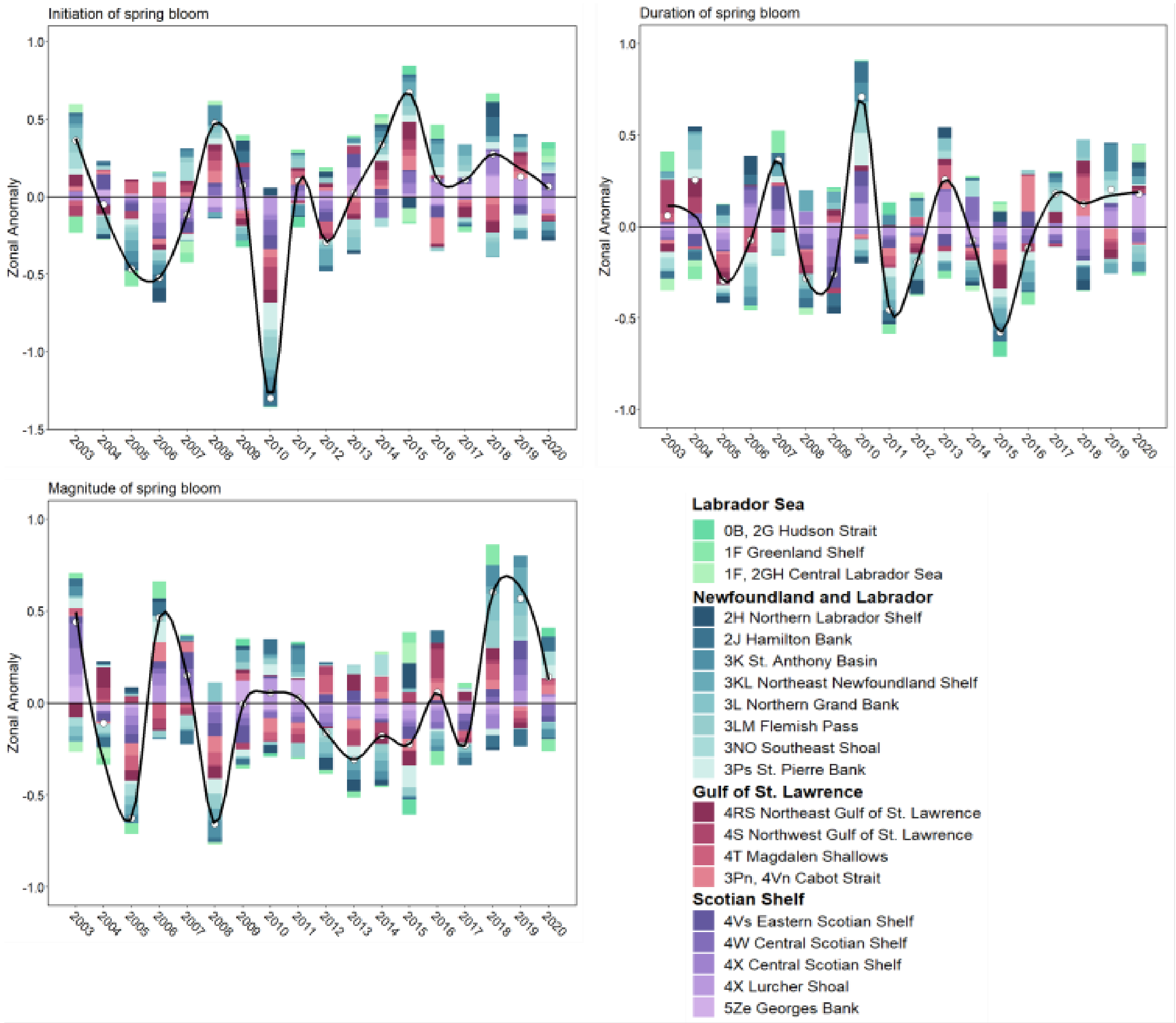

Figure 4.3-3. Standardized anomalies of the initiation (top left), duration (top right) and magnitude (bottom left) of the spring phytoplankton bloom (derived from remote sensing ocean colour observations) for different statistical subregions of the Canadian Atlantic from 2003 to 2020. Coloured bars indicate the relative contribution of each subregion to the mean zonal anomaly (open circles). The black line (loess regression) indicates the overall temporal trend. See Section 1.2 for biogeographical boundaries and Section 4.3 for interpretation of anomalies.

### *4.3.3 Zooplankton*

Zooplankton include a broad variety of small animals that drift in the water column with ocean currents. Zooplankton are collected by vertical net tows extending typically from near bottom to the surface of the water column. Net samples thus provide indices of the overall abundance, biomass, and the diversity of the zooplankton community. Monitoring methods of coastal zooplankton are discussed in Section 11.5.2 in *Scientific Innovations to Advance Ecosystem Understanding*. Copepods are the most abundant zooplankton organisms in the NWA. *Calanus finmarchicus* is a large, energy-rich and broadly distributed copepod species present across the NWA. Because of its large size and high energy content, *C. finmarchicus* significantly contributes to total zooplankton biomass and represents a key source of food for pelagic fish, invertebrates, whales, and some seabirds. Although less energy-rich, smaller but highly abundant copepods *Pseudocalanus* spp. are also an important source of food for larger zooplankton and early stages of some fish species. They are also representative of the small copepod taxa that numerically dominate zooplankton assemblages. Non-copepod zooplankton are less abundant than copepods and include krill, amphipods, chaetognaths (arrow worms), gelatinous species, and larval stages of benthic invertebrates.

The biomass and total abundance of zooplankton (partitioned into copepods and non-copepods) as well as the abundance of the key copepod taxa *C. finmarchicus* and *Pseudocalanus* spp. are used here to assess the overall status of the zooplankton community (Fig. 4.3-4). Zooplankton biomass and *C. finmarchicus* abundance follow similar patterns of temporal and spatial distribution since the large *C. finmarchicus* copepod contributes a significant fraction of the zooplankton biomass. There is strong evidence of important and coherent shifts in the zooplankton community since 1999. In particular, the period of 2010–2012 appears pivotal in distinguishing between shifts occurring in the abundance of *C. finmarchicus* (from higher to lower than normal) and that of non-copepods (from lower to higher than normal).

- Across the Atlantic zone, the abundance of *C. finmarchicus* has rebounded from the record-low levels of 2015 that followed a steady decline since the early 2000s. *C. finmarchicus* abundance increased to near-normal levels in 2019–2020; however, increases in abundance are not occurring at the same rate across the zone.
- *Pseudocalanus* spp. has shown a decreasing trend toward near-normal levels across the Atlantic zone from 2016 to 2020 following maximum levels reached in 2015.
    - In the GSL, abundance has been predominantly near or above normal since 2014, except for 2017 and 2020.
    - On the SS, abundance has been predominantly near or below normal since 2014.
    - On the NLS, abundance has been predominantly near or above normal since 2013.
- Abundance of non-copepods peaked in 2015 then gradually declined, but has remained mainly above average on the NLS and in the GSL until 2020.

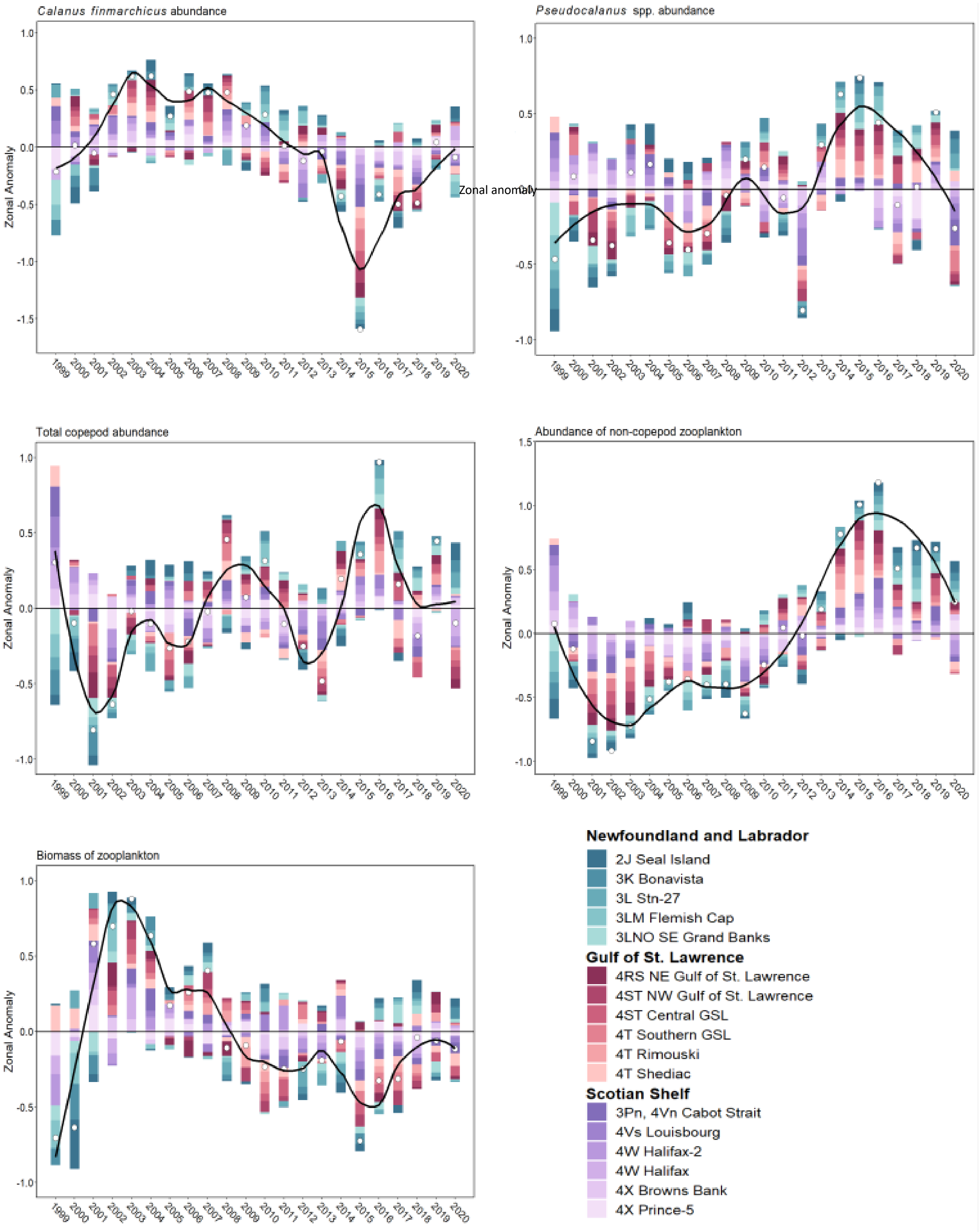

Figure 4.3-4. Standardized anomalies of the abundance of *Calanus finmarchicus* (top left), *Pseudocalanus* spp. (top right), total copepod abundance (middle left), total non-copepod abundance (middle right) and zooplankton biomass (bottom left) in the water column (from bottom or near bottom to surface) for different statistical subregions and fixed stations of the Canadian Atlantic from 1999 to 2020. Coloured bars indicate the relative contribution of each section/station to the mean zonal anomaly (open circles). The black line (loess regression) indicates the overall temporal trend. See Section 1.2 for biogeographical boundaries and Section 4.3 for interpretation of anomalies.

## 4.4 Drivers of Change

A shift toward warmer ocean conditions on the Atlantic shelves had occurred prior to the implementation of the AZMP in 1999. Since then, and particularly during the past decade, further increases in water temperatures were observed. Sea-surface temperatures reached record values across the Atlantic zone in summer 2012 and bottom temperatures in the GSL were mainly above normal in the GSL and on the SS since 2012 (see Section 2.3.1 *Ocean Temperature*). Warmer ocean conditions, which are driven by local heat exchange and changes in Atlantic basin–scale circulation (Chen et al. 2015; Gonçalves Neto et al. 2021) are associated with multi-year trends in phytoplankton and zooplankton community composition and declines in the abundance of *C. finmarchicus* (see Section 11.4.1 in *Predator–Prey Interactions*).

In general, important changes in the patterns of productivity from lower trophic levels appear to have taken place in recent years. The overall decline in nutrient and chlorophyll *a* inventories and in zooplankton biomass may be indicative of lower ecosystem production potential compared to the previous decade. Despite evidence that the shift in zooplankton community structure from large lipid-rich copepods to smaller taxa has moderated at the end of the 2010s, the higher-than-normal abundance of small copepods and non-copepods in recent years may be indicative of changes in the transfer efficiency from primary producers to higher trophic levels. Further changes in atmospheric forcing over the NWA shelf seas may have impacts on trophic level composition and production that affect prey availability to upper trophic levels including pelagic fish, invertebrates, whales, and seabirds.

## 4.5 Research Gaps and Uncertainties

There is considerable uncertainty in estimates of overall abundance of phytoplankton and zooplankton. This uncertainty is caused in part by the life cycle of the animals, their patchy distribution in space, and by the limited coverage of the region by the monitoring program.

Chemical (nutrients) oceanographic variables are effectively measured, because they exhibit fairly conservative properties that are unlikely to show precipitous changes either spatially or from year to year. In addition, measurements of these variables are made with a good degree of precision. The only exception occurs in surface waters, where rapid changes in the abundance of phytoplankton—particularly during the spring bloom—can cause rapid depletion of nutrients.

The greatest source of uncertainty comes in our estimates of phytoplankton abundance from *in situ* observations because of the difficulties in determining the inter-annual variations in the timing, magnitude, and duration of the spring phytoplankton bloom. Phytoplankton may undergo rapid changes in abundance on time scales of days to weeks. The spring phytoplankton and other important variables may not be sampled adequately because oceanographic sampling is limited in time and occasionally suffers from gaps in coverage because of vessel unavailability or weather. In particular, access to high-frequency sampling stations during the winter and early spring are often limited, causing major events in the seasonal cycle to be missed (e.g. the onset of the spring phytoplankton bloom). Reductions in vessel scheduling within regions have also reduced the number of full observations at some sites. Also, variations in the timing of the spring phytoplankton bloom across a region and in relation to spring oceanographic surveys may limit our ability to determine inter-annual variations in maximum phytoplankton abundance.

We are more able to describe inter-annual variations in the abundance of dominant zooplankton species because their seasonal cycle occurs at time scales of weeks to months as a result of their longer generation times relative to phytoplankton. However, zooplankton show greater variability in their spatial distribution. Although inter-annual variations in the abundance of dominant groups (e.g. copepods) can be adequately assessed, variations in the abundance of rare, patchily distributed or ephemeral species cannot currently be reliably estimated.

## 4.6 Technical Notes

The change of the reference period from 1999–2015 to 1999–2020 for calculating the climatology of the biogeochemical indices increases stability and generally reduces the amplitude of anomalies. For example, the zooplankton community shift observed since 2014, characterized by lower abundance of the large energy-rich copepod *C. finmarchicus* and higher abundance of small copepods and non-copepods, is currently fully integrated into the climatological period. The very large anomalies reported for recent years will appear diminished somewhat using the new climatology, and the closer-to-normal and variable anomalies reported for the period that preceded the community shift will now change to either above or below normal.

Indices of nitrate and chlorophyll *a* inventories and zooplankton abundance and biomass are derived from observations collected *in situ* as part of the AZMP over the period 1999–2020. Characteristics of the spring phytoplankton bloom (i.e. initiation, duration, and magnitude) are derived from daily composite observations of surface chlorophyll *a* obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) over the period 2003–2020. Details of the *in situ* sampling protocol, data analysis, and complete observations are summarized in reports produced annually in each region of the Atlantic zone (e.g. Blais et al. 2021 for the GSL; Casault et al. 2022 for the SS; and Maillet et al. 2019 for the NLS). Key nutrients and lower trophic levels indices are also summarized annually in a zonal science advisory report (DFO 2022).

For each index, the height of the vertical bars represents the contribution from each subregion/section/station to the mean zonal anomaly, which is denoted by open circles. The black line is a LOESS (locally estimated scatterplot smoothing) regression and represents the smoother, main trend across each time series.

## 4.7 References

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# 5. MARINE MACROPHYTES

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## 5.1 Key Messages

- Marine macrophytes in Atlantic Canada are highly diverse. Although over 300 species are present, their biomass is dominated by less than a dozen species. While notable fisheries were developed to harvest a select number of abundant species, there remain many unknowns on the status or trends of most macrophyte species throughout Atlantic Canada.
- Macrophytes are probably extensively distributed throughout the region, however, relatively few field observations are available. For example, data of Eelgrass on the Labrador coast are particularly lacking, while the most extensive data for kelps are available for the Atlantic coast of Nova Scotia.
- The majority (69%) of eelgrass beds with data on status and trends are stable or increasing in their extent and plant cover and 31% are in decline. However, these conclusions are based on relatively few data. The majority of known declining beds are in Atlantic Nova Scotia and the Gulf of St. Lawrence.
- Eelgrass loss in the Gulf of St. Lawrence has been linked to nutrient loading. Other important stressors throughout Atlantic Canada include coastal construction, invasive species, land runoff, and climate change impacts (e.g. warming, more storms).
- Kelp forests along the Atlantic coast of Nova Scotia have declined in abundance by 80–90% since the 1950s. Kelp in the Gulf of St. Lawrence have been stable in a low abundance state since the 1980s due to overgrazing by sea urchins. The historical trajectory of kelps in all other parts of Atlantic Canada are not well known.
- Kelp loss in Nova Scotia has been linked to warming temperatures, invasive species, and competitive interactions with other macroalgae. Sea urchin grazing is also a dominant driver of spatial and temporal variability of kelps in Newfoundland and the Gulf of St. Lawrence, although the current extent of the impacts are unknown.

## 5.2 Background

Marine vegetated habitats in Atlantic Canada include seaweed, salt marsh, and seagrass communities. Marine macrophytes in Atlantic Canada are a highly diverse group, representing over 300 species (Chopin and Ugarte 2006), although most of the biomass is represented by fewer than a dozen species (Bundy et al. 2014; Appendix 1).

Macrophytes exist in a wide range of habitats, from very sheltered brackish waters to the full salinity of wave-exposed coasts and from soft sediments to rocky substrates. The abundance (biomass) and spatial configuration of macrophytes is controlled by the amount of available space on the substrate with suitable physical conditions (e.g. temperature, salinity, wave exposure, hours of desiccation at low tide, available light, ice coverage). The strongest gradient in environmental conditions is water depth, resulting in a zonation of the shoreline from the highest tidal levels to subtidal depths of ~30 m (Novaczek and McLachlan 1989). Ice scour, particularly along northern shorelines of the Gulf of St. Lawrence and Newfoundland, can partially or completely remove macrophytes in the winter, resulting in patchy vegetation (Johnson et al. 2019).

Macrophytes provide important ecosystem services (e.g. storing carbon, cycling nutrients) and are important for herbivore-driven and detrital food webs (DFO 2009; Krumhansl and Scheibling 2012; Wong 2018). Macrophytes also create habitat for other algae (i.e. epiphytes), invertebrates, and fish, providing settlement sites, protection from predators, or a buffer against the environmental extremes common to the intertidal zone (Johnson and Scheibling 1987). Many of these invertebrate and fish species are directly commercially valuable or forage species for other commercially harvested stocks (Vandermeulen 2013; Wong et al. 2016). See Section 11.3.1 in *Habitat* for further discussion of the role of macrophytes as biogenic habitat.

## 5.3 Status and Trends

Status and trends of two ecologically important marine macrophyte species groups (seagrasses and kelps), for which increased research has occurred within the last decade, are presented Atlantic Canadian waters for the Gulf of St. Lawrence (GSL), the Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS). Status and trends are also summarized in Appendix 1.

In Atlantic Canada, there are no standardized annual surveys to monitor the abundance and distribution of marine macrophytes on a regional scale. Data representing Eelgrass (*Zostera marina*) and kelp status and trends come from various studies conducted for many purposes, ranging from fine-scale investigations of plant physiology to bioregional-scale mapping initiatives. Spatial data can be collected through many methods including direct observation via snorkelling, SCUBA, or drop camera as well as remote sensing (e.g. satellite, sonar). For Eelgrass communities, the spatial scale of observation strongly affects detection and the creation of maps; fundamental differences between different remote sensing data sources complicate comparability and assessment of trends. Each approach offers strengths and weaknesses depending on Eelgrass bed characteristics and environmental context, and the use of multiple methods can add value (Barrell et al. 2015). Remote sensing technologies are not as easily applied to subtidal kelp forests due to the deeper depth distribution (Cavanagh et al. 2021). Therefore, kelp monitoring mainly relies on direct observation methods.

Eelgrass data included in the distribution map (Fig. 5.3-1) were collected by various investigators using satellite imagery, LiDAR, benthic sonar, video, drone imagery, and field observations. These techniques continue to be used to locate and map Eelgrass beds in Atlantic Canada (e.g. Aarts et al. 2020; Forsey et al. 2020; Wilson et al. 2020). Note that the compilations often only included Eelgrass presence, so absences in Figure 5.3-1 indicate no observations, and not necessarily the absence of Eelgrass.

The locations of recently published studies (since 2016) evaluating status and trends of kelp and key interacting species in Atlantic Canada are shown in Figure 5.3-2. Investigators used a variety of data collection methods including drop-camera surveys, SCUBA-based field observations and experiments, settlement collectors, intertidal transect surveys, and satellite-based remote sensing methods.

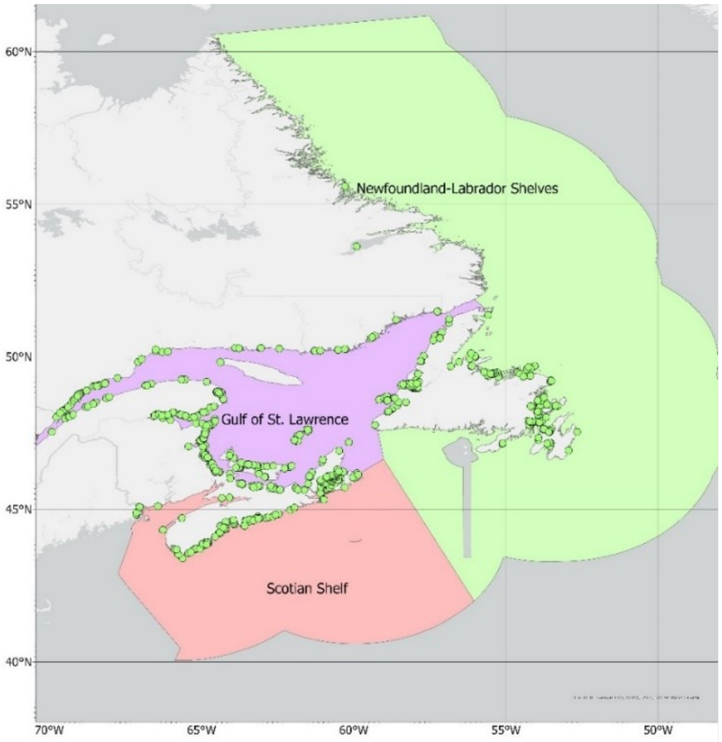

Figure 5.3-1. Distribution of Eelgrass across Atlantic Canada's three marine bioregions. Green circles represent locations of published studies or inventories where Eelgrass beds have been observed. Note that the studies often only included Eelgrass presence, so absences indicate no observations, not necessarily the absence of Eelgrass. Adapted from Murphy et al. (2021).

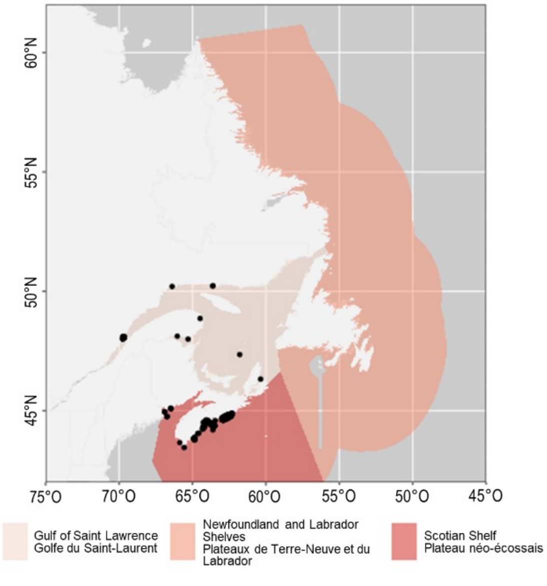

Figure 5.3-2. Distribution of new data collection efforts on kelp ecosystems in three bioregions of Atlantic Canada from peer-reviewed studies published from 2016 to 2022.

### 5.3.1 Marine Plants

Seagrasses are marine flowering plants that form structurally complex meadows (beds) in soft-sedimentary coastal areas. The most common species of seagrass in Atlantic Canadian waters is Eelgrass; aside from Eelgrass, the only other seagrass species occurring in the region is widgeon grass (*Ruppia maritima*), which typically grows in brackish rather than full saline areas.

Eelgrass is widely distributed throughout the coastal bays and estuaries of Atlantic Canada, primarily in shallow subtidal and occasionally intertidal areas (ECCC 2020; Murphy et al. 2021). Specifically, Eelgrass has been observed in the northern GSL (nGSL), southern GSL (sGSL), and on the SS, although less frequently in the Bay of Fundy likely because the extreme tidal range and high sediment loads limit its establishment. In Newfoundland, Eelgrass beds have been found on most coastlines, although few observations are available for the Labrador and southern coasts. Multi-year observations of Eelgrass presence were available for 36 beds in Atlantic Canada allowing analyses of temporal trends in shoot density, cover, biomass, or bed extent (Fig. 5.3-3, Murphy et al. 2021). However, there are relatively few long-term datasets (i.e. >3 years) included, so results should be interpreted with caution.

- Sixty-nine percent of Eelgrass beds in Atlantic Canada were stable or increasing and 31% of the beds showed a decrease in plants or bed extent.
    - In the GSL, more than half of the beds were decreasing.
    - In the SS, half of the beds were stable and half were decreasing.
    - In the NLS, most of the beds were either stable or increasing, except for Placentia Bay on the south coast, where declines have been observed (Matheson et al. 2016).

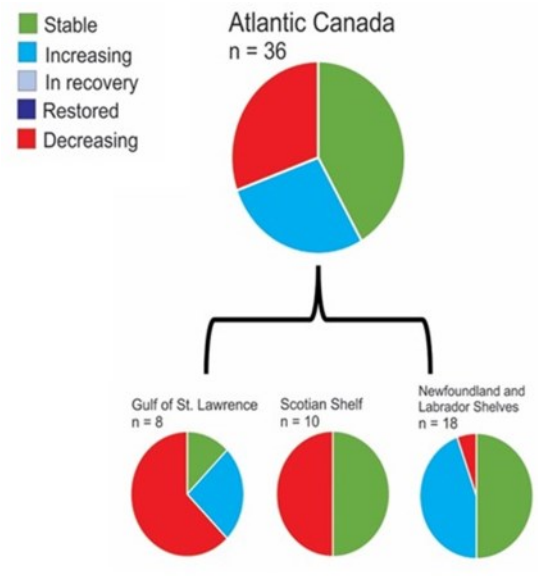

Figure 5.3-3. Temporal trends of Eelgrass beds (based on biomass, extent, cover, or shoot density data) in Atlantic Canada's three marine bioregions. Measured variables across the previous 2 to 10 years were either decreasing, stable (within the expected range of natural variation) or increasing. Adapted from Murphy et al. (2021).

### *5.3.2 Algae*

Brown, green, and red algae occupy various nearshore habitats throughout Atlantic Canada. Kelp, large brown seaweeds in the order Laminariales, create habitat by offering three-dimensional seascape structure and are the most dominant and studied group. Turf algae, a consortium of smaller, fast growing opportunistic species of green, brown, and red algae also occur in the understory of kelp beds and as turf-dominated communities (mats) where kelps are absent or low in abundance. Turf mats now dominate in many areas where kelp forests or sea urchin—dominated barren areas existed prior to 2014 (Filbee-Dexter et al. 2016). The invasive brown algae *Fucus serratus*, introduced to eastern Canada in the 19th century (Edelstein et al. 1973), has also now become a dominant macrophyte along vast stretches of the Atlantic coast of Nova Scotia, particularly along the southwestern coast (Garbary et al. 2021).

The high abundance of three macroalgal species, Irish moss (*Chondrus crispus*), rockweed (*Ascophyllum nodosum*), and dulse (*Palmaria palmata*) led to the development of notable fisheries, particularly in Nova Scotia, New Brunswick, and Prince Edward Island (Chopin and Ugarte 2006; DFO 2013).

A study of seaweed assemblages at 51 sites along the Atlantic coast from southern Labrador to Cape Elizabeth, Maine, revealed two distinct subregions (Subarctic and Boreal) based on species composition and marine climate (Adey and Hayek 2011). Subarctic seaweed assemblages extend from southern Labrador to the nGSL and are mainly composed of cold-adapted species, whereas Boreal subregion communities occur in Nova Scotia and are composed almost entirely of warm-water tolerant species (Adey and Hayek 2011). Because of these biogeographic differences, the status, trends, and drivers of change vary between the subregions.

There are five dominant kelp species in Atlantic Canada: *Saccharina latissima*, *Laminaria digitata*, *Hedophyllum nigripes, Alaria esculenta*, and *Agarum clathratum* (McDevit and Saunders 2010; Merzouk and Johnson 2011; Longtin and Saunders 2016). The distribution of kelps in this region is driven by spatial patterns in environmental conditions, including substrate availability, wave exposure, temperature, nutrients, and light (Wilson et al. 2019). Water temperature has direct physiological effects on kelps by scaling photosynthetic and metabolic rates, with high temperatures (>23°C) reducing growth and recruitment and increasing mortality (Simonson et al. 2015). Kelps occur mainly on semi- to wave-exposed shores, and the dominant kelp species varies depending on the level of wave exposure. *L. digitata* and *H. nigripes* are adapted for higher wave forces and tend to dominate on wave-exposed shores, whereas *S. latissima* dominates in areas with lower wave exposure (Longtin and Saunders 2016; Krumhansl and Scheibling 2011). Depth also drives spatial patterns in the distribution of kelps through effects on light and physical forces. *A. esculenta, L. digitata*, and *H. nigripes* are more common at shallow depths and *S. latissima* and *A. clathratum* dominate at deeper depths. Light availability sets the lower depth limit of all kelp species at around 30 m.

Historically, sea urchins were prevalent grazers in rocky subtidal ecosystems along the Atlantic coast of Nova Scotia, and caused widespread losses of kelp across hundreds of kilometres of coastline (Filbee-Dexter and Scheibling 2014). From the 1960s to the early 2000s, areas grazed by sea urchins (urchin barrens) alternated with a kelp-dominated ecosystem state, driven by recurrent disease outbreaks that caused mass mortalities of sea urchins. Beginning around 2010, sea urchin disease outbreaks increased in frequency and severity, resulting in the near complete loss of this grazer from shallow water along the Atlantic coast of Nova Scotia (Feehan and Scheibling 2014; Vandermeulen 2018). As a result, sea urchin barrens are no longer a feature in this part of the region. In contrast, sea urchin barrens remain a dominant feature in the GSL and Newfoundland, leading to low abundances of kelps and other fleshy seaweeds throughout areas where they occur (Johnson et al. 2019; Narvaez 2019).

### *Gulf of St. Lawrence and Newfoundland and Labrador Shelves*

- Kelp beds are patchily distributed with respect to sea urchin barrens, and barrens remain a dominant feature along the rocky coastlines of these areas (Blain and Gagnon 2014; Frey and Gagnon 2015, 2016; Johnson et al. 2019; Narvaez 2019). Grazing on *A. esculenta* and *L. digitata* occurs at the shallow, wave-exposed margin of urchin barrens, and *A. clathratum* occurs as deeper patches of grazing-resistant species in sea urchin barrens (Merzouk and Johnson 2011; St-Pierre and Gagnon 2020). There has been no recent comprehensive assessment of the extent of barrens and resulting effects of grazing on kelp abundances.
- In the St. Lawrence Estuary, the presence of kelp (mainly *A. esculenta* and *S. latissima*) was observed at Batture-aux-Alouettes (DFO 2021).
- Kelp abundances did not appear to change from 1978 to 2011 (Merzouk and Johnson 2011; Johnson et al. 2019; Narvaez 2019), although data used for this assessment were extremely sparse. There have been no recent studies documenting the current distribution and trajectory of kelp forest ecosystems in Newfoundland nor the GSL.

### *Scotian Shelf*

- Mean kelp biomass at three sites along the Atlantic coast of Nova Scotia declined by 85–99% over the past 4 to 6 decades (Filbee-Dexter et al. 2016).
- The current distribution of *S. latissima*, *L. digitata*, and *A. clathratum* is mainly wave-exposed rocky headlands and offshore ledges. Here, losses have occurred but are less extreme (Filbee-Dexter et al. 2016; Vandermeulen 2018).
- In the subtidal zone, mats of turf algae dominate (Filbee-Dexter et al. 2016) or the invasive *Fucus serratus* (Garbary et al. 2021), where *S. latissima*, *L. digitata*, and *A. clathratum* were historically the most abundant seaweeds (Mann 1972).

## 5.4 Drivers of Change

Stressors related to human activities (i.e. harvesting, deterioration to water quality, climate change) can significantly change macrophyte populations over short and long timescales (Ugarte et al. 2009; Sharp et al. 2006; Kay et al. 2016). Multiple species invasions over the last two centuries have also altered macrophyte community structure along various portions of the Atlantic coast of Canada: the Common Periwinkle *Littorina littorea*, the bryozoan *Membranipora membranacea*, the European Green Crab *Carcinus maenas*, the Oyster Thief *Codium fragile* ssp. *tomentosoides* (Chapman et al. 2002), the red algae *Dasysiphonia japonica* (Savoie and Saunders 2013) and *Bonnemaisona hamifera* (Bird 1980), and the brown alga *F. serratus* (Garbary et al. 2021).

Nutrient loading remains one of the leading human threats to Eelgrass beds in Atlantic Canada, specifically those located in the GSL. Excess nutrients can originate from multiple sources, including land runoff, atmospheric deposition, industrial pollution, and finfish aquaculture operations. Significant declines in Eelgrass coverage have been observed in estuaries with high nitrogen (nitrate) loading attributed to agricultural runoff (van den Heuvel et al. 2019; Coffin et al. 2021). Impacts on Eelgrass from finfish aquaculture operations in combination with other environmental factors requires further investigation—see Section 11.2.3 in *Multiple Stressors* for a more detailed discussion.

The effects of climate change on Eelgrass in Atlantic Canada are varied. Future temperature increases have been projected to expand Eelgrass habitat along the coast of Atlantic Canada due to northward range shifts (Wilson and Lotze 2019). However, localized extreme temperature events driven by climate change, such as heat waves that have been documented in some Atlantic Canadian bays and estuaries, have been linked to lower Eelgrass productivity and resilience (Krumhansl et al. 2021). Climate change will also expand the range of invasive species, some of which will grow on or near Eelgrass (Carman et al. 2019). For example, several Eelgrass beds in Atlantic Canada have been increasingly colonized in recent years by a variety of non-native tunicate species that threaten Eelgrass health by settling on leaves and potentially reducing growth (Carman et al. 2019). Other potential effects of climate change on macrophyte communities include changes in storm frequency and intensity, altered ice dynamics, and changes in ocean chemistry (e.g. acidification).

There have been recent efforts to quantify and compare the extent of human activities within and near Eelgrass beds in Atlantic Canada both individually (Murphy et al. 2019) and using a cumulative effects approach (Murphy et al. 2022). Murphy et al. (2022) developed a cumulative effects threshold to evaluate the risk of Eelgrass beds to multiple human activities using known thresholds for when Eelgrass is likely to decline at certain levels of an activity or stressor. When applied to 187 Eelgrass beds across the SS and southern GSL (sGSL), 26% exceeded the threshold estimate and were considered at higher risk of degradation from multiple human activities. The majority (88%) of these beds were in Prince Edward Island; however, the authors also identified several beds that exceeded the cumulative effects threshold located in New Brunswick and Nova Scotia.

Faunal communities in Atlantic Canadian Eelgrass beds are strongly influenced by physical conditions as well as their structure (Thistle et al. 2010). Secondary production and diversity of benthic invertebrates (infauna and epifauna ≥500 μm) are typically higher in Eelgrass beds than adjacent bare sediments, particularly at cool, deep and well-flushed sites (Wong 2018; Wong and Dowd 2021). These aspects play a key role for biodiversity–ecosystem functioning relationships in the nearshore (Wong and Dowd 2021). Fish taxonomic diversity followed a similar pattern, being influenced by Eelgrass canopy height, sediment organic carbon, wave exposure, and bed size (Wong and Kay 2019). Faunal assemblages also differ among subregions within Atlantic Canada. Fish and large invertebrate assemblages in sGSL Eelgrass were more similar than in SS Eelgrass, which was a function of water temperature (Namba et al. 2018). Macroinvertebrate diversity, abundance, and biomass in eelgrass were highest in the GSL, intermediate on the SS, and lowest in the NLS, reflecting nutrient availability and primary production (Cullain et al. 2018).

Globally, kelp ecosystems are threatened by a range of anthropogenic pressures such as ocean warming, eutrophication, overharvesting, and sedimentation (Strain et al. 2014; Filbee-Dexter and Wernberg 2018). However, local stressors and region-specific responses to global drivers play a large role in shaping regional trajectories in kelp abundance (Krumhansl et al. 2016). In Atlantic Canada, the most significant threats to kelp ecosystems are the interactive effects of increasing seawater temperature from climate change and invasive species (see Section 11.2.5 in *Multiple Stressors*).

The occurrence and abundance of kelp is also strongly determined by biotic interactions, including grazing by sea urchins (Frey and Gagnon 2016) and competitive interactions with aquatic invasive species (Scheibling and Gagnon 2009). These interactions are strongly mediated by environmental variables such as temperature and wave action (Lauzon-Guay and Scheibling 2007; Krumhansl et al. 2014) and vary in their resulting effects on kelp abundances throughout the region.

## 5.5 Research Gaps and Uncertainties

Eelgrass in Atlantic Canada naturally occurs in configurations ranging from highly fragmented to continuous meadows. Natural variability in Eelgrass distribution through time is not well understood, obscuring the detection of trends and assessment of causation. This is compounded by Eelgrass phenology, which can be similarly variable between sites. Additionally, Eelgrass morphology (e.g. above ground/below ground biomass ratio) and reproductive strategy (e.g. lateral/rhizomatic vs. sexual) can change in response to environmental conditions, contributing to uncertainty in data interpretation. In the absence of long-term monitoring with consistent methods, the scale of spatiotemporal and interannual variability and its effect on interpretation of trends is uncertain, representing a major knowledge gap.

Efforts to characterize Eelgrass status and trends in Atlantic Canada have been limited by the factors described above. Given the widespread distribution of Eelgrass throughout the region, it is apparent that only a small proportion of extant beds have been studied directly. The uncertainty surrounding Eelgrass dynamics is exacerbated by shifting environmental conditions related to climate change (e.g. temperature, storms) that are likely to affect the distribution and health of Eelgrass habitat. Effective conservation and management of Eelgrass habitat will require enhanced datasets at high spatial and temporal resolution to establish baseline conditions from which trends can be established.

This chapter provides some of the first insight into Eelgrass status in Atlantic Canada. However, there are relatively few long-term datasets included and so results should be interpreted with caution. Inclusion of new data from standardized long-term monitoring efforts would further refine temporal trend estimates and our understanding of Eelgrass status in Atlantic Canada.

Spatial biases in the distribution of research effort limit our ability to assess regional variation in the status and trends of kelp ecosystems and the drivers that shape these patterns. As has historically been the case, new data collection efforts on kelp ecosystems in Atlantic Canada from peer-reviewed studies between 2016 to present largely occurred along the SS with relatively few studies covering the GSL, SLE, and particularly the NLS (Fig. 5.3-3). Of the SS studies, these were largely restricted to the Atlantic Coast with minimal effort in the Bay of Fundy. As kelp distributions contract at their southern limits and expand at their northern range edges (Wilson et al. 2019), it will become increasingly important to invest greater research effort to evaluate how changing species interactions and environmental conditions will impact kelp ecosystems of the GSL and NLS.

The invasive bryozoan *Membranipora membranacea*, known to negatively impact kelps in Nova Scotia (Scheibling and Gagnon 2009; Saunders and Metaxas 2008), is widely distributed throughout the GSL (Denley et al. 2019) and west coast of Newfoundland (Caines and Gagnon 2012). However, the impacts of this species on kelp distributions and abundances in this part of the region are unknown.

Eelgrass beds are generally considered important blue carbon habitats (i.e. they capture and store carbon), but kelp beds have only recently been recognized as a potentially significant source of blue carbon (Filbee-Dexter and Wernberg 2020). However, sufficient data for both Eelgrass and kelp contributions to blue carbon to inform regional carbon budgets and offset strategies are lacking. While Eelgrass likely stores most captured carbon in the sediments, the vast majority of the prolific primary production generated by kelp forests in Atlantic Canada is exported through detrital pathways and provides a substantial resource subsidy to recipient communities (Krumhansl and Scheibling 2011, 2012). Carbon is sequestered when this macroalgal material is transported offshore (Filbee-Dexter et al. 2018; Kokubu et al. 2019) and buried in deep sediments (Ortega et al. 2019). Improved quantification of key carbon fluxes and identification of regionally important carbon sinks are required to fully evaluate the potential contribution of both Eelgrass and kelp to carbon storage and sequestration and how this ecosystem service may be affected by changing climatic conditions.

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# 6. LARGE MARINE INVERTEBRATES

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## 6.1 Key Messages

- Commercial fishing pressure, warming waters and ocean acidification are important drivers of change for some species of large marine invertebrates in Atlantic Canadian waters, impacting physiology, recruitment dynamics, population distributions and predator–prey interactions.
    - From 2017 to 2020, American Lobster abundance was at or near historic highs in all bioregions, attributed to warming of coastal waters.
    - From 2017 to 2020, Snow Crab landings were lower than average for the northern Gulf of St. Lawrence, Scotian Shelf, and Newfoundland and Labrador Shelves and higher than average in the southern Gulf of St. Lawrence. Shrinking of bottom areas favourable to this cold-adapted species may be responsible for the decline in landings in some areas.
    - Northern Shrimp abundance has declined since 2016 in the northern Gulf of St. Lawrence, the Scotian Shelf, and the Newfoundland and Labrador Shelves. Unfavourable environmental conditions are thought to be responsible for the decreased abundance—warming and increased predation in the northern Gulf of St. Lawrence and decreased larvae food supply along the Newfoundland and Labrador Shelves.
    - From 2017 to 2020, scallop landings were near average on the Scotian Shelf and well below average in the northern and southern Gulf of St. Lawrence.
- Smaller scale fisheries for other crustacean, mollusc, and echinoderm species (i.e. crabs, sea urchin, sea cucumber, whelks, cockles, clams) occur in specific inshore and offshore areas throughout the bioregions. Landings are highly variable from year to year for most species, although some were declining or at low levels in 2017–2020. Causes of these declines or inter-annual variations are poorly understood, as many are data poor, with limited or no fishery-independent data nor environmental data.

## 6.2 Background

Large marine invertebrates are an extremely abundant and diverse group of marine animals, including but not limited to sponges, corals, crustaceans, molluscs, echinoderms, and worms, occupying all habitats, trophic levels, and ecological niches within the ocean. Some invertebrates can be important ecosystem engineers as discussed in the previous State of the Atlantic Ocean Synthesis Report for corals, sponges, and intertidal flats (Clements et al. 2018). Marine invertebrates play essential roles in ecosystem functioning, greatly contributing to the ecological and economic services upon which human societies depend. Despite this importance, they are often underrepresented and understudied compared to more charismatic marine species.

The ecological role of sponges and their identification in the Gulf of St. Lawrence are discussed in Section 11.5.3 in *Scientific Innovations to Advance Ecosystem Understanding*.

Since the collapse of demersal fish stocks in the late 1980s and early 1990s, crustacean fisheries have been the most valuable of all fisheries in Atlantic Canadian waters, with American Lobster (*Homarus americanus*) and Snow Crab (*Chionoecetes opilio*) contending for first place depending on year and bioregion (DFO 1990, 1995, 2000, 2005, 2010, 2015, 2020b). The scallop fishery is the fourth most important fishery in Atlantic Canadian waters in terms of value. Changes in abundance of these species have major economic impacts in Atlantic Canadian waters.

Impacts of climate change and other stressors on crustacean populations are discussed in more detail in Section 11.1 *Climate Change* for American Lobster (Section 11.1.1) and Snow Crab (Section 11.1.2) and in Section 11.2 *Multiple Stressors* for Northern Shrimp (Section 11.2.1).

## 6.3 Status and Trends

Status and trends of commercially fished marine invertebrates are presented for the more prominent crustaceans, molluscs, and echinoderms that are harvested in Atlantic Canadian waters, compared across bioregions: southern and northern Gulf of St. Lawrence (sGSL and nGSL), Scotian Shelf (SS), and the Newfoundland and Labrador Shelves (NLS). Status and trends are also summarized in Appendix 1. Large marine invertebrates are assessed differently in different regions and often there is no fishery-independent survey encompassing the entire distribution for a species. Commercial landings are the most practical way to display changes in abundance for most of the macroinvertebrates of Atlantic Canadian waters, but research vessel surveys are also used when possible. To facilitate comparisons between bioregions and/or species, each time series of landings or survey indices was transformed into a series of standardized anomalies (see Section 6.6 *Technical Notes*).

Only a few invertebrate populations and species from Atlantic Canadian waters have a Precautionary Approach (PA) framework in place (see Section 1.3 *Legislation and Management*): Northern Shrimp (*Pandalus borealis*) in the nGSL (Savard 2012), SS, and NLS, American Lobster in the sGSL (DFO 2014a) and SS, Snow Crab in the sGSL (DFO 2014b), and Sea Scallop (*Placopecten magellanicus*) in the SS. A PA framework is in progress for Snow Crab along the NLS, and a reference points-based PA has been implemented for Snow Crab on the SS (DFO 2012).

### *6.3.1 Crustaceans*

Crustacean fisheries primarily target American Lobster (Fig. 6.3-1), Northern Shrimp (Fig. 6.3-2), and Snow Crab (Fig. 6.3-3). Other crab species are fished in Atlantic Canadian waters: Rock Crab (*Cancer irroratus*), Jonah Crab (*Cancer borealis*), Toad Crab (*Hyas* spp.), and Red Crab (*Chaceon quinquedens*) (Fig. 6.3-4). These are small but locally important fisheries with landings below 1–2 thousands of tonnes for any species in any bioregion, compared to landings of 5–13 thousands of tonnes for Snow Crab in the nGSL and SS, and 10–70 thousands of tonnes in the sGSL and the NLS. Even though recent landings data are available to observe status and trends, many of these fisheries have never been formally assessed or not been assessed in recent years (e.g. Toad Crab in the GSL, DFO 1996). Striped Shrimp (*Pandalus montagui*) have a small bycatch fishery in shrimp fishery area (SFA) 4 on the NLS, but there is no PA framework in place. The fishing exploitation has been low since a bycatch quota was implemented in 2013.

- American Lobster is in the Healthy Zone in the sGSL (DFO 2014a) and the SS (DFO 2021f–k), where PA frameworks are in place.
- For American Lobster, total landings across all bioregions were at record highs from 2017 to 2020.
    - Mean yearly landings in thousands of tonnes were 3.6 (nGSL), 19.9 (sGSL), 30.4 (SS), and 2.4 (NLS).
    - In the GSL, landings reached record high values during the 2017–2020 reporting period, continuing a steady increase that began in 2008–2010 after a period of stability since 1990 (DFO 2019a–c, e). The survey index anomaly for American Lobster doubled in the sGSL between 2016 and 2020 and, like landings, were at record values from 2017 to 2020 (DFO 2019e).
    - In the SS, landings remained near record high values from 2017 to 2020, although values dropped in 2020 (DFO 2021f–k).
    - In the NLS, landings increased progressively from 2017 to 2019, reaching the highest level in a century in 2019, despite stable and low landings in the Avalon and the Northeast fishing areas (DFO 2021l).
- For Northern Shrimp, three fishing areas in the nGSL were in the Healthy Zone and one was in the Cautious Zone but improving (DFO 2021d). In 2020, the eastern SS stock (SFA 13–15) was in the Healthy Zone (DFO 2021p) and in 2021 it was in the Cautious Zone (DFO 2022a). The three NLS stocks were in Critical, Healthy, and Cautious zones in SFAs from south to north respectively (DFO 2021e).
- From 2017 to 2020, Northern Shrimp landings were at or well below average across all bioregions. Survey indices followed the same trends as for landings, where available, reaching values at or below historic lows in the nGSL and the NLS (Fig. 6.3-2).
    - Mean yearly landings in thousands of tonnes were 26.7 (nGSL), 3.4 (SS), and 71.3 (NLS).
- Snow Crab is in the Healthy Zone in the sGSL (DFO 2014b, 2021m) and above their limit reference point in the NLS (DFO 2021n, 2022b).
- For Snow Crab, total landings across all bioregions have been declining since 2016. Survey indices were high but variable in the sGSL during the reporting period, whereas they were low but increasing in the NLS.
    - Mean yearly landings in thousands of tonnes were 7.4 (nGSL), 20.4 (sGSL), 10.3 (SS), and 44.7 (NLS).
    - Landings were high in the sGSL in 2017 and 2018; landings were also high in the nGSL in 2017 but declined to a very low value by 2020 (DFO 2021a).
    - In the SS and NLS, landings declined to very low values in 2017 and 2018 and increased in 2019 and 2020 but were still well below average (DFO 2021o, n; DFO 2022b).
- Most other crab species had low and/or declining landings from 2017 to 2020.
    - Mean yearly landings in thousands of tonnes were 0.73 (Jonah Crab–SS), 0.053 (Red Crab–SS), 1.37 (Rock Crab–nGSL), 4.00 (Rock Crab–sGSL), 0.35 (Rock Crab–SS), 0.37 (Toad Crab–sGSL), and 0.15 (Toad Crab–nGSL).
    - Rock Crab in the sGSL (DFO 2019f) and nGSL (DFO 2018a) as well as Toad Crab in the sGSL all had low and/or declining landings; Toad Crab in the nGSL (Lambert et al. 2020) had high landings from 2017 to 2019 but showed a strong

decline in 2020. Survey indices for Rock Crab and Toad Crab in the sGSL were variable from 2017 to 2020, declining to low values in 2020.

- Jonah Crab and Rock Crab in the SS had low or declining landings; Red Crab had high landings from 2017 to 2020, but declined sharply in 2020.

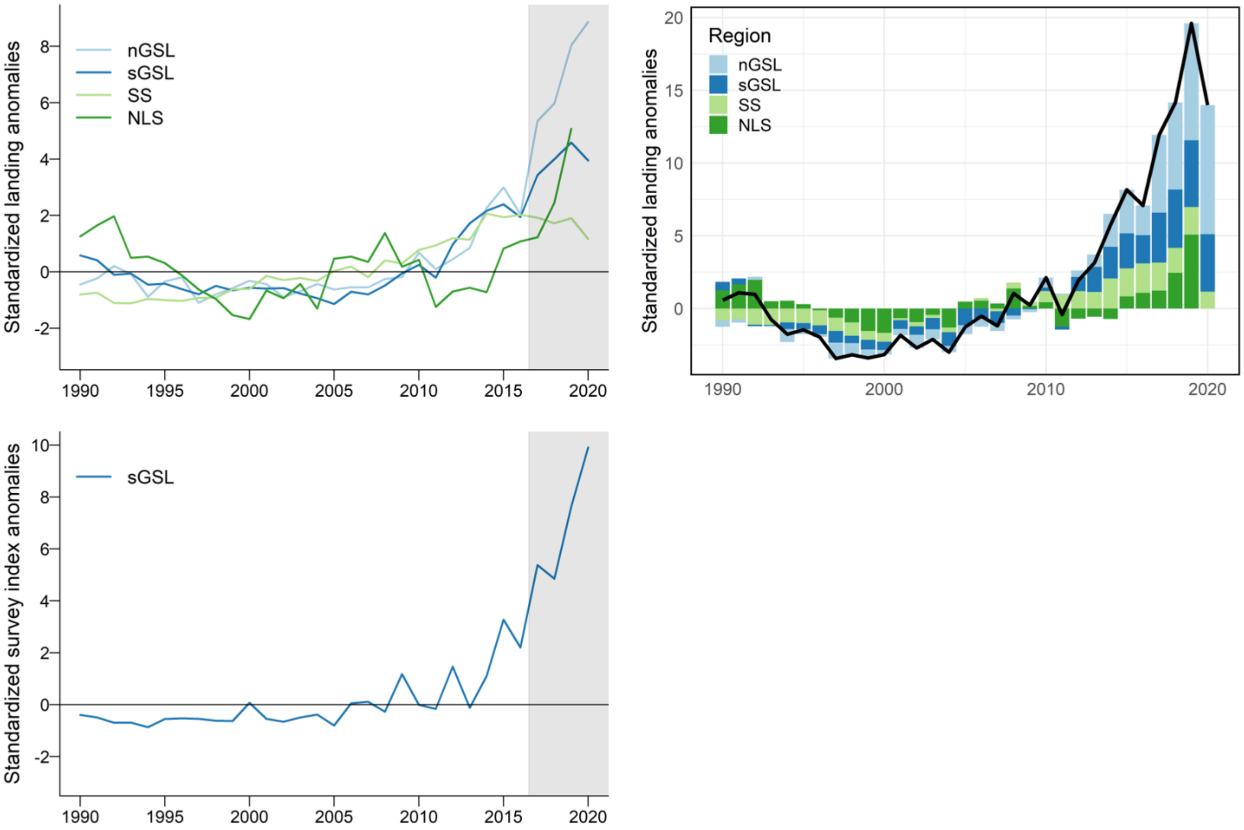

Figure 6.3-1. Landing anomalies (top panels) and survey index anomalies (bottom left panel) of American Lobster in Atlantic Canadian waters. Left: regions are on separate lines; right: regional anomalies are stacked on top of each other if there are results from more than one region; the thick black line represents the sum of all anomalies for a given year. The decreasing sum of anomalies in 2020 is in part caused by the fact that 2020 landings for NLS were not available when this report was written. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

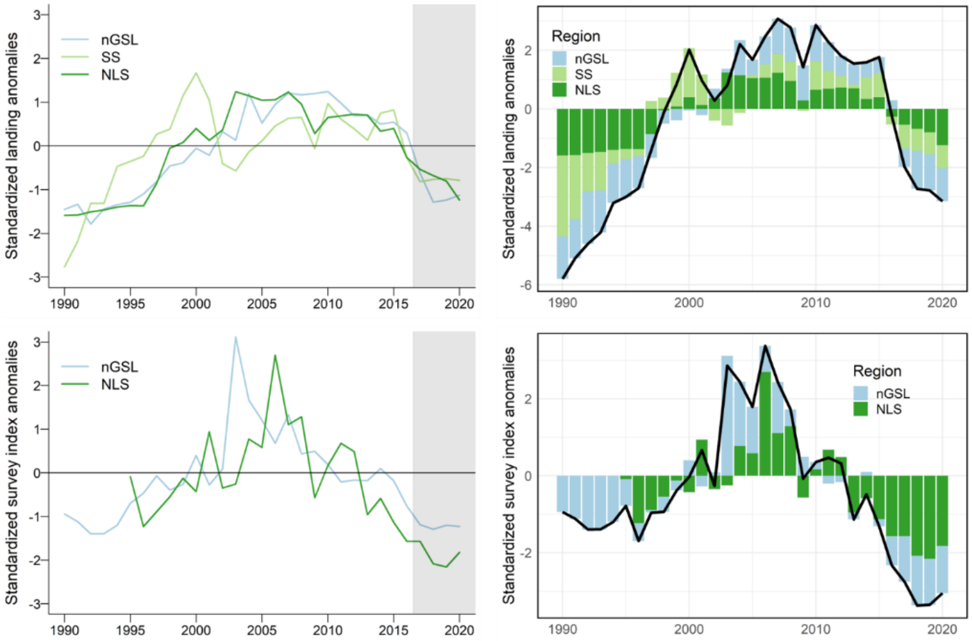

Figure 6.3-2. Landing anomalies (upper panels) and survey index anomalies (bottom panels) of Northern Shrimp in Atlantic Canadian waters. Left: regions are on separate lines; right: regional anomalies are stacked on top of each other if there are results from more than one region. Landings have been calculated by fiscal year (April 1–March 31) instead of calendar year starting in 2003 for the NLS, so 2003 to 2020 should be interpreted as 2003–2004 to 2020–2021. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

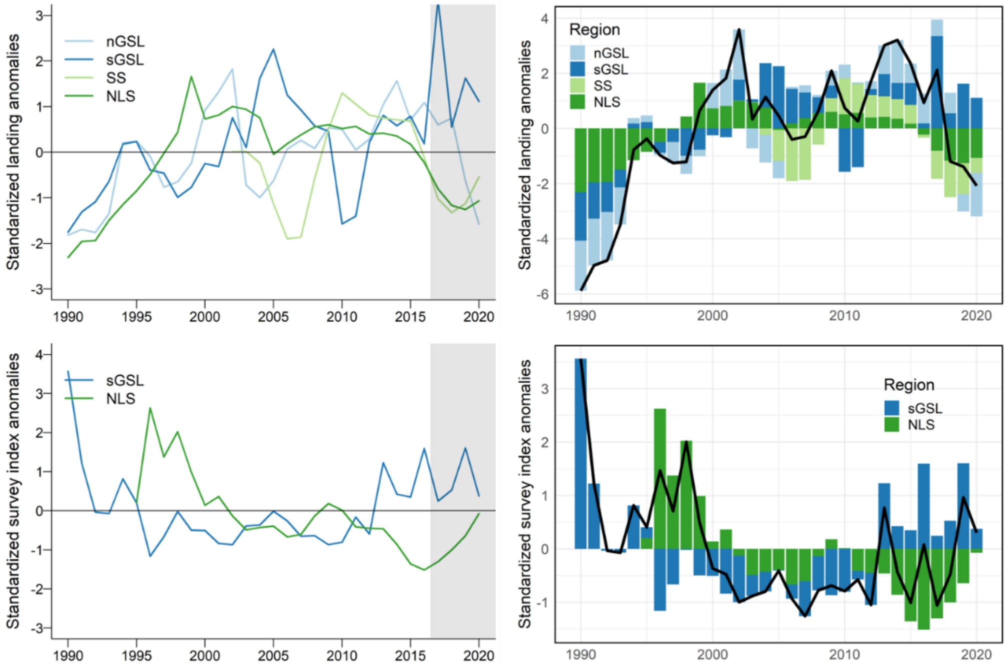

Figure 6.3-3. Landing anomalies (upper panels) and survey index anomalies (bottom panels) of Snow Crab in Atlantic Canadian waters. Left: regions are on separate lines; right: regional anomalies are stacked on top of each other if there are results from more than one region. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

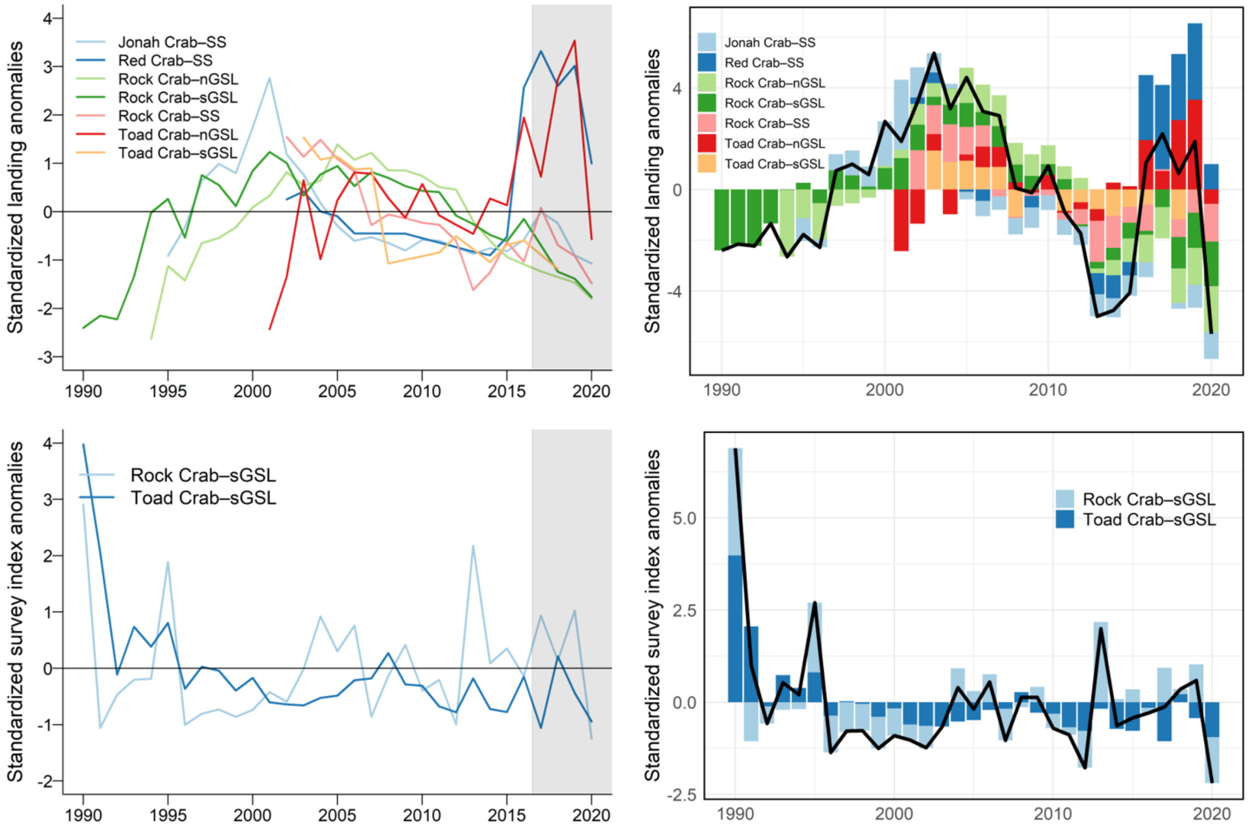

Figure 6.3-4. Landing anomalies (upper panels) and survey index anomalies (bottom panels) of other crab species in Atlantic Canadian waters. Left: species per region are on separate lines; right: bioregional anomalies are stacked on top of each other. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

### *6.3.2 Molluscs*

Sea Scallop is the primary mollusc species targeted by Atlantic Canadian fisheries and is harvested in all bioregions (Fig. 6.3-5); a second species, Icelandic Scallop (*Chlamys islandica*), is only fished in the nGSL. In the SS, there are inshore and offshore scallop fisheries with PA framework in place. Only meat (muscle mostly) is landed and converted to live mass using a factor of 8.3 (the conversion factor is variable for the SS offshore fishery).

Other mollusc species are harvested in the nGSL and SS, supporting smaller-scale fisheries within these bioregions. Arctic Surfclam (*Mactromeris polynyma*) fisheries were initiated in the SS in the 1980s (offshore) and in the nGSL in 1993 (Fig. 6.3-6). Several other clam species are retained in the SS offshore fishery, including Greenland Cockle (*Serripes groenlandicus*), Northern Propeller Clam (*Cyrtodaria silique*), and Ocean Quahog (*Arctica islandica*), which are included in Arctic Surfclam landings. A fishery for Atlantic Surfclam (*Spisula solidissima*) was initiated in 2002 in the Magdalen Islands, both recreationally and commercially, although landings are reported for the commercial fishery only. A small fishery for the Atlantic Jackknife (or Razor) Clam (*Ensis leei*) was initiated in the early 1990s on the north shore of the St. Lawrence Estuary (SLE) and a few years later in the Magdalen Islands, where most of this fishery takes place (DFO 2013). The fishery for the Common Softshell Clam (*Mya arenaria*) has a long history, being harvested both recreationally and commercially in the nGSL, although recreational landings are undocumented. There is also a whelk fishery that targets mainly

*Buccinum undatum*. Status and trends for Atlantic Jackknife Clam, Atlantic Surfclam, Common Softshell Clam, and Whelk are presented together in Figure 6.3-7. Although no longer a commercial species in the GSL, Northern Shortfin Squid (*Illex illecebrosus*), a known predator of shrimp, are caught in research surveys in the nGSL (Fig. 6.3-8).

- Scallop on the SS were in the Healthy Zone for all assessed areas with reference points in the most recent assessments (DFO 2020c–e; 2021q).
- From 2017 to 2020, scallop landings were variable among bioregions. Mean yearly landings in thousands of tonnes were 1.6 (nGSL), 1.4 (sGSL), 13.3 (SS inshore), and 50.3 (SS offshore).
    - Landings for the sGSL and nGSL were stable but at the lowest values relative to the mean (DFO 2021b; Niles et al. 2021) and have been clearly below average since 2005.
    - Landings for inshore and offshore scallop on the SS were relatively stable at levels that are typical for these stocks since the implementation of the PA framework.
- For Arctic Surfclam, the sums of the landing anomalies for the nGSL and SS have been positive since 2009 but more variable from 2017 to 2020.
    - Mean yearly landings in thousands of tonnes were 0.6 (nGSL) and 21.3 (SS offshore).
    - In the nGSL, landings were stable from 2017 to 2020 (DFO 2021b) after declining by about 25% between 2013 and 2016.
    - In the SS, landings have been variable but above average from 2017 to 2020 after increasing steadily since the early 2000s.
- From 2017 to 2020, the sums of standardized landing anomalies for Common Softshell Clam, Atlantic Jackknife Clam, and Whelk in the nGSL showed large negative anomalies, but not Atlantic Surfclam.
- Mean yearly landings for nGSL in thousands of tonnes were 0.46 (Common Softshell Clam), 0.22 (Atlantic Surfclam), 0.02 (Atlantic Jackknife Clam), and 1.20 (Whelk).
    - Landings of Common Softshell Clam remained at very low values from 2017 to 2020 after declining between 2000 and 2010.
    - Landings of Atlantic Surfclam increased until 2009 and remained well above the average value until 2019 but dropped to a value close to the average in 2020 (DFO 2019d).
    - Landings of Atlantic Jackknife Clam were quite variable over the time series, increasing in 2017 from a low value in 2015 then declining from 2018 to 2020.
    - Whelk landings declined year after year from 2017 to 2020 with below average values from 2018 to 2020 (DFO 2018b). This followed an above average period in 2016.
- The survey index for Northern Shortfin Squid in the nGSL has increased since 2017.

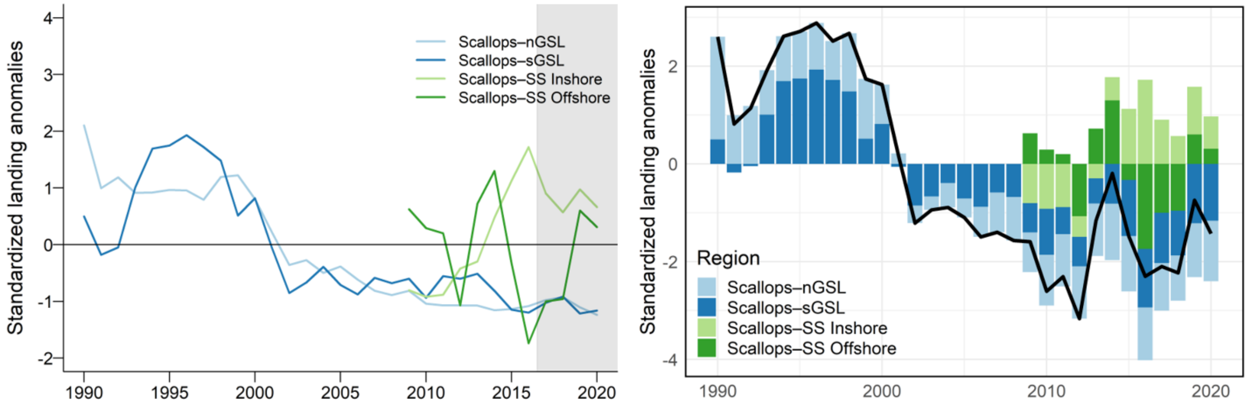

Figure 6.3-5. Landing anomalies for scallops in Atlantic Canadian waters. Left: regions are on separate lines; right: bioregional anomalies are stacked on top of each other. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

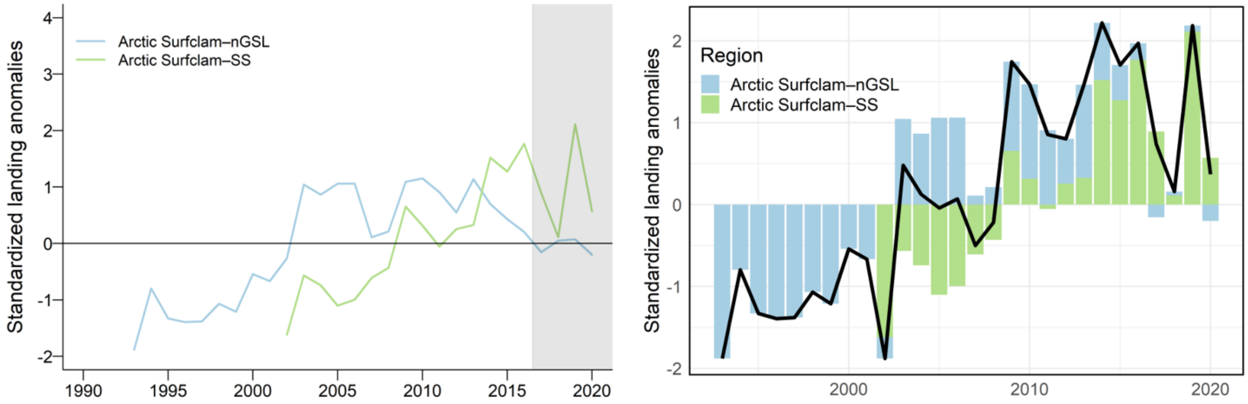

Figure 6.3-6. Landing anomalies for Arctic Surfclam in the northern Gulf of St. Lawrence (nGSL) and on the Scotian Shelf (SS). Left: regions are on separate lines; right: regional anomalies are stacked on top of each other. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

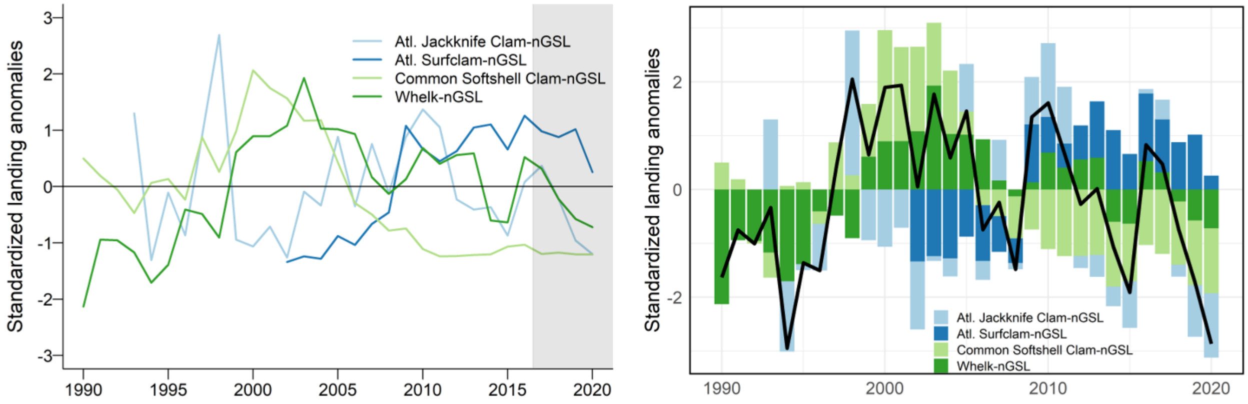

Figure 6.3-7. Landing anomalies for other mollusc fisheries of the northern Gulf of St. Lawrence (nGSL). Left: species are on separate lines; right: species anomalies are stacked on top of each other. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

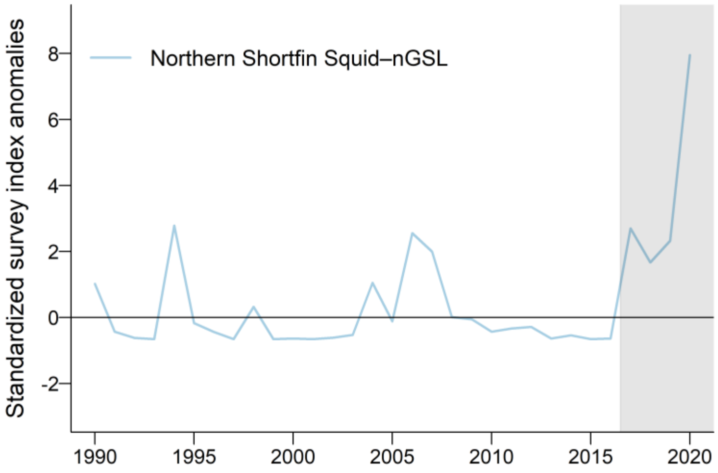

Figure 6.3-8. Survey index anomalies of Northern Shortfin Squid in the northern Gulf of St. Lawrence (nGSL). See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

### *6.3.3 Echinoderms*

Echinoderm fisheries are relatively recent in the nGSL and sGSL and a complementary fishing activity for most fishers. Landings reflect, in part, this variable effort on the part of the fishers. In the nGSL, the Green Sea Urchin (*Strongylocentrotus droebachiensis*) fishery started first, in 1991 (DFO 2016a) and an Orange-footed Sea Cucumber (*Cucumaria frondosa*) fishery was initiated in 2008 (Fig. 6.3-9).

- Green Sea Urchin landings in the nGSL declined overall from 2017 to 2020 but were still above average in 2020.
- Green Sea Urchin survey index anomalies for the sGSL increased from a low in 2016 to an above average value in 2017 and then declined until 2020—the largest negative anomaly in the time series. There was an overall decline from 1990 to 2020.
- Orange-footed Sea Cucumber landings in the nGSL have remained close to the mean since 2015 after increasing rapidly from 2008 to 2014 (DFO 2021c).

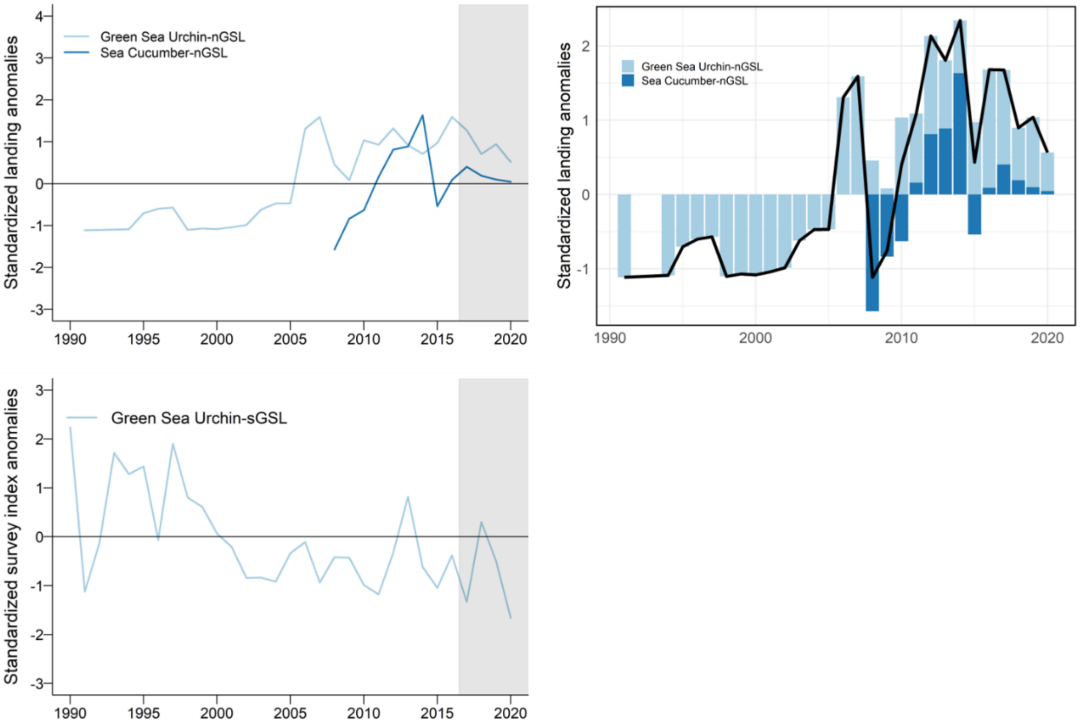

Figure 6.3-9. Landing anomalies (upper panels) and survey index anomalies (bottom panel) of echinoderms in the Gulf of St. Lawrence. Left: regions are on separate lines; right: regional anomalies are stacked on top of each other if there are results from more than one species or region. See Section 1.2 for biogeographical boundaries and Section 6.6 *Technical Notes* for interpretation of anomalies.

## 6.4 Drivers of Change

In the long term, climate change will likely involve warming and acidification of surface layers throughout Atlantic Canadian waters (Loder et al. 2013). These changes will in turn influence plankton species composition and the timing of plankton blooms, which has the potential to have great impact, positive or negative, on larval survival and growth and therefore recruitment of most invertebrate species mentioned in this report, including juvenile and adult stages of coastal species. Populations that are at the southern portion of their distribution in Atlantic Canadian waters, such as Northern Shrimp and Snow Crab, are particularly at risk.

Northern Shrimp are a cold stenothermic species affected by warming, hypoxia, predation by redfish, and changes to zooplankton (see Section 11.2.1 in *Multiple Stressors*). Distribution changes have already been observed for shrimp in the nGSL. In the eastern SS, the stock shows signs of instability that are mainly caused by water temperatures (DFO 2021p).

Sea-surface temperature and the thickness and temperature of the cold intermediate layer are changing (Galbraith et al. 2021) and are expected to continue to do so (Loder et al. 2013). These changes have negatively impacted Snow Crab habitat in the nGSL (DFO 2021a) and are expected to become harmful to Snow Crab of the sGSL (Chassé et al. 2006; DFO 2021m). The cyclical nature of the Snow Crab fishery, with periods of good recruitment to the fishery interspersed with periods of poor recruitment, makes it difficult to establish links between temperature and abundance or biomass. However, the narrow temperature range that Snow Crab can tolerate suggests this fishery will be negatively impacted by the long-term warming trend expected with climate change (Chabot et al. 2013; DFO 2022b; see Section 11.1.2 in

*Climate Change*). In contrast, warming has positively impacted American Lobster in the nGSL (see Section 11.1.1 in *Climate Change*) and sGSL (DFO 2019a–c; Chassé et al. 2014; Rondeau et al. 2015), although acidification is expected to have negative impacts on the species (Tai et al. 2021).

It is more difficult to attribute changes in abundances of other crustaceans, molluscs, and echinoderms to climate, possibly because many of these are coastal species that are subjected to naturally large variations in environmental conditions, but also because of gaps in knowledge (see Section 6.5 *Research Gaps and Uncertainties*). Commercial landings of Common Softshell Clam declined between 2000 and 2010 and remained at very low values up to 2020. This decline was due to low yields after the peak of 2000 and lack of interest by harvesters compounded by the closure of processing plants (DFO 2020a). The reduction of winter ice coverage observed in the nGSL in the last few decades (Galbraith et al. 2021) resulted in increased sediment agitation on mud flats used by this species, which could reduce recruitment. Shoreline erosion could also reshape their habitat in some bioregions (DFO 2020a). Sea Scallops typically have temperature tolerances between 0 and 18°C, with optimal temperatures between 10 and 15°C, stressful temperatures above 18°C and lethal temperatures at 21°C (Young-Lai and Aiken 1986; Stewart and Arnold 1994; Frenette 2004). No link with environmental conditions has been made so far to explain changes in landings, which likely reflect changes in resource availability (DFO 2021b). Declines in Rock Crab landings were caused by a combination of diminishing effort, population depletion (as suggested by diminishing catch rates in some areas), and increased predation by expanding American Lobster populations after 2008. In the nGSL, other factors include a reduction of Rock Crab quotas both as a response to declining populations and to ensure that American Lobster have sufficient access to this prey (DFO 2018a) as Rock Crab has been shown to be essential for growth and gonad maturation of American Lobster (Gendron et al. 2001).

Commercial fishing usually consists of one of the primary stressors on fishery stocks, including the risk of overfishing. Not only can overfishing have a direct impact by removing unsustainable amounts of biomass from the ecosystem, it can also have impacts on the population structure of species being overfished. For example, in certain male-only targeted fisheries such as with Snow Crab, the risk of overfishing can contribute to a sex-asymmetric reduction in body size by consistently removing larger males from the population (Mullowney and Baker 2021).

## 6.5 Research Gaps and Uncertainties

Little evidence exists on the indirect effects of climate change on invertebrate species, such as changes in the type and abundance of predator species or changes in the abundance, species composition, and nutritional value of prey species. For example, some shrimp predators have been found at much higher abundance in the nGSL since 2011 (i.e. Silver Hake *Merluccius bilinearis*) and 2017 (Northern Shortfin Squid) (Bourdages et al. 2021) and these may have increased predation pressure on shrimp in recent years. Silver Hake is a known predator of shrimp in the Gulf of Maine and southwest SS (Garrison and Link 2000) and Longfin Squid (*Doryteuthis pealeii*) was recently suggested as the cause of decline of Gulf of Maine shrimp (Richards and Hunter 2021).

Coastal species in the nGSL are often data poor, with limited or no fishery-independent data. The availability of environmental data is also lacking. For example, inshore temperature must often be inferred from sea-surface temperature offshore. The gaps are even worse for non-commercial species. As a result, we lack baseline biodiversity data, which will make it difficult to assess the impact of environmental changes on the coastal ecosystems of Atlantic Canadian waters. In 2019, to help fill this gap, DFO Quebec Region initiated a regional comprehensive monitoring strategy in coastal areas to improve the abundance and availability of bentho-demersal biodiversity data over time. The project is taking advantage of regular DFO stock assessment surveys on commercial benthic invertebrates in four locations: St. Lawrence Lower Estuary (Snow Crab, Whelk), Northern Gulf of St. Lawrence/Mingan Archipelago (Icelandic Scallop), Northern Gulf of St. Lawrence/Lower North Shore (Snow Crab), and Magdalen Islands (American Lobster, Sea Scallop). The initiative is rooting its foundation into improving current coastal biodiversity data management practices: enhanced protocols at sea, prompt expert data validation (Nozères and Roy 2021), reliable data archiving, and annual open diffusion of occurrence data (Federal Geospatial Platform, Open Data, OBIS, e.g. Brulotte 2021). In addition, the initiative maximizes *in situ* environmental data collection during coastal surveys (data loggers on fishing gears, CTD profiles at targeted stations). These biodiversity–environmental time series will become crucial to support our understanding of the effects of climate change on coastal areas (e.g. changes in distribution range of indigenous and non-indigenous species) and to support an ecosystem approach to fisheries management (e.g. trophic interactions, predators and prey of commercial species, juvenile stages of offshore species).

The impacts of climate shifts on the productivity and health of Sea Scallop on the SS is unknown. Increased bottom temperatures could result in increased prevalence of diseases currently associated with warmer waters and could result in larger and more frequent hypoxic events. In addition, declines in ocean pH could result in lower growth rates and a decline in survival at the larval stage. Alternatively, for Sea Scallop, climate shifts could result in lower mortality, higher growth, and/or increased recruitment in some management units within the SS where temperatures are colder than optimal at present.

As nGSL and sGSL American Lobster stocks become more abundant, there is concern about carrying capacity of the habitat and in particular the availability of Rock Crab, an essential prey. For this reason, the Gulf Region has allocated more resources to Rock Crab research questions.

There is little evidence of climate effects for molluscs and echinoderms, except for a possible negative impact of reduced ice coverage and increased coastal erosion on recruitment of the very shallow water Common Softshell Clam and increased presence on the Lower North Shore of the Common Sea Star (*Asterias rubens*), a predator of Sea Scallop. The impacts of these threats cannot be quantified at the moment.

## 6.6 Technical Notes

To facilitate comparisons between bioregions and/or between species, landings or survey results were transformed into standardized anomalies. For each time series (for example landings of American Lobster in the nGSL for 1990–2020), this was accomplished by calculating the mean value for a reference period that excluded the reporting period (1990–2016), then subtracted this mean from the value for each year, then dividing these values by the standard deviation for the reference period. The reference value was always 1990–2016, except for some new fisheries which started after 1990.

In the figures, anomalies for landings and survey results are always shown on different panels when both types of data are available. In each panel, different bioregions and sometimes different species are shown on separate lines on left panels. If more than one line is shown, a second panel on the right shows stacked anomalies. For each year, positive anomalies of the different lines are piled up above the zero horizontal line, whereas negative anomalies are piled down below the zero line. Furthermore, the sum of all anomalies for a given year is calculated and shown as a thick black line.

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# 7. MARINE AND DIADROMOUS FISH

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## 7.1 Key Messages

- Across the Atlantic zone, most small pelagic fish stocks have continued to decline or have remained stable at low levels since 2017. The continued low abundance of these forage fishes may be inhibiting the production of other commercially valuable finfish in some areas.
- A diverse array of pelagic shark species occur throughout Atlantic Canadian waters. Status and trends for most species are currently unknown, although there is evidence of recent population increase for two endangered species: the Porbeagle Shark and White Shark.
- Since 2017, there have been limited changes observed in the biomass of groundfish in most areas. Many commercial species remain low or have not recovered to historical levels. An exception is Atlantic Halibut, which remains at higher than average levels throughout Atlantic Canadian waters.
- Across all bioregions, redfish species were the most or among the most abundant component of the demersal fish community in recent years.
- Biomass estimates and survey catch weights for many demersal shark and skate species are highly variable from year to year, and trends over time are species-specific. Demersal sharks and skates, in general, comprise a small proportion of the total demersal fish biomass, except for Black Dogfish in the northern Gulf of St. Lawrence and Spiny Dogfish on the western Scotian Shelf, where they are more prominent members of the demersal fish community.
- Thorny Skate biomass has been stable in the Gulf of St. Lawrence over the last decade; however, long-term declines have been observed on the Scotian Shelf while long-term increases have been observed on the Newfoundland and Labrador Shelves.
- Historic low abundance of Striped Bass in the southern Gulf of St. Lawrence in the 1990s resulted in the closure of the commercial and recreational fisheries and suspension of the Indigenous Food, Social, and Ceremonial fishery allocations. Reduced fishing pressure and favourable environmental conditions are thought to have played a role in the increased population abundance observed since the mid-1990s.
- Many wild Atlantic Salmon stocks across Atlantic Canada have declined to low abundance since the mid-1990s compared to historical levels. Threats occurring in both the freshwater and marine environments could be acting individually or in combination to cause the declines. In contrast, some populations in eastern and western Newfoundland and Labrador are stable or show increasing trends.

- Observed changes in fish species abundance over time are thought to be brought about by a long history of overfishing, a rapidly changing environment, and altered trophic interactions, but many of these trends remain to be fully explained.

## 7.2 Background

Marine communities include fish species that occupy various habitats near the seafloor or in the water column, from the coast to offshore, open water areas. Marine fish occupy different levels of the food web, often at different stages of their life cycles, and play an important role in the transfer of energy between various trophic levels and in sustaining commercial fishing activities.

Pelagic fish inhabit the water column, many travelling in schools, while others swim alone or drift with ocean currents. They comprise both small, energy-rich forage fish and their large apex predators. Forage fish undertake feeding migrations to productive areas to feed on zooplankton, which can affect the distribution of their predators (groundfish, marine mammals, seabirds; Buren et al. 2014a). See Section 11.4.2 in *Predator–Prey Interactions* for the impact of reduced forage fish availability on seabirds). Large pelagic fish can occupy different trophic levels, even as they grow from juveniles to adults; some are filter-feeders and others are piscivorous. Some migrate over long distances to complete their life cycles and switch prey species to remain in waters with their preferred environmental conditions.

Demersal fish live near or in close association with the seafloor on the continental shelves of Atlantic Canada, mostly consuming smaller fish, zooplankton, and/or bottom invertebrates. Demersal fish are diverse in shape and include groundfish, sharks, and skates. Groundfish have both economic and ecological importance in Atlantic Canadian waters as targets of major fisheries that provide jobs and food resources to local economies but also in their role as secondary consumers or predators that exert top-down influences on food webs. Dogfishes and skates are opportunistic feeders, consuming a wide variety of cephalopods, crustaceans, jellyfish, and other small demersal or pelagic fish. In turn, they may be preyed upon by other demersal fish or sharks, larger sharks, and marine mammals.

Diadromous fish are migratory, spending part of their lifecycle in the ocean and part in freshwater and have an important function in aquatic ecosystems as they transport and exchange nutrients and biomass between freshwater and marine ecosystems. Threats to Atlantic Salmon are discussed in more detail in Section 11.2.2 in *Multiple Stressors*.

## 7.3 Status and Trends

Assessing the state of fish communities requires careful monitoring and scientific analysis to obtain sufficient and reliable information for such a diverse multitude of species. Many species are fished commercially, and although landings from these fisheries provide useful information for targeted species, they do not reflect the overall fish community. Scientific methodologies, such as multi-species bottom trawl surveys, acoustic surveys, longline and gillnet surveys, dive surveys, mark–recapture, and tagging and tracking, fill some of these gaps by collecting data on the wider fish communities and specific species of interest. Non-extractive underwater imagery methods are also increasingly used to improve the understanding of fish communities, while minimizing the impacts of scientific data collection on marine species and habitats.

Most status and trends of different species are reported on by bioregion: northern Gulf of St. Lawrence (nGSL) and southern Gulf of St. Lawrence (sGSL), Scotian Shelf (SS), and Newfoundland and Labrador Shelves (NLS). However, due to the specificity of research survey methodologies, management activities (see Section 1.3 *Legislation and Management* for information on the Precautionary Approach), and variations in the spatial distributions among species broader or more specific subareas may be used. Status and trends of marine and diadromous fish are presented below and summarized in Appendix 1.

### *7.3.1 Small Pelagic Fish*

Small pelagic species are not well-captured on multi-species bottom-trawl surveys, so select species/stocks are targeted with acoustic surveys. NAFO Divisions (see Fig. 1.2-1) are used throughout for individual stocks.

#### *Northern Gulf of St. Lawrence*

In the nGSL, Atlantic Herring (*Clupea harengus*), Atlantic Mackerel (*Scomber scombrus*), and Capelin (*Mallotus villosus*) are the most common commercially exploited small pelagic fish. Atlantic Mackerel are part of the Northwest Atlantic (NWA) stock, which includes two genetically distinct spawning contingents (Gíslason et al. 2020). Figure 7.3-1 includes the annual biomass from the acoustic index for spring- and fall-spawning Atlantic Herring and the estimated biomass index for Atlantic Mackerel. Capelin in 4RST is assessed based on commercial landings and a fishery performance index as DFO currently has no scientific survey aimed at estimating capelin abundance in the GSL.

- Spring-spawning Atlantic Herring biomass in 4R increased in 2017 and again in 2019 from the lowest level ever observed in 2015. In 4Sw, spring spawners also increased in 2019 and 2020 from low levels.
- Fall-spawning Atlantic Herring biomass increased slightly in 2020 and is comparable to levels observed in the early 2000s in 4R (DFO 2021a) and from 2009 to 2011 in 4Sw (DFO 2021b).
- Spawning stock biomass for Atlantic Mackerel increased slightly from 2016 to 2018 but declined again from 2019 to 2021 reaching its lowest level ever observed in 2020 (DFO 2021c). The stock has remained near or below the Limit Reference Point for the last decade after collapsing in the 2010s.
- Commercial landings of Capelin in 4RST vary annually. Landings from 2018 to 2020 were near the series average, whereas the fishery performance index (tonnes per boat per day) remained above the time series average (DFO 2021d).

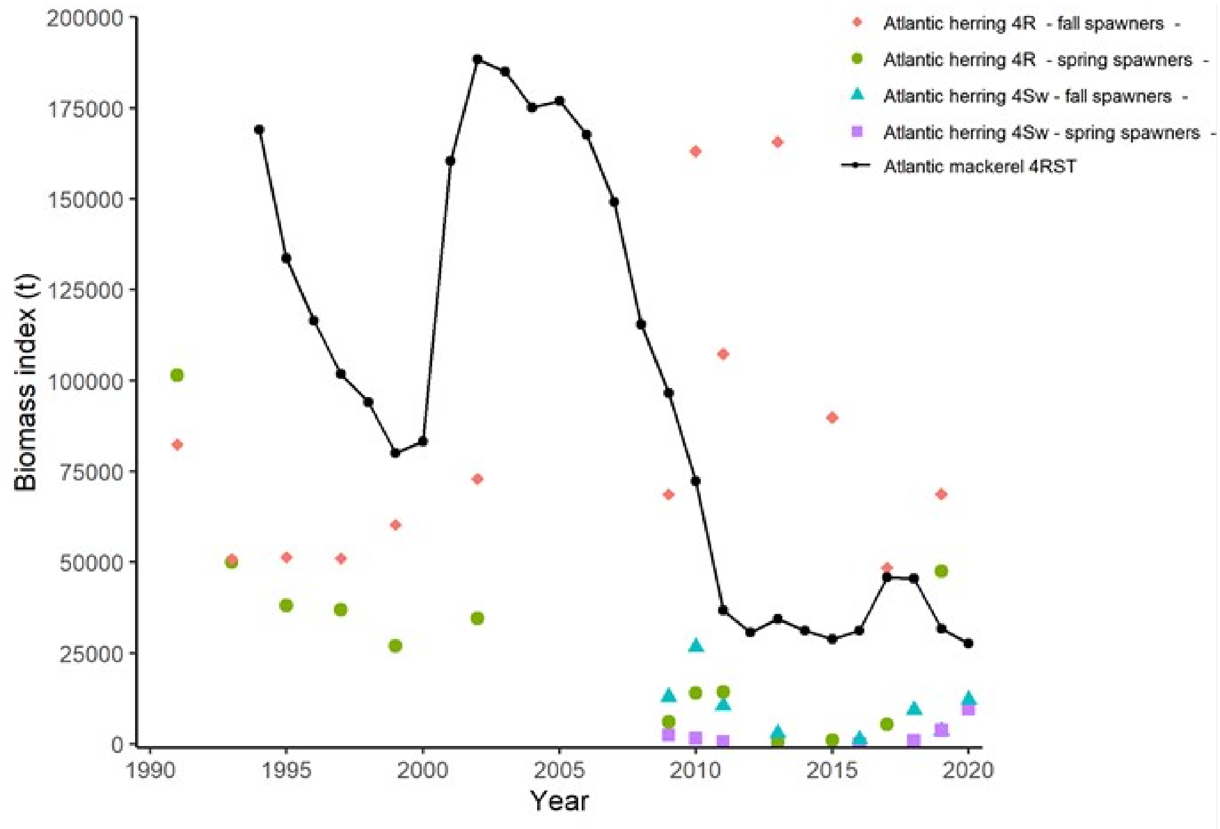

Figure 7.3-1. Acoustic biomass index (tonnes) of Atlantic Herring (NAFO Divisions 4R and 4Sw) and estimated biomass index (tonnes) of Atlantic Mackerel (NAFO Divisions 4RST) in the northern Gulf of St. Lawrence from 1990 to 2020. See Section 1.2 for biogeographical and NAFO division boundaries.

### *Southern Gulf of St. Lawrence*

In the sGSL, pelagic fish biomass has been dominated by Atlantic Herring since the mid-1980s. Figure 7.3-2 shows the biomass index for total pelagic fish and individual species based on the research vessel survey. Gaspereau refers to two species of fish that are not differentiated during the survey: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*).

- Total pelagic fish biomass was at very low levels from 2018 to 2020. In 2021 levels returned to those seen in 2016 and 2017.
    - Atlantic Herring biomass declined from 2016 to 2020 to low levels last observed in the 1970s and 1980s (DFO 2022a).
    - In 2021, Atlantic Mackerel had the highest biomass on record in the research vessel survey. However, this contradicts the stock assessment that showed the lowest spawning stock biomass for the northern contingent of Atlantic Mackerel in 2021 (DFO 2023).
    - Gaspereau biomass in the Margaree River—the only river with abundance information—declined since the 1980s (DFO 2022b) and remains low.
    - Capelin biomass was low in 2018–2019 then increased in 2020 and 2021, although to lower biomass than levels recorded in 2017 (DFO 2021d).

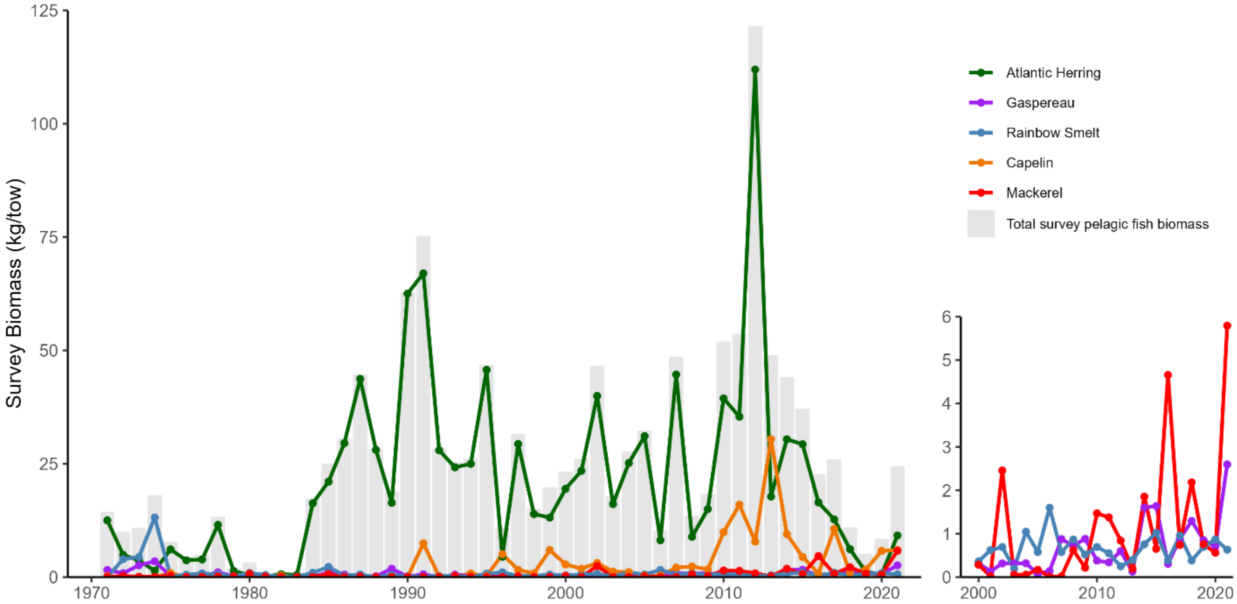

Figure 7.3-2. Research vessel survey index of biomass (kg/tow) for total pelagic fish and most abundant species in the southern Gulf of St. Lawrence from 1971 to 2021 (left) with magnification for less abundant species from 2000 to 2020 (right). Biomass values were standardized across the time series according to Benoît and Swain (2003). See Section 1.2 for biogeographical boundaries.

### *Scotian Shelf*

In the SS, small pelagic species are dominated by Atlantic Herring and Atlantic Mackerel; historically, the western SS, including the Bay of Fundy, supported a large abundance and an important pelagic fishery of Atlantic Herring. Figure 7.3-3 shows total commercial landings across the entire SS and Figure 7.3-4 shows landings for Atlantic Herring and Atlantic Mackerel by NAFO Division: 4W and 4V (4Vn and 4Vs) for the eastern SS and 4X for the western SS.

- Across the entire SS, total commercial landings of small pelagic fish from 2016 to 2021 are low compared to numbers from the late 1980s and early 1990s, although they have remained relatively stable since 2010.
    - Landings of Atlantic Herring on the eastern SS remain at historically low levels in 4V but have been low and relatively stable since 2018 in 4W. Atlantic Herring landings on the western SS were low from 2016 to 2021 and continue to slowly decline from their peak in 1988.
    - Landings of Atlantic Mackerel on both the western and eastern SS remain at very low levels (~1000 tonnes or less since 2010).

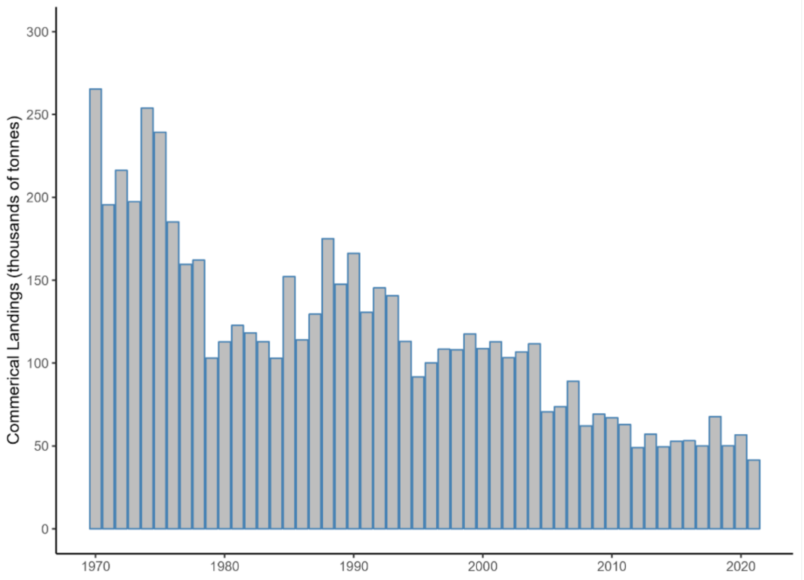

Figure 7.3-3. Total commercial landings (thousands of tonnes) of small pelagic fish across the Scotian Shelf. See Section 1.2 for biogeographical boundaries.

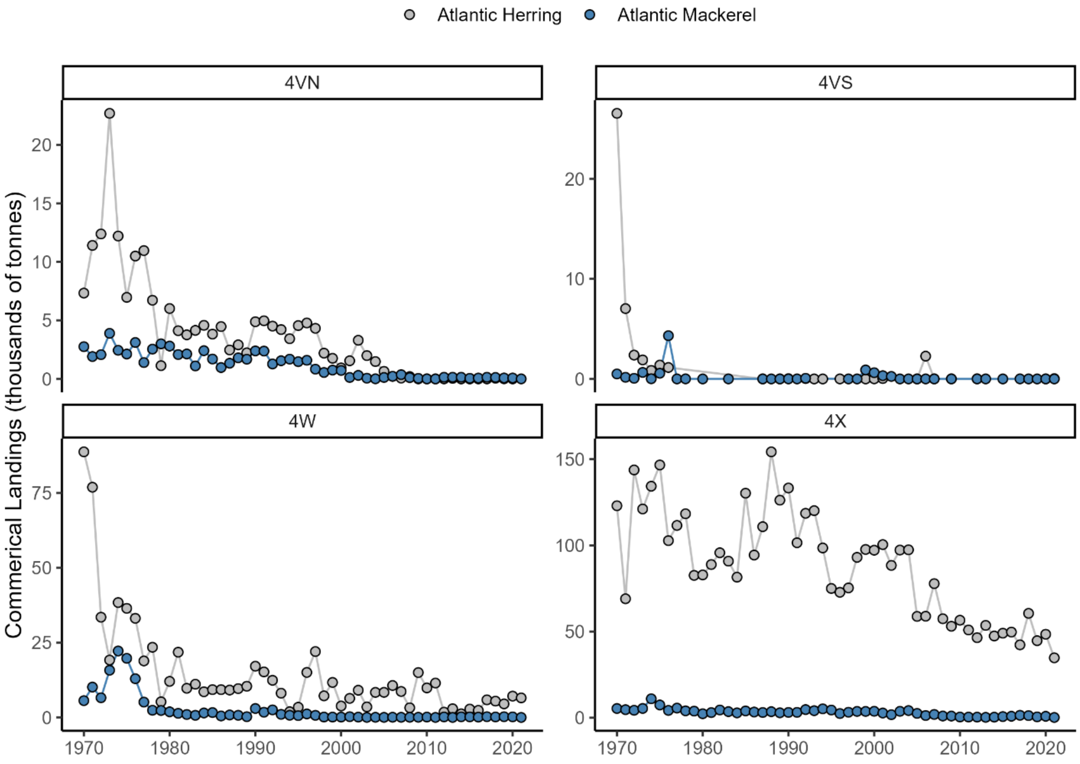

Figure 7.3-4. Commercial landings (thousands of tonnes) of Atlantic Herring and Atlantic Mackerel in the eastern Scotian Shelf (NAFO Divisions 4Vn, 4Vs, and 4W) and western Scotian Shelf (4X) from 1970–2021. See Section 1.2 for biogeographical and NAFO division boundaries.

### *Newfoundland and Labrador Shelves*

In the NLS, pelagic species include Arctic Cod (*Boreogadus saida*), Sand Lance (*Ammodytes dubius*), Atlantic Herring, and Capelin. Capelin is the dominant small pelagic fish and keystone forage species in the NLS marine food web (Buren et al. 2014) and the only pelagic species for which there is currently a biomass index. The biomass index captures a portion of the maturing Capelin stock prior to summer spawning, based on a spring acoustic survey and is shown in Figure 7.3-5 for NAFO Division 3L. Note that the spring acoustic survey was not conducted in 2020 due to COVID-19 limitations so a Capelin forecast model was used here in its stead for that year.

- The Capelin biomass index was near the 20-year average in 2018 and 2019 and slightly lower in 2017, still well below levels observed in the late 1980s prior to the stock collapse in 1991.
- The Capelin forecast model projected that the spring acoustic biomass index in 2020 would be lower than 2019, returning to levels similar to those observed in 2017 (DFO 2022c).

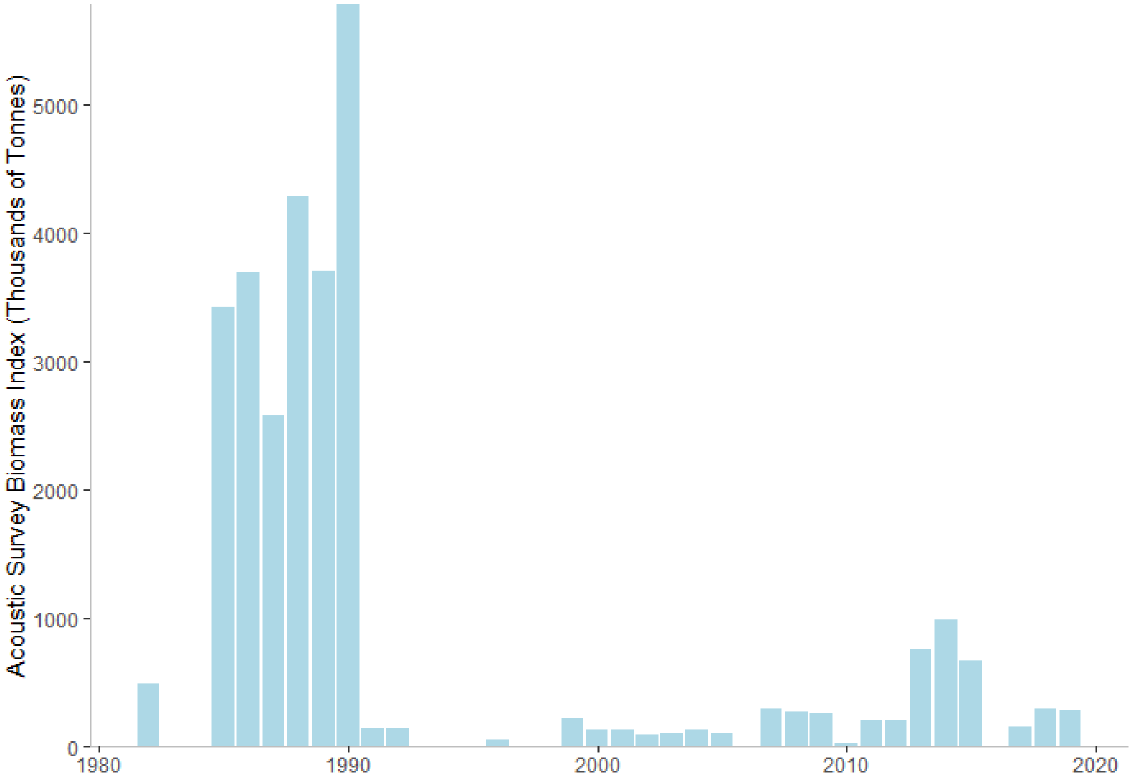

Figure 7.3-5. Capelin spring acoustic survey biomass index (thousands of tonnes) for NAFO Division 3L from 1980–2019. See Section 1.2 for NAFO Division boundaries.

### *7.3.2 Large Pelagic Fish*

Tunas, including North Atlantic Swordfish (*Xiphias gladius*), and many sharks are migratory with broad distributions throughout and beyond Atlantic Canadian waters. Some sharks reside year-round and others are seasonal or occasional visitors (Campana et al. 2015a; Showell et al. 2017), which makes it difficult to accurately assess population size. Currently, there are commercial fisheries for some tuna species and a recreational catch and release shark fishery with four to six tournaments per year that, as of 2019, allow retention of only Blue Shark (*Prionace glauca*) (Bowlby et al. 2020). Historically, there was a directed shark fishery for Porbeagle Shark (*Lamna nasus*), and Shortfin Mako Shark (*Isurus oxyrinchus*) could be landed as bycatch, but these are no longer permitted due to conservation concerns (see Section 11.2.4 in *Multiple Stressors* for an overview). Pelagic sharks are not intercepted by DFO's annual multi-species bottom trawl surveys so landings as bycatch discarded at sea from commercial fisheries (Campana et al. 2013) and tournament landings are the main sources of data.

Atlantic populations of Porbeagle Shark, Shortfin Mako Shark, and White Shark (*Carcharodon carcharias*) are considered endangered by COSEWIC (2014, 2019, 2021) and the Atlantic population of Basking Shark (*Cetorhinus maximus*) has a status of Special Concern (COSEWIC 2009a). White Shark is also listed as endangered under Canada's *Species at Risk Act*, and Porbeagle, Shortfin Mako, and Basking sharks are all under consideration for addition to Schedule 1.

- White Shark (DFO 2017b) and Porbeagle Shark (Campana et al. 2013) are showing signs of population increase.
- Since 2014, there have been extremely limited landings of pelagic sharks as bycatch from commercial fisheries.
- Shark tournament landings increased from approximately 4 metric tons in 1993 (the first year) to an average of 11 metric tons since 2006 (Campana et al. 2015b). Blue Sharks account for 99% of all tournament landings, with Shortfin Mako Shark, Common Thresher Shark (*Alopias vulpinus*), and Porbeagle Shark being caught periodically.

### *7.3.3 Demersal Fish*

Groundfish (e.g. Atlantic Cod *Gadus morhua*, Atlantic Halibut *Hippoglossus hippoglossus*, Greenland Halibut *Reinhardtius hippoglossoides*, redfish, White Hake *Urophycis tenuis*, American Plaice *Hippoglossoides platessoides*, Haddock *Melanogrammus aeglefinus*, Silver Hake *Merluccius bilinearis*), demersal sharks (e.g. Spiny Dogfish *Squalus acanthias*, Black Dogfish *Centroscyllium fabricii*), and skates (e.g. Thorny Skate *Amblyraja radiata*, Smooth Skate *Malacoraja senta*) are all assessed based on DFO's annual multi-species bottom trawl surveys and form the basis for the majority of the status and trends. Large Atlantic Halibut are not well-captured on multi-species bottom-trawl surveys and DFO–Industry collaborative longline surveys are used to monitor biomass for stock assessment. Many demersal fish are or have been previously targeted by commercial fisheries (see Section 11.2.4 in *Multiple Stressors* for the history of the Spiny Dogfish commercial fishery in Atlantic Canada); however, commercial landings are only presented occasionally as supplementary information.

Distinguishing between Deepwater Redfish (*Sebastes mentella*) and Acadian Redfish (*Sebastes fasciatus*) during research surveys is difficult due to fine morphological differences, so they are assessed together. In some cases, catch species composition has been determined using information from the fishery; recent improvements to methodologies may permit species-level identification in future research surveys (Senay et al. 2021). In the NLS, a third species, Golden Redfish (*Sebastes marinus*) is managed and assessed with the other two species (DFO 2020a).

Most status and trends for demersal fish are reported at the bioregional level; however, Spiny Dogfish and Thorny Skate are designated as Special Concern as an Atlantic population (COSEWIC 2010a, 2012a). Smooth Skate is also at risk across the Atlantic with an Endangered population in the NLS (Funk Island Deep population) and a population of Special Concern on the SS and in the GSL (Laurentian-Scotian population) (COSEWIC 2012b). Winter Skate (*Leucoraja ocellata*) is also listed as Endangered by COSEWIC (2015).

Demersal fish are considered separately for the nGSL and sGSL, and NAFO Divisions (see Fig. 1.2-1) are used throughout for individual stocks. Generally, groundfish are presented separately from sharks and skates (with the exception of Spiny Dogfish on the SS) because sharks and skates make up a relatively small proportion of total demersal fish biomass and their trends are better visualized separately.

### *Northern Gulf of St. Lawrence*

A bottom trawl survey is conducted annually in August to estimate the relative abundance of demersal fish in the nGSL. Figure 7.3-6 shows the total annual survey catch of demersal fish and the average catch weight for the main groundfish; Figure 7.3-7 shows the average catch weight for the main shark and skate species caught in the survey.

- The abundance of demersal fish reached its highest levels between 2016 and 2021, mainly attributable to an increase in redfish. This continues a sharp increasing trend that began in 2010.
    - Redfish biomass reached a maximum in 2019 and maintained a general upward trend in 2021. This marked increase is mainly due to high recruitment of the Deepwater Redfish in 2011, 2012, and 2013 (Senay et al. 2021); the Acadian Redfish remained in the Cautious Zone in 2020 (DFO 2020b).
    - In 2019, Atlantic Halibut landings were the largest in the last 60 years (Gauthier et al. 2021; Shackell et al. 2021). Its biomass has been increasing relatively steadily since the 2000s (DFO 2018a) until 2021 (DFO 2021f).
    - Atlantic Cod abundance had an upward trend in 2020 and 2021 (DFO 2020c, 2021g) after a decline in 2017 (DFO 2017c, 2018b).
    - The Greenland Halibut stock status indicator stabilized in 2019 after a decrease in biomass of more than 60% between 2008 and 2017 (Bourdages et al. 2021; DFO 2021h). There was a slight increase in the Greenland Halibut stock status indicator in 2020 and 2021 caused by the arrival of a large cohort in 2018, which shows a normal growth rate and could recruit as early as 2024 (DFO 2021h).
    - Abundance of Thorny Skate increased slightly in 2020 after a long period of stability, then decreased again to previously observed levels in 2021 (Bourdages et al. 2021).
    - Survey catches of Smooth Skate continued to decrease during 2017 to 2021 (Bourdages et al. 2021).
    - Catches of Black Dogfish reached a record high in 2021 after increasing since 2012 to levels above the survey time-series average.

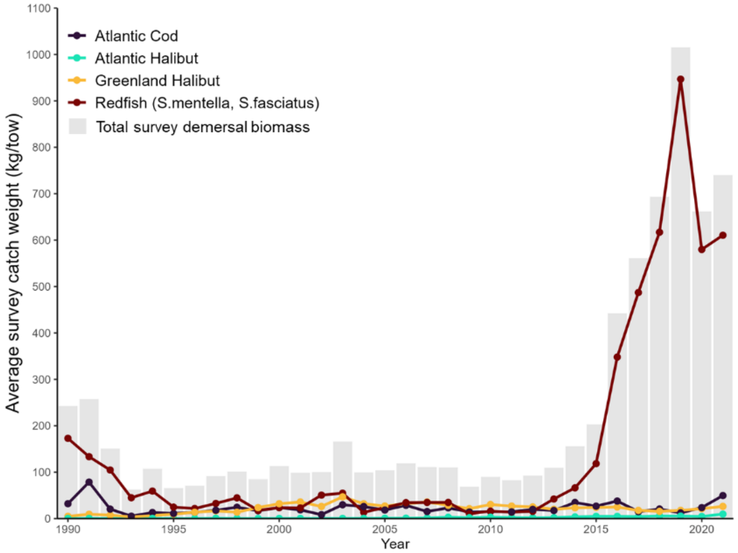

Figure 7.3-6. Average survey catch weight (kg/tow) of all demersal fish (bars) and most abundant species in the northern Gulf of St. Lawrence from 1990 to 2021. See Section 1.2 for biogeographical boundaries.

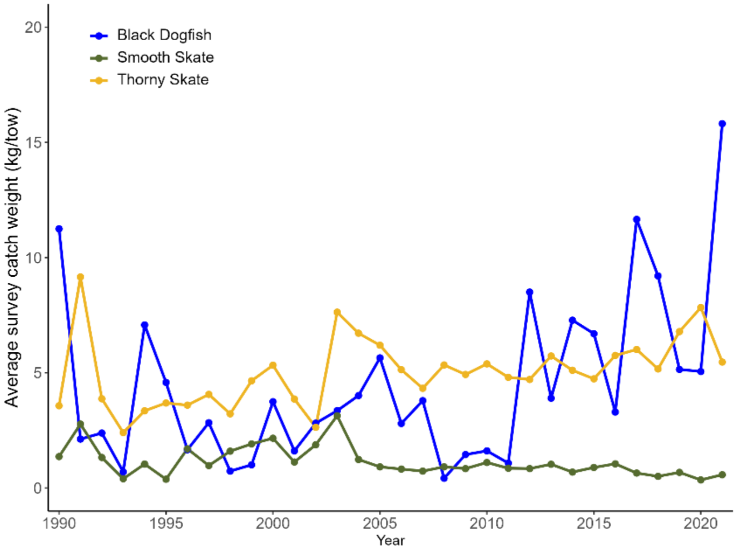

Figure 7.3-7. Average survey catch weight (kg/tow) of most abundant shark and skate species in the northern Gulf of St. Lawrence from 1990 to 2021. See Section 1.2 for biogeographical boundaries.

### *Southern Gulf of St. Lawrence*

A bottom trawl survey is conducted annually in September to estimate the relative abundance of demersal fish in the sGSL. Figure 7.3-8 shows the total survey biomass and the survey biomass for the main groundfish; Figure 7.3-9 shows the survey biomass of the main shark and skate species caught in the survey.

- From 2017 to 2021, the biomass of demersal fish species in the sGSL has remained fairly consistent to levels observed since the mid-1990s.
    - Redfish biomass has been higher than average since 2016 and are one of the few demersal species that have continued to increase in biomass in recent years.
    - Atlantic Cod, American Plaice, and White Hake have remained at low levels.
    - Thorny Skate comprises the largest proportion of elasmobranch biomass but is at historic lows with respect to the entire time series.
    - Smooth Skate and Winter Skate remain at low abundance.
    - Spiny Dogfish and Black Dogfish have been virtually absent in recent years, which is a large change from high catches seen in the late 1980s and early 1990s.

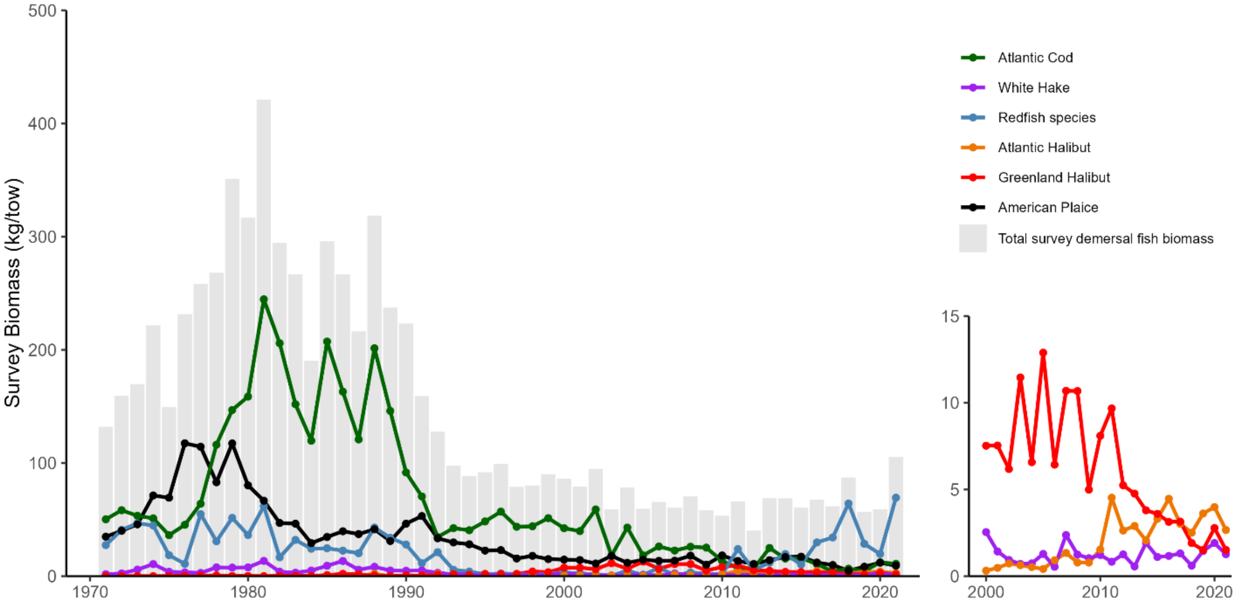

Figure 7.3-8. Research vessel survey index of biomass (kg/tow) for all demersal fish (bars) and most abundant species in the southern Gulf of St. Lawrence from 1971 to 2021 (left) with magnification for less abundant species from 2000 to 2020 (right). Biomass values were standardized across the time series according to Benoît and Swain (2003). See Section 1.2 for biogeographical boundaries.

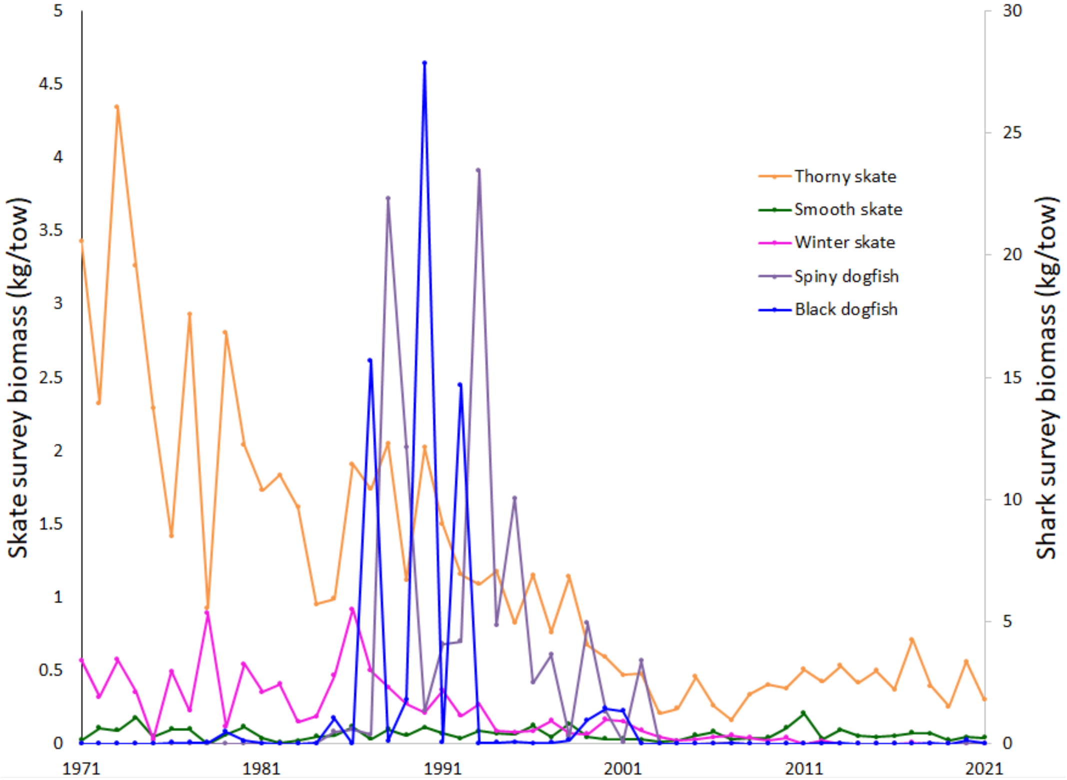

Figure 7.3-9. Research vessel survey index of biomass (kg/tow) for shark and skate species in the southern Gulf of St. Lawrence from 1971 to 2021. Biomass values were standardized across the time series according to Benoît and Swain (2003). See Section 1.2 for biogeographical boundaries.

### *Scotian Shelf*

The annual multi-species bottom trawl research survey on the SS captures demersal fish on the eastern SS (4VW) and the western SS (4X). No survey biomass indices are available for 2018 on the eastern SS due to incomplete survey coverage. Figure 7.3-10 shows total demersal fish biomass on the eastern SS as well as biomass for individual groundfish and shark species; Figure 7.3-11 shows biomass for individual skate species. Figures 7.3-12 and 7.3-13 show the same for the western SS.

- On the eastern SS, total biomass index for demersal fish remains low.
    - Redfish, Haddock, and Silver Hake have comprised most of the biomass index since 2016. However, Haddock and Silver Hake have declined since 2017 while redfish have been relatively stable since 2012.
    - Atlantic Halibut continues to have higher than average biomass since 2017 but appears to have reached a peak and is beginning to decline.
    - In 2020, Atlantic Cod reached its highest biomass level in the past decade, yet remains at relatively low levels compared to historical abundances.
    - Biomass of Spiny Dogfish is variable from year to year but remains at low levels.
    - All skates remain at very low levels: Smooth Skate, Winter Skate, and Thorny Skate have declined significantly from historically higher levels, whereas Barndoor Skate (*Dipturus laevis*) has increased since the early 2000s after not being captured in the survey in decades.

- On the western SS, Spiny Dogfish, redfish, and Haddock continue to comprise most of the demersal fish biomass index. Total demersal fish biomass has been highly variable over the time series, driven by inter-annual variability in Spiny Dogfish and redfish.
    - Strong recruitment events in 2009, 2012, and 2016 led to the highest biomass index on record for redfish in 2016. However, these biomass peaks were not maintained and redfish biomass has since declined and remained low from 2018 to 2020.
    - Silver Hake biomass remained low from 2016 to 2020 after strong recruitment and biomass peaks in 2010 and 2014.
    - Haddock biomass has declined since 2015 and remains below the time series average.
    - Atlantic Cod biomass has declined since 2016, and hit a record low level in 2019.
    - Atlantic Halibut hit record high biomass levels in 2015 and 2018 but has since declined to below the time series average levels in 2019 and 2020.
    - Biomass of Spiny Dogfish has been highly variable over the time series and currently remains at below average levels in 2019 and 2020. This species has dominated the research survey biomass index in most years since the 1980s and has comprised 75–99% of the total elasmobranch biomass since 1990.
    - Thorny Skate has continued to decline since the time series high in 1975 and remains at very low levels.
    - Barndoor Skate and Little Skate (*Leucoraja erinacea*) have increased since the 1990s and remain at higher than average levels in 2020.
    - Winter Skate reached a record high biomass in 2020.
    - Smooth Skate has increased since the low values observed in the 1990s yet remains slightly below average levels in 2019 and 2020.

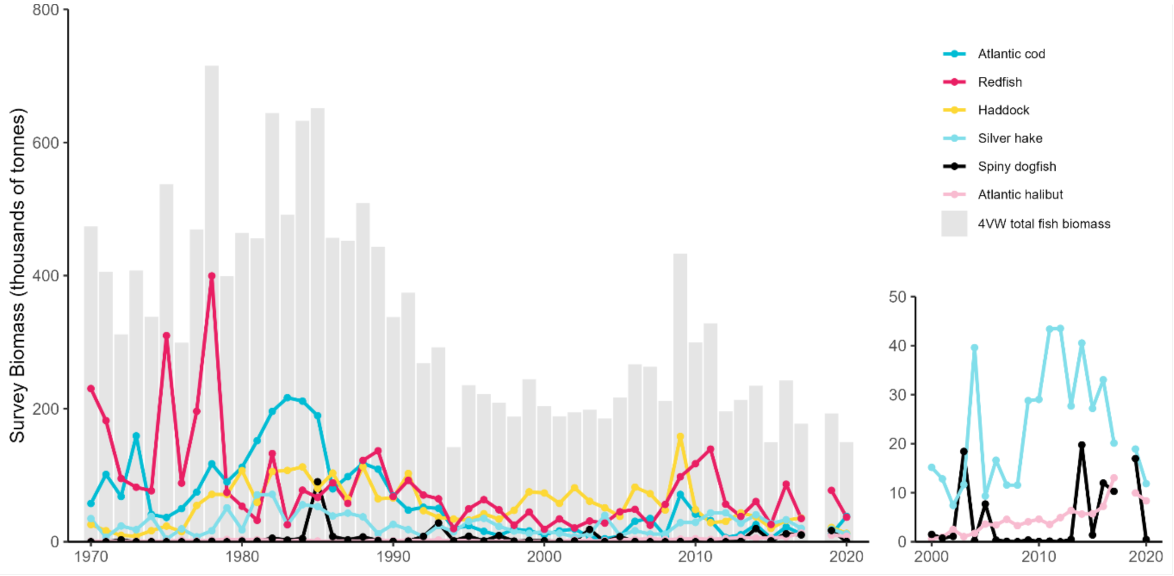

Figure 7.3-10. Research survey biomass (thousands of tonnes) for all demersal fish (groundfish and Spiny Dogfish) (bars) and most abundant species on the eastern Scotian Shelf (4VW) from 1970 to 2020 with magnification for Silver Hake, Atlantic Halibut, and Spiny Dogfish from 2000 to 2020 (right). See Section 1.2 for biogeographical and NAFO Division boundaries.

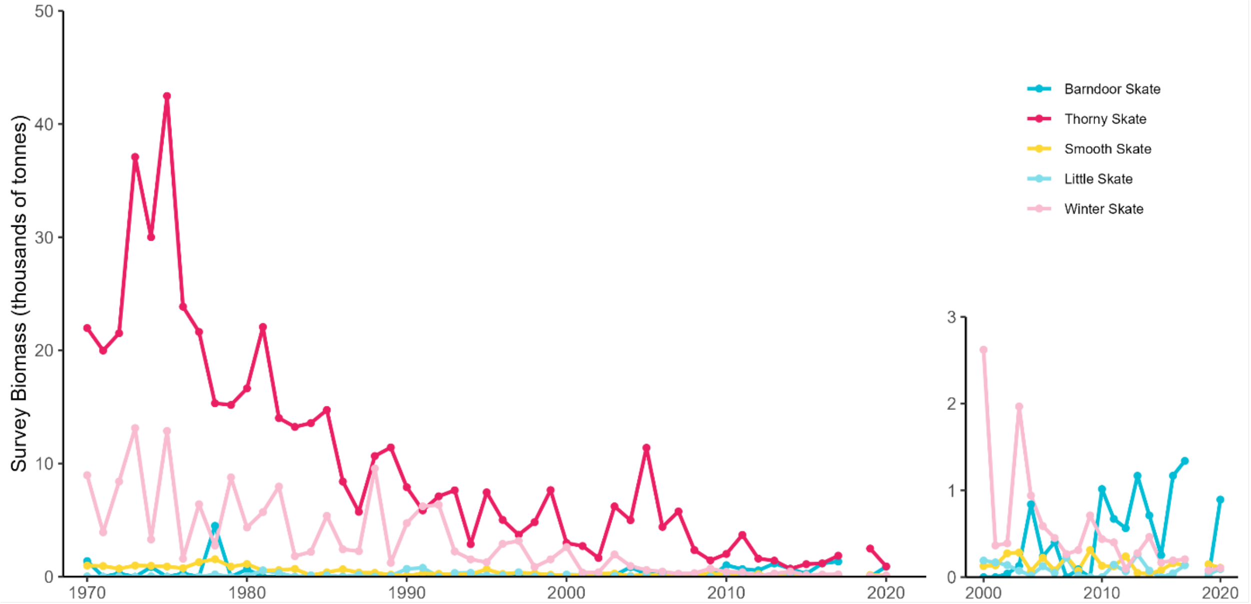

Figure 7.3-11. Research survey biomass (thousands of tonnes) of skates on the eastern Scotian Shelf (4VW) from 1970 to 2020 with magnification for less abundant species from 2000 to 2020 (right). See Section 1.2 for biogeographical and NAFO Division boundaries.

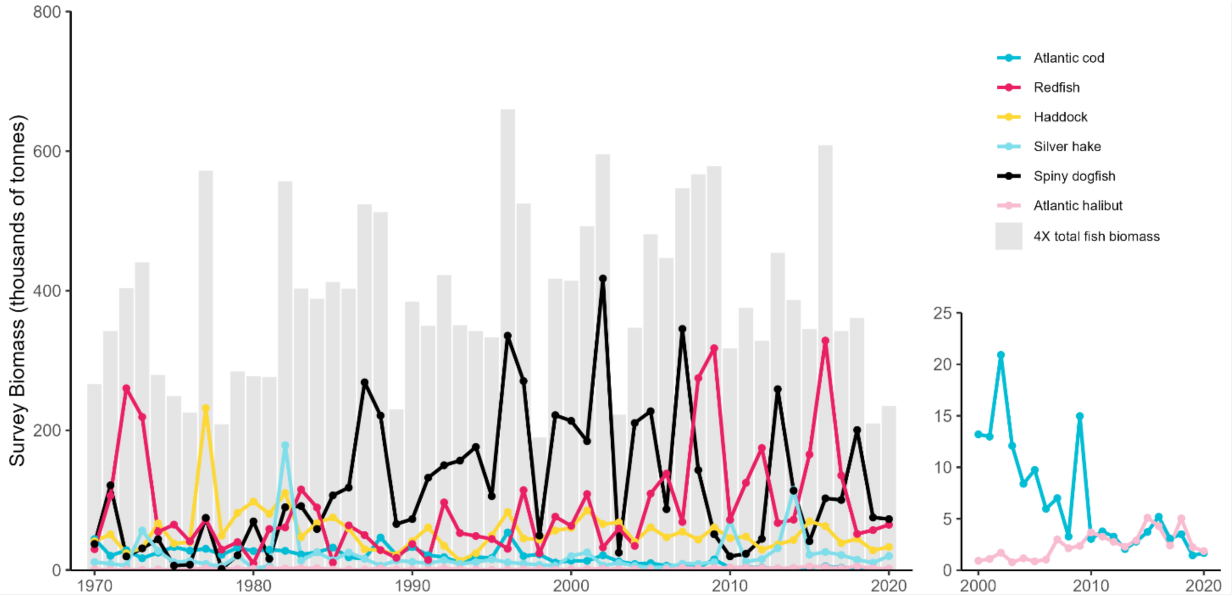

Figure 7.3-12. Research survey biomass (thousands of tonnes) of all demersal fish (groundfish and Spiny Dogfish) (bars) and most abundant species on the western Scotian Shelf (4X) from 1970 to 2020 with magnification for Silver Hake and Atlantic Halibut from 2000 to 2020 (right). See Section 1.2 for biogeographical and NAFO Division boundaries.

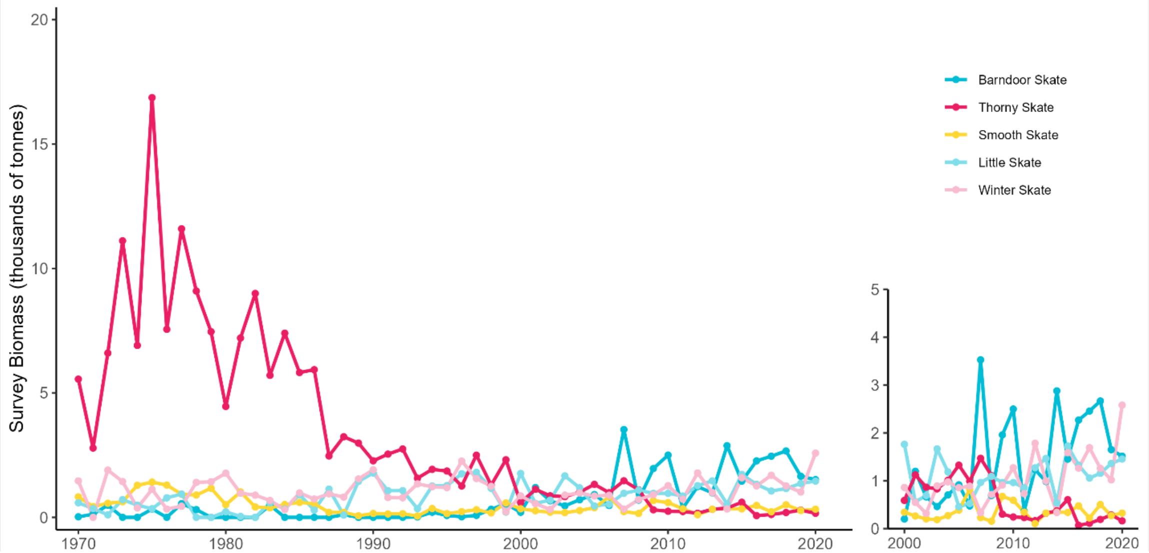

Figure 7.3-13. Research survey biomass (thousands of tonnes) of skates on the western Scotian Shelf (4X) from 1970 to 2020 with magnification for less abundant species from 2000 to 2020 (right). See Section 1.2 for biogeographical and NAFO Division boundaries.

### *Newfoundland and Labrador Shelves*

There are three main bioregions in the NLS that have annual multi-species research vessel surveys: Newfoundland Shelf (NAFO Division 2J3K in fall), Grand Banks (NAFO Division 3LNO in spring and fall), and southern Newfoundland (NAFO Division 3Ps in spring). Not all surveys were completed in all subdivisions in the last four years. For the Newfoundland Shelf, total survey biomass and biomass for individual groundfish are shown in Figure 7.3-14 and biomass for shark and skate species are shown in Figure 7.3-15. The same are shown for the Grand Banks in Figures 7.3-16 and 7.3-17 and for southern Newfoundland in Figures 7.3-18 and 7.3-19.

- Total biomass in the three subregions remains well below pre-collapse levels, despite recent increases in some species. Atlantic Halibut has continued to increase in recent years in all three subregions, but represents only a minor component of the overall demersal fish community. Redfish have reached peak or near peak biomass in all three subregions since 2016.
- There has been little recovery of Atlantic Cod, American Plaice, and White Hake despite ongoing moratoria on these stocks.
- On the Newfoundland Shelf, overall biomass of demersal fish was generally high from 2016 to 2020, except for 2017 when it was somewhat lower.
  - The increase in Atlantic Cod biomass after 2010 appears to have stalled, yet levels remain generally higher than observed from 1990 to 2010.
  - Greenland Halibut and American Plaice continue to comprise a large proportion of the total demersal fish biomass.
  - Redfish had its second-highest peak in 2018.
  - Witch Flounder (*Glyptocephalus cynoglossus*), although a small component of the overall biomass, has continued to increase since 2010.

    - Biomass of Thorny Skate reached a peak in 2018, continuing an increase over the 25 year time series.
    - Arctic Skate (*Amblyraja hyperborea*) reached peak biomass in 2016 then returned to the series average biomass levels.
    - Smooth Skate biomass has been at higher than average levels from 2017 to 2020.
- On the Grand Banks, overall biomass was relatively high in 2016 then decreased in 2019 and 2020.
    - Redfish biomass was high in 2016 but decreased sharply to lower levels in 2018 and 2019.
    - Yellowtail Flounder (*Limanda ferruginea*) continues to comprise a large proportion of the total demersal fish biomass.
    - Atlantic Cod biomass has increased since 2017 and remains at average levels.
    - American Plaice biomass has been relatively stable since 2016 but at lower levels than the time series average.
    - Spiny Dogfish biomass peaked in 2017 but was not caught in appreciable numbers either before or after.
    - Black Dogfish biomass peaked in 2014 but has been highly variable over the time series.
    - Thorny Skate comprise the majority of skate biomass (98–99%); its biomass and abundance on the Grand Banks and St. Pierre Bank (3LNOPs) are relatively stable at low levels after a decline from 1985 to 1995 (Simpson and Miri 2020).
    - Smooth Skate and Spinytail Skate (*Bathyraja spinicauda*) were caught consistently (2–3% of total biomass) but had fluctuating biomass from 1995 to 2019. Despite the high variability, Spinytail Skate has been increasing since 2003. The Smooth Skate biomass index continued to decline from its highest level in 2009.
- In southern Newfoundland, high levels of demersal fish biomass were observed in 2019 and 2021, driven mostly by redfish.
    - Silver Hake and American Plaice are becoming more prominent.
    - Redfish reached its second-highest biomass level in 2019 and remains a dominant component of the demersal fish community.
    - Although biomass is at low levels overall, Atlantic Halibut continues on an increasing trend since the mid-2000s.
    - Spiny Dogfish reached peak abundance in 2019 then declined to near zero in 2021.
    - Black Dogfish has declined from the time series high in 1995 and remains well below average levels in 2021.
    - Thorny Skate has increased over the time series and reached record biomass in 2021. All other skate species are at very low biomass.

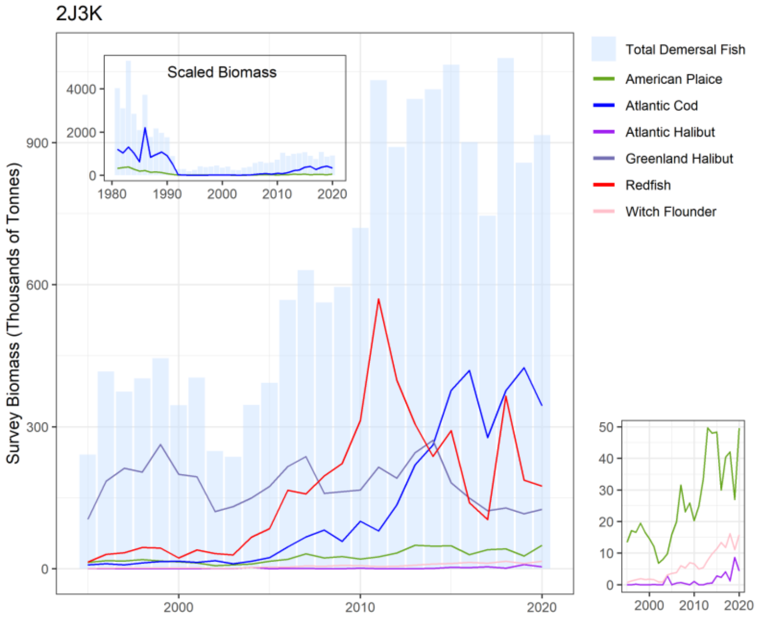

Figure 7.3-14. Survey biomass (thousands of tonnes) of all demersal fish (bars) and most abundant species on the Newfoundland Shelf (NAFO divisions 2J3K) from 1995 to 2020 (main plot) with magnification for less abundant species (right) from 2000 to 2020. Inset shows full time series from 1981 to 2020 with scaling factors applied to make biomasses coarsely comparable after a change in sampling gear in 1995/1996 (NAFO 2014; Dempsey et al. 2017). See Section 1.2 for biogeographical and NAFO Division boundaries.

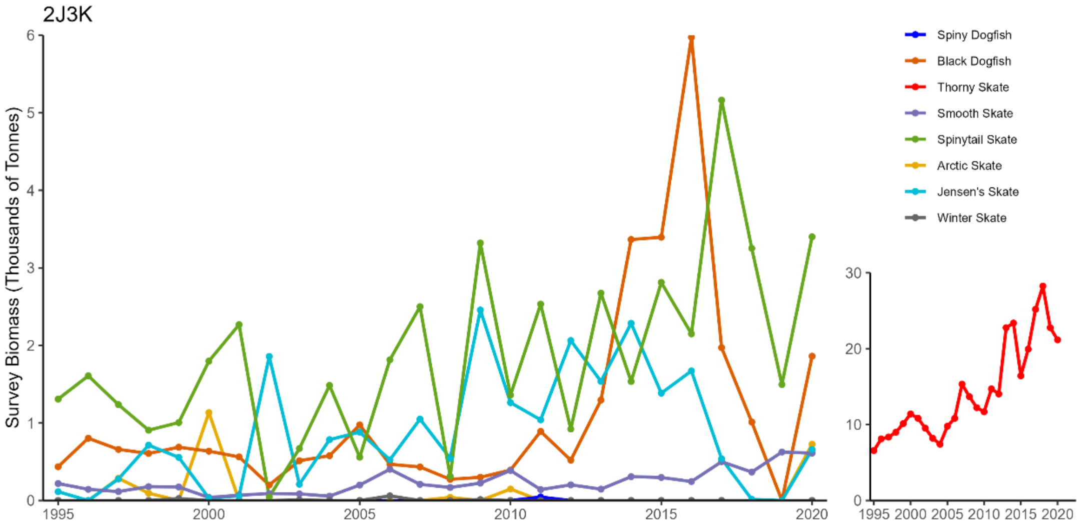

Figure 7.3-15. Research survey biomass (thousands of tonnes) for demersal sharks and skates (left) with magnification for Thorny Skate (right) on the Newfoundland Shelf (NAFO division 2J3K) from 1995 to 2020. See Section 1.2 for biogeographical and NAFO Division boundaries.

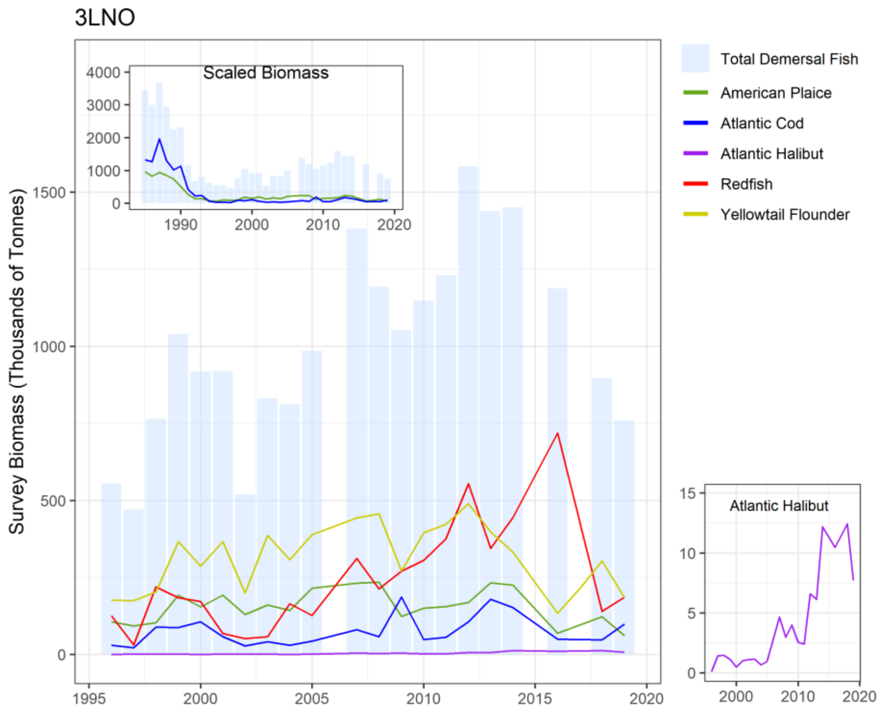

Figure 7.3-16. Survey biomass (thousands of tonnes) of all demersal fish (bars) and most abundant species on the Grand Banks (NAFO Divisions 3LNO) from 1996 to 2019 (main plot) with magnification for Atlantic Halibut (right). Inset shows full time series from 1981 to 2020 with scaling factors applied to make biomasses coarsely comparable after a change in sampling gear in 1995/1996 (NAFO 2014; Dempsey et al. 2017). See Section 1.2 for biogeographical and NAFO Division boundaries.

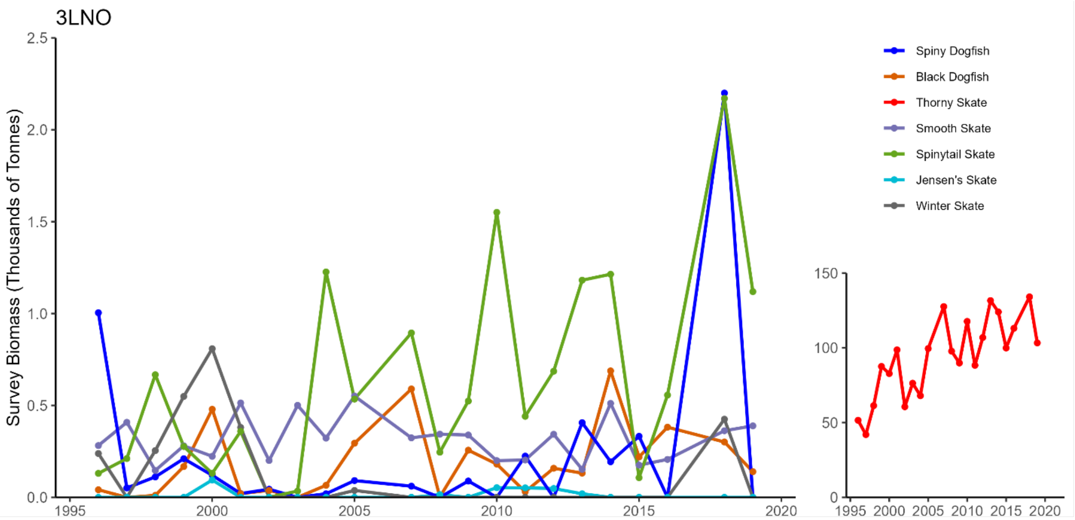

Figure 7.3-17. Research survey biomass (thousands of tonnes) for demersal sharks and skates (left) with magnification for Thorny Skate (right) on the Grand Banks (NAFO division 3LNO) from 1996 to 2019. See Section 1.2 for biogeographical and NAFO Division boundaries.

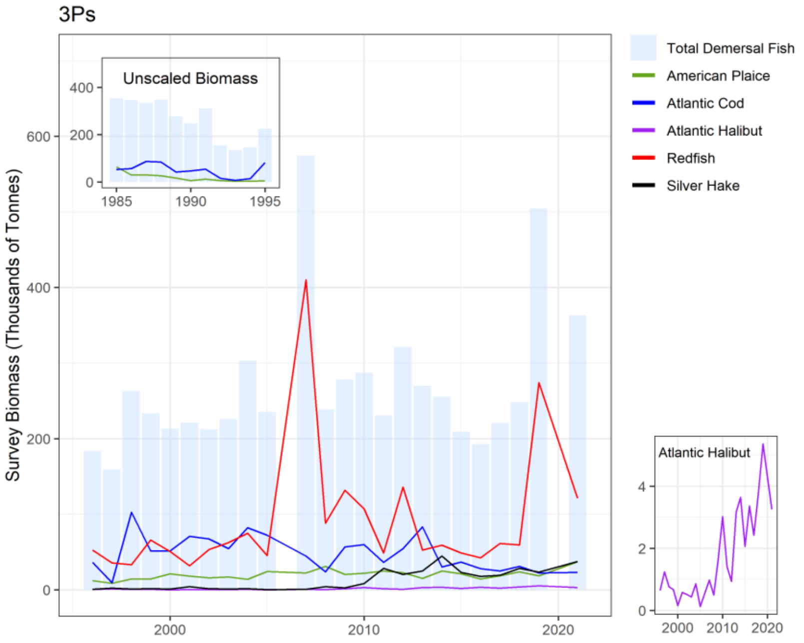

Figure 7.3-18. Survey biomass (thousands of tonnes) of all demersal fish (bars) and most abundant species from southern Newfoundland (NAFO Division 3Ps) from 1996 to 2021 (main) with magnification for Atlantic Halibut (right). Inset shows unscaled survey biomass (thousands of tonnes) from 1985 to 1995; gear was changed in 1996 but there is currently no accepted method for scaling and comparing the two time series. See Section 1.2 for biogeographical and NAFO Division boundaries.

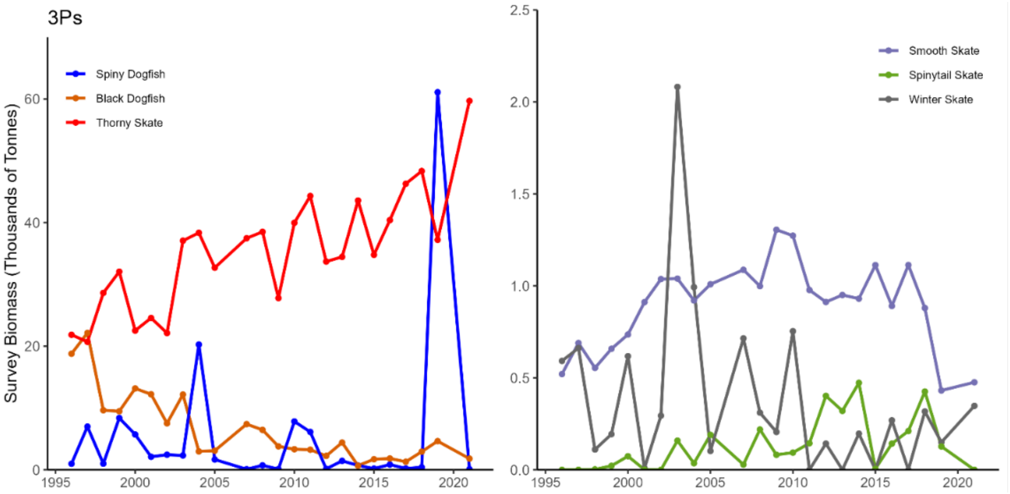

Figure 7.3-19. Research survey biomass (thousands of tonnes) of demersal sharks and skates for most abundant species (left) and magnification of less abundant species (right) in southern Newfoundland (NAFO division 3Ps) from 1996 to 2021. See Section 1.2 for biogeographical and NAFO Division boundaries.

### *7.3.4 Diadromous Fish*

Assessing status and trends for diadromous fish varies by species and stock due to their complex lifecycles. Atlantic Salmon (*Salmo salar*) and Striped Bass (*Morone saxatilis*) are presented here by bioregion for the sGSL, SS, and NLS, but are further subdivided into subregions or management areas related to their freshwater habitat or differences in life history traits (e.g. freshwater residence time, timing of return migration, age at first spawning, and the extent of ocean migration). Gaspereau status and trends are included in Section 7.3.1 *Small Pelagic Fish*.

The status of Atlantic Salmon throughout Atlantic Canada is assessed in 23 different Salmon Fishing Areas (SFAs; Fig. 7.3-20), management areas that include all the waters that flow into that specific area regardless of provincial origin. Adults can be enumerated along fishways at dams, at counting fences and trapnets deployed in rivers, or with snorkel surveys and from catch and effort data from recreational fisheries. Typically, total adult returns are assessed at index rivers as well as smolt-to-adult return rates (the percentage of smolt returning as spawning adults), which are used as a proxy for marine survival. Index rivers are monitored populations of salmon that are chosen to represent the general health and status of neighbouring, but unmonitored, populations, based on similar life-history characteristics and habitat type of the rivers. For Atlantic Salmon, adults are categorized by size as either small salmon or grilse (fork length ≥63 cm) or large salmon (fork length ≥63 cm) as well as by years at sea prior to returning to spawn. Generally, small salmon have returned after one year at sea (1 seawinter or 1SW) and large salmon have returned after two or more years at sea (e.g. 2SW, 3SW). Repeat spawners or multi-sea-winter salmon (MSW) can be either consecutive or alternate-year spawners.

Management measures have been put in place for some diadromous species due to conservation concern. Most populations of Striped Bass have been assessed by COSEWIC (2012c) and designated as either Special Concern or Endangered (see Appendix 1 for full list of populations and conservation status). The Inner Bay of Fundy population of Atlantic Salmon is also Endangered under the *Species at Risk Act* and listed on Schedule 1. In 2010, it was estimated that the Inner Bay of Fundy population was comprised of less than 200 spawning individuals (COSEWIC 2010b) and without human intervention and the support of a live gene bank stocking program, these populations would be completely extirpated (DFO 2008; Gibson et al. 2009).

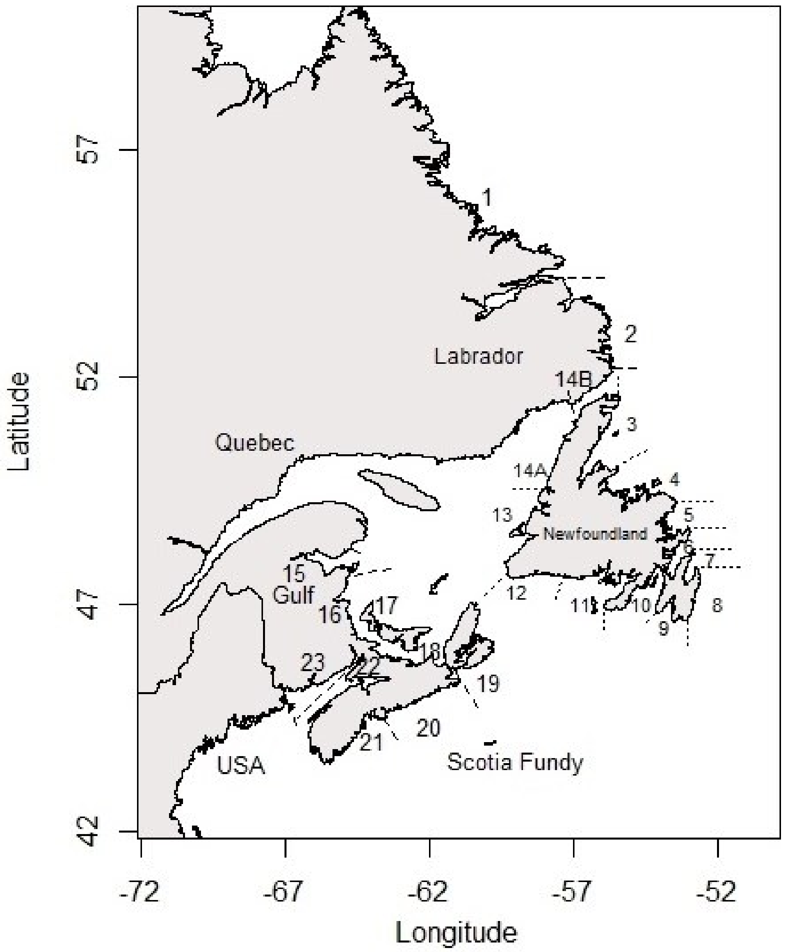

Figure 7.3-20. Salmon Fishing Areas 1 to 23 in Atlantic Canada.

### *Southern Gulf of St. Lawrence*

Striped Bass is widely distributed throughout estuaries and coastal waters of the sGSL, from the northern tip of Cape Breton Island, NS, in the east to the north shore of the Gaspé Peninsula, QC, in the west. The sGSL population is considered the northernmost extant spawning population of its distribution. Estimates of the mature Striped Bass population in the sGSL are obtained using movement patterns of individually tagged fish in combination with counts and biological characteristics collected from fish caught in Gaspereau trapnets in the Miramichi River (DFO 2021i). Figure 7.3-21 shows the estimated adult spawner abundance of Striped Bass in the Northwest Miramichi Estuary.

- Estimated spawner abundance of Striped Bass peaked in 2017 at over 900,000, then decreased to around 300,000 in 2018 and 2019 (DFO 2021i). There were fewer than 5,000 spawners in the late 1990s, but abundance increased to over 200,000 in 2011 after several management interventions: the closure of the commercial fishery in 1996 and the closure of the recreational fishery and the suspension of Indigenous Food, Social, and Ceremonial fishery allocations in 2000.

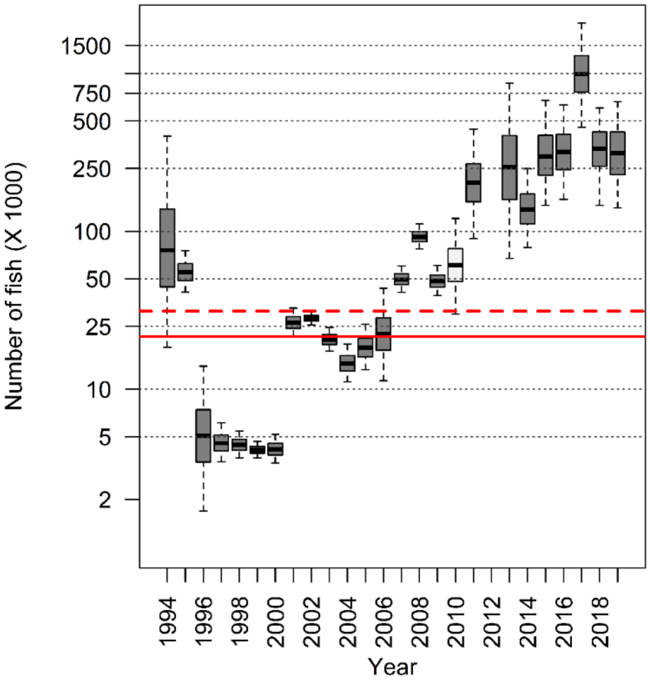

Figure 7.3-21. Estimated abundance (log scale) of adult Striped Bass spawners in the Northwest Miramichi estuary from 1994 to2019 (DFO 2020e). The estimate for 2010 (unshaded interquartile box) is an underestimate and 2012 is missing due to the earlier timing of the spawning events prior to onset of monitoring activities (Douglas and Chaput 2011; DFO 2013). Boxplot rectangles represent the interquartile range (25th to 75th percentile), solid black line is the median, and whiskers show the 5th to 95th percentile ranges. The solid and dashed horizontal lines show the limit and target recovery objectives, respectively (DFO 2006).

Estimates of total returns of large salmon and small salmon are developed for each SFA and overall for the sGSL based on estimates from monitored rivers (DFO 2020f). All rivers flowing into the sGSL are included in SFAs 15 to 18; this includes rivers from New Brunswick, Nova Scotia, and Prince Edward Island (Fig. 7.3-22). Figure 7.3-23 shows estimates of total returns of large and small salmon for SFAs 15 to 18 and to the overall Gulf Region.

- From 2007 to 2019 (approximately two generations), overall abundances of large salmon in the sGSL declined by 27%.
    - Abundances declined by 5% in SFA 17 and SFA 18, 28% in SFA 16, and 46% in SFA 15.
- From 2007 to 2019, overall abundance of small salmon in the sGSL declined by 63%.
    - Abundances declined by 30% in SFA 18, 32% in SFA 17, 51% in SFA 15, and 9% in SFA 16.

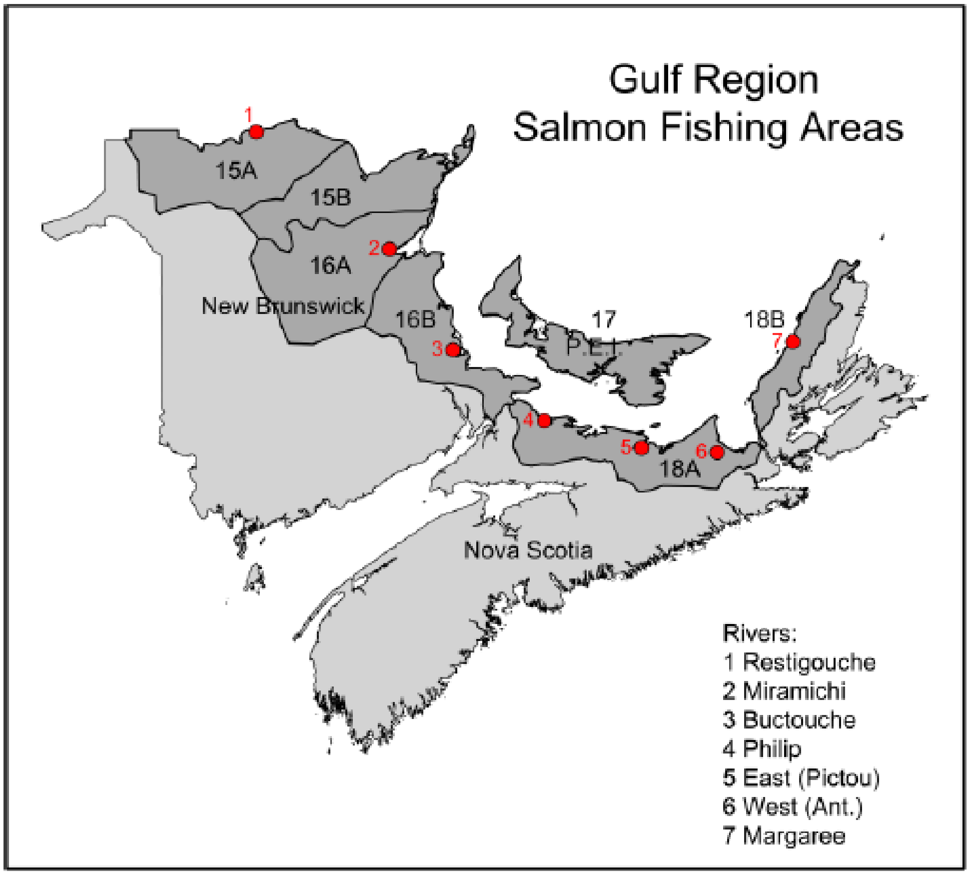

Figure 7.3-22. Salmon Fishing Areas 15 to 18 and monitored rivers in the southern Gulf of St. Lawrence (DFO 2020f).

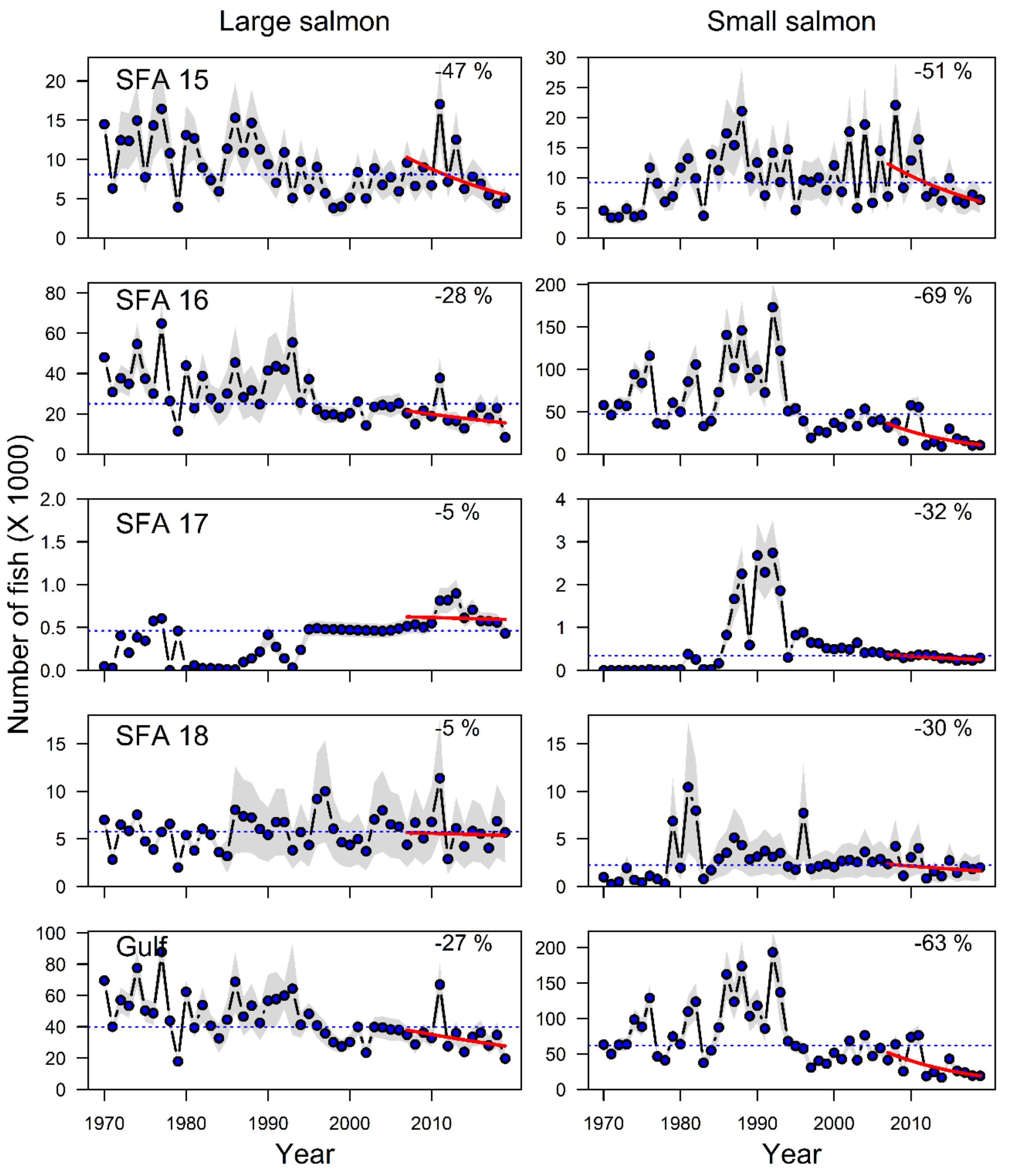

Figure 7.3-23. Estimates (medians are coloured symbols, shaded contours are the 5th to 95th percentile ranges) of total returns of large salmon (left panels) and small salmon (right panels) to each of SFA 15, 16, 17, and 18, and to Gulf Region rivers overall, 1970–2019. The trend line (exponential regression, red line) in the median of the estimated returns over the 2007–2019 period and the corresponding percent change over that period are shown in each panel. The light horizontal dashed line in each panel is the median abundance for the time series 1970–2019. See Figure 7.3-22 for map of SFAs and locations for each monitored river.

### *Scotian Shelf*

Evaluation of the status of Atlantic Salmon in the SS is based on abundance monitoring for a number of index populations (Fig. 7.3-24). For most index populations where adult returns are available, status is evaluated using a comparison of the estimated egg deposition, which is calculated from the estimated abundance and biological characteristics of salmon stocks, relative to a reference point known as the conservation egg requirement (CER). Conservation requirements for many of the rivers in the SS bioregion are reported in O'Connell et al. (1997). COSEWIC uses four designatable units (DUs) to evaluate population status: Eastern Cape Breton, Southern Upland, Inner Bay of Fundy, and Outer Bay of Fundy.

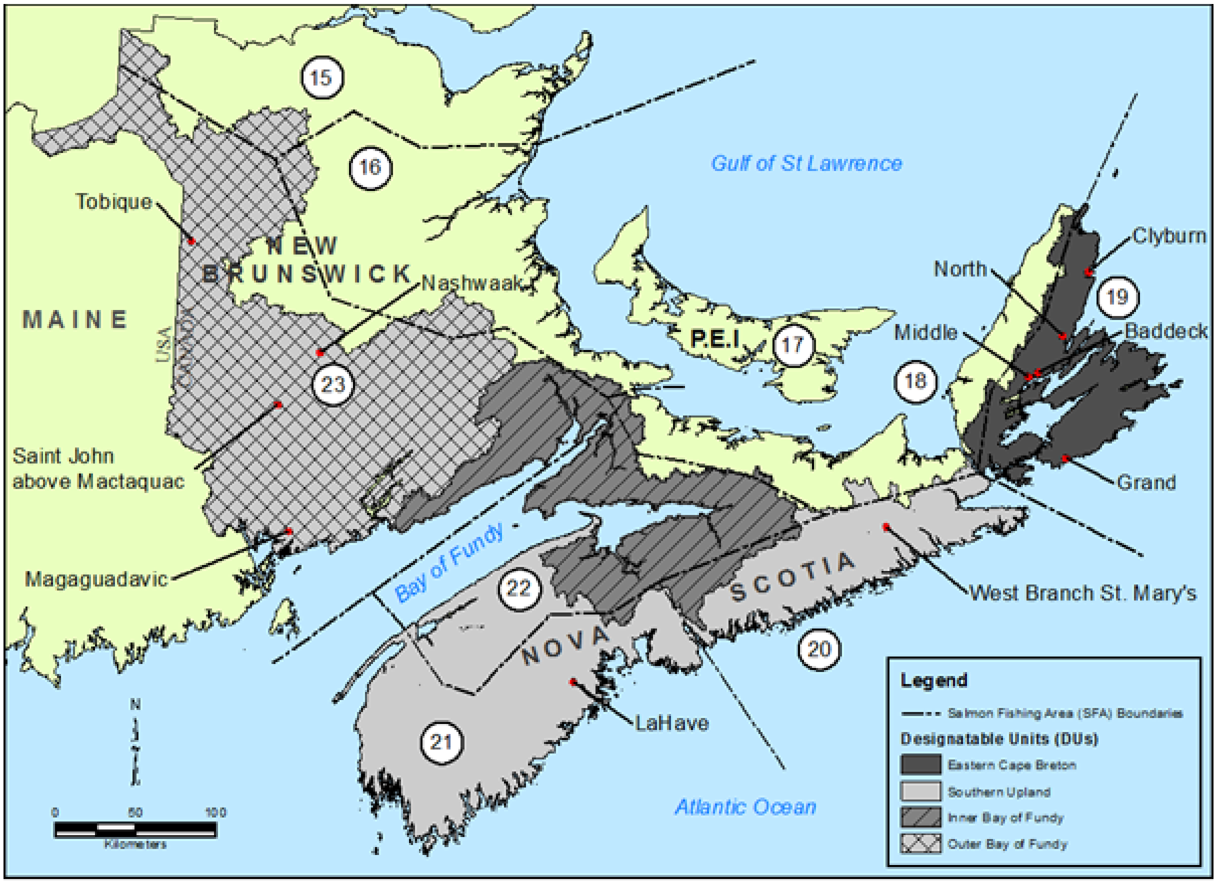

Figure 7.3-24. Locations of rivers where monitoring for Atlantic Salmon predominately occurred. Salmon Fishing Area (SFA) numbers are in white circles. Designatable Units (DUs) adapted from NS Secondary Watershed Layer (NS Dept. of Environment) and NB Watershed Level 1 Layer (NB Dept. of Natural Resources).

In the Eastern Cape Breton DU, estimated total number of spawners from dive surveys and percent of the CER for Middle River and Baddeck River are shown in Figure 7.3-25 and for North River in Figure 7.3-26.

In the Southern Upland DU, adult salmon assessments are currently focused on the LaHave River, the index population for SFA 21. Counts of adult salmon on LaHave River have occurred at Morgan Falls since 1970, where a fishway was constructed on the late-1960s to bypass a large natural obstacle that limited access to the upper watershed. DFO began a stocking program to enhance the developing salmon run. Figure 7.3-27 shows total returning adults and estimated egg deposition for the LaHave River.

There are three index rivers in the Outer Bay of Fundy DU: the Saint John River (above the Mactaquac Dam), the Nashwaak River (below the Mactaquac Dam), and the Magaguadavic River. The population above the Mactaquac Dam is supported in part by a smolt-to-adult supplementation program. Figure 7.3-29 shows returns above the Mactaquac Dam—the total number of fish collected at the fishway at the dam and passed above the dam—and returns to the Nashwaak River, estimated by mark–recapture methodology from fish collected at a counting fence. Figure 7.3-30 shows estimated smolt-to-adult return rates for both rivers.

In the Inner Bay of Fundy DU, returns to the Gaspereau River are the total number of fish collected at the fishway at the White Rock dam and passed above the dam. Big Salmon River returns are estimated by snorkel and seine survey. Figure 7.3-31 shows returns of adults for the Gaspereau and Big Salmon Rivers.

- In the Eastern Cape Breton DU in 2020, index populations of Middle River and Baddeck River had 70% and 64% of CER, respectively; North River was assessed at 102% of CER. Trends in CER on all three rivers have been relatively stable over the past two decades of monitoring. There is uncertainty in the status of populations in non-index rivers, which has been inferred from recreational catch data and limited electrofishing data (Levy and Gibson 2014).
- In the Southern Upland DU, egg deposition was estimated at 4% of CER in 2019 and recent adult salmon returns were among the lowest on record. Smolt-to-adult return rates for 1SW and 2SW salmon were less than 1% from 2013 to 2016, the lowest values on record.
- In the Outer Bay of Fundy DU in 2019, assessment values were 4% of the CER for the Saint John River and 5% of the CER for the Nashwaak River. Returning adults in the Saint John and Nashwaak Rivers were at historically low numbers, having declined considerably since the 1990s (DFO 2020g). Return rates for the Saint John River were 0.25% in 2017, having declined steadily since the 1980s. Return rates for the Nashwaak River were 3% in 2016 but have varied over time. In the Magaguadavic River, only one MSW adult salmon returned in 2019.
- In the Inner Bay of Fundy DU in 2019, index populations in the Gaspereau River and Big Salmon River saw few adults returning to spawn—22 and 33 fish respectively. Annual egg deposition on the Gaspereau River above White Rock Dam was less than 10% of the CER in 15 of 17 years assessed. Egg depositions in the Big Salmon River were below 10% of the CER in 15 of 17 years assessed and averaged ~5% from 2000 to 2016 (Jones et al. 2020). Smolt-to-adult return rates have been less than 1% from 2007 to 2017 for the Gaspereau River and from 2001 to 2018 for the Big Salmon River.

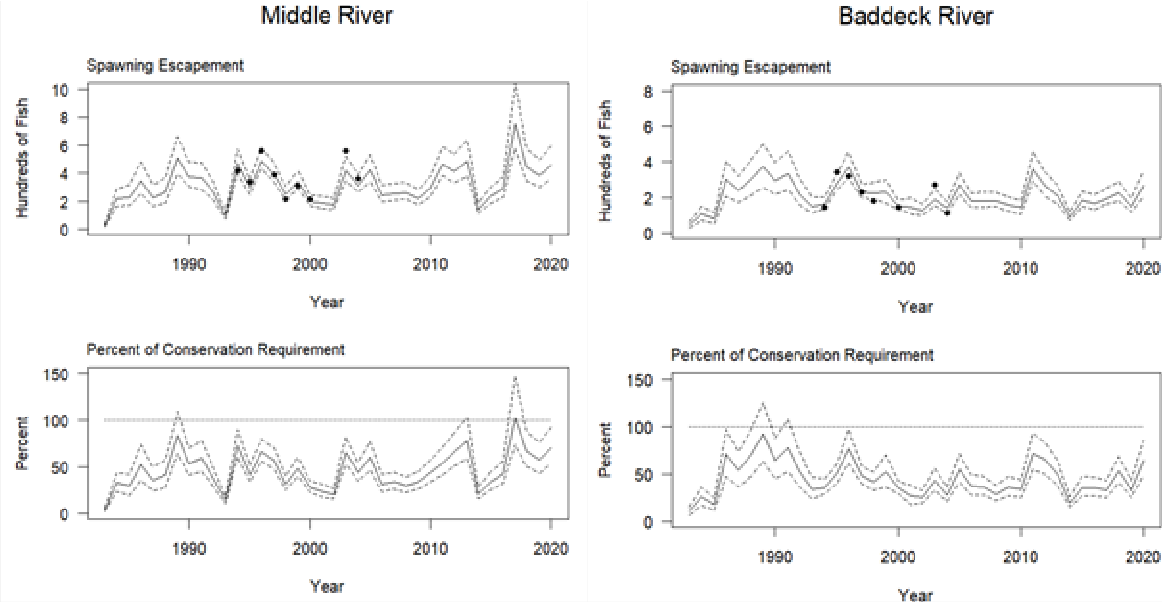

Figure 7.3-25. Estimated total number of Atlantic Salmon spawners (top) and percent of the CER (bottom) for Middle River (left) and Baddeck River (right) from 1983 to 2020. Model fits derived from two methods are shown. Solid lines show maximum likelihood estimates of annual abundance. Dashed lines show Bayesian 90% credible interval for annual abundance estimates. Points in the top graphs are population estimates obtained by mark–recapture during dive surveys. Horizontal dashed lines in the bottom graphs indicate 100% of the CER for each river. See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2021j).

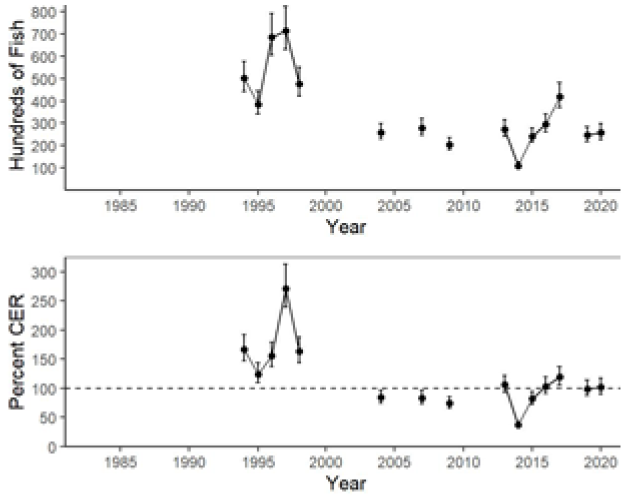

Figure 7.3-26. Estimated spawning escapement (top) and percent of the CER (bottom) of Atlantic Salmon returning to North River as derived from dive surveys. Horizontal dashed line indicates 100% of the CER. Error bars represent 95% confidence intervals. See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2021j).

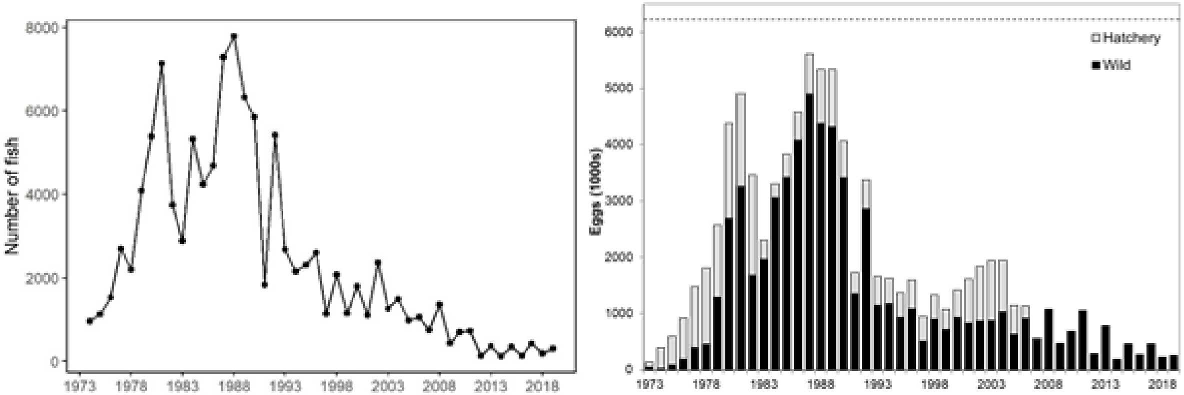

Figure 7.3-27. Population metrics for Atlantic Salmon on the LaHave River from 1973 to 2019. Total returning adults (numbers of fish) are based on returns to the Morgan Falls fishway adjusted for total watershed area (left) and estimated egg deposition (thousands) relative to the conservation egg requirement (CER) (right) by wild-origin and hatchery-origin salmon above Morgan Falls. The horizontal dashed line in the right panel indicates the CER above the Morgan Falls fishway. Hatchery-origin smolts were no longer introduced after 2005. See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2020g).

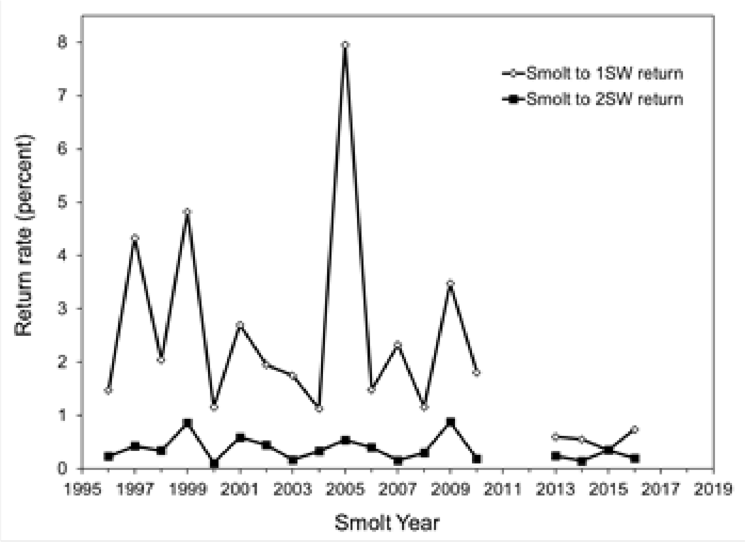

Figure 7.3-28. Estimated smolt-to-adult return rates for 1SW and 2SW salmon on the LaHave River (above Morgan Falls). See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2020g).

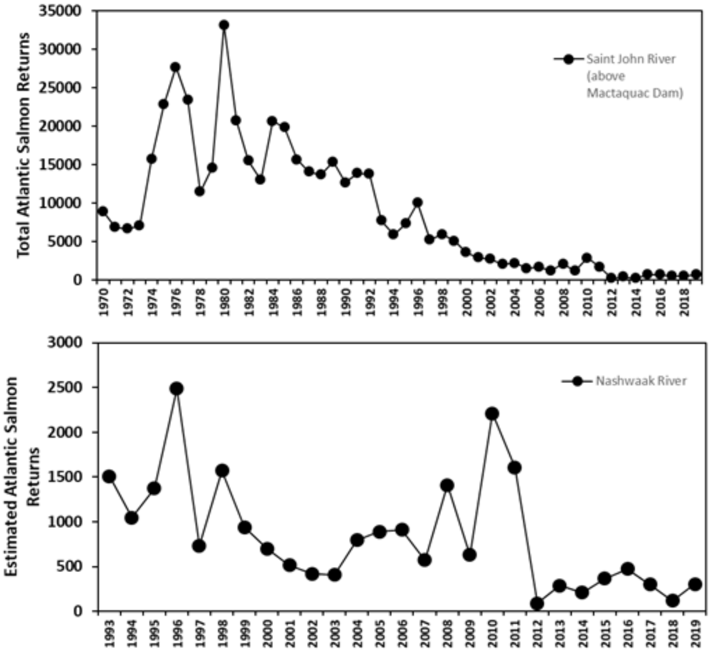

Figure 7.3-29. Returning adult Atlantic Salmon on the Saint John River above the Mactaquac Dam (upper) and below the Mactaquac Dam (lower; Nashwaak River). See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2020g).

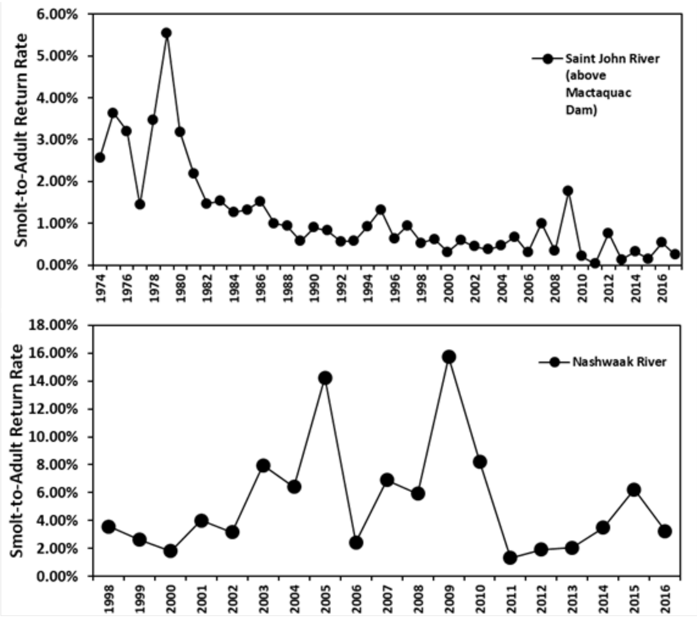

Figure 7.3-30. Estimated smolt-to-adult return rates for one-sea-winter (1SW) and maiden two-sea-winter (2SW) Salmon (combined) on the Saint John River above the Mactaquac Dam (upper) and below the Mactaquac Dam (lower; Nashwaak River). See Figure 7.3-24 for map of SFAs and locations of monitored rivers. Adapted from DFO (2020g).

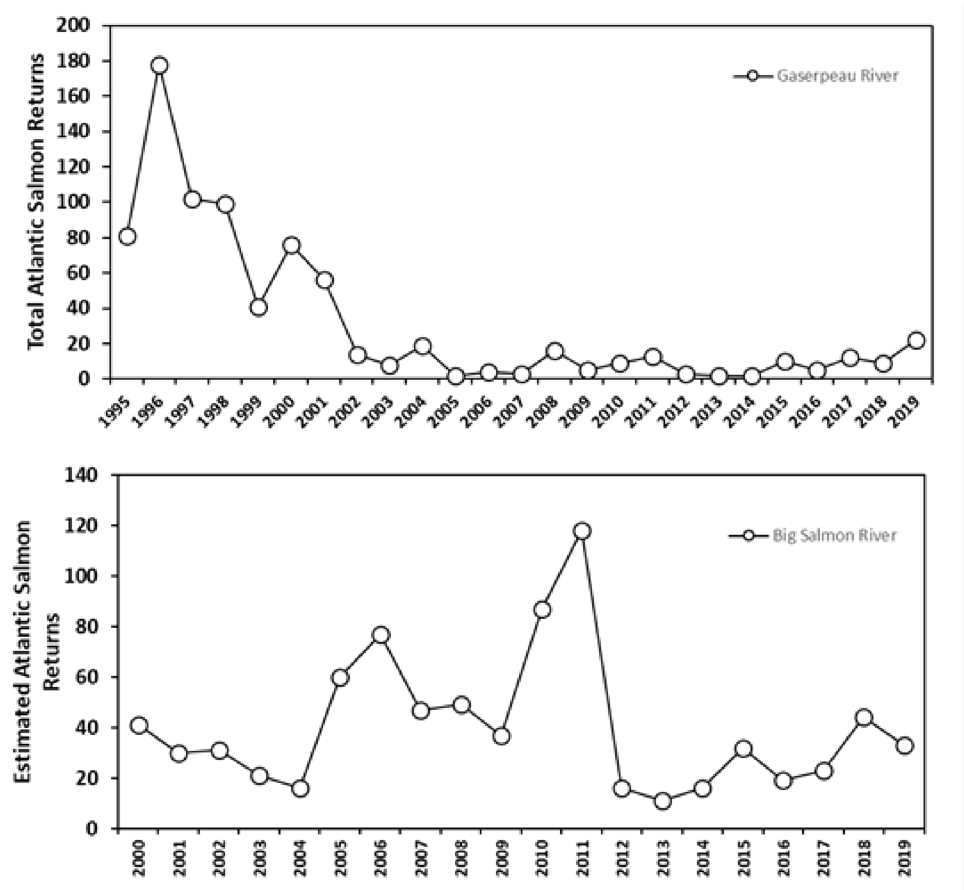

Figure 7.3-31. Returning adult Atlantic Salmon on the Gaspereau River (upper) and Big Salmon River (lower). See Figure 7.3-24 for map of SFAs and locations of monitored rivers.

### *Newfoundland and Labrador Shelves*

There are 15 Atlantic Salmon SFAs (1–14B) on the NLS (Fig. 7.3-32). Within these areas there are 407 rivers known to contain Atlantic Salmon. Returns of Atlantic Salmon are assessed for 18 rivers; populations are not assessed in SFAs 3, 6, 7, 8, 12 and 14B. The abundance of smolts migrating to sea is assessed annually on five rivers in Newfoundland (Fig. 7.3-32). Marine survival is estimated annually by comparing smolt abundance in one year to the number of returning small salmon the following year.

Estimates of total Atlantic Salmon returns are derived for each monitored river and incorporate estimates of recreational harvest and mortality from catch-and-release angling (assumed to be 10% of the estimated number of released fish per river). For each monitored river, total returns are compared to the previous generation average (previous five and six years for Newfoundland and Labrador rivers, respectively). Figure 7.3-33 shows total returns from monitored rivers in Newfoundland (SFAs 4, 5, 9, 10, 11, 13, and 14A) and Figure 7.3-34 shows the same from Labrador (SFAs 1 and 2). Figure 7.3-35 highlights marine survival rates of smolt-to-adult small salmon for select rivers in Newfoundland (in SFAs 4, 9, 11, and 14A).

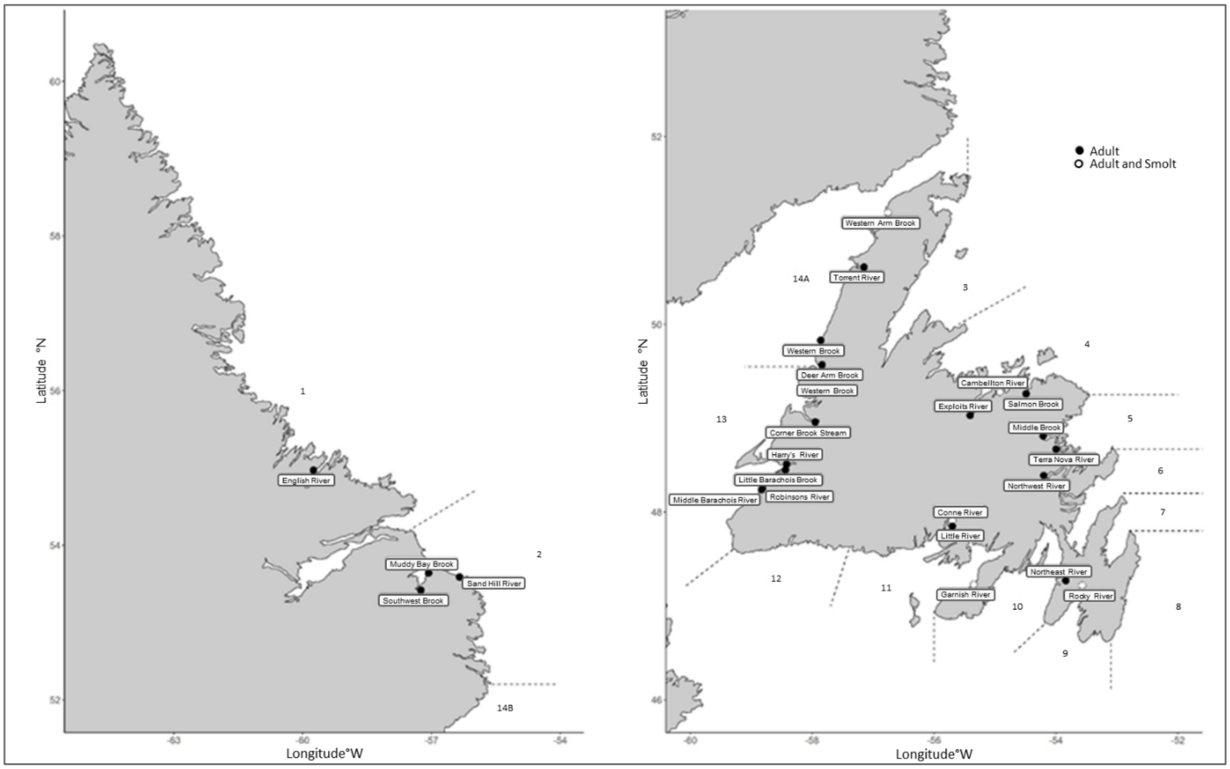

Figure 7.3-32. Monitored Atlantic Salmon rivers in Newfoundland (right panel) and Labrador (left panel) in recent years. Salmon Fishing Area boundaries are designated by dashed lines. Rivers in Newfoundland represented by white circles indicate populations where both returning adult salmon and out-migrating salmon smolts are counted annually.

- The abundance of large Atlantic Salmon in 2019 was below the previous generation average on 61% of monitored rivers with sufficient time series data (DFO 2020d).
- In 2019, total returns were lower than the previous generation average in 14 rivers, higher in 3 rivers, and similar (less than 10% difference) in 1 river. Significant declines in salmon returns in 2019 are consistent with declining trends for assessed rivers on the south coast of Newfoundland (SFA 11) in recent decades.
    - In SFA 1, English River total returns declined by >50% compared to the previous generation average. Total returns had more than doubled in recent years from 1999, when initial monitoring began.
    - In SFA 2, total returns to three monitored rivers had no clear trend over the past 20 years.
    - In SFA 4, Exploits River, one of the largest salmon rivers in Newfoundland, has been on a declining trajectory since 2010 with total returns reaching the lowest observed number since 2000 in 2019. Marine survival estimates on Campbellton River continued to fluctuate between 4% and 10% annually.
    - In SFA 5, record high returns were observed on Terra Nova River and Northwest River on the northeast coast of Newfoundland.
    - In SFA 9, marine survival estimates in Rocky River reached a record high of just over 14% in 2019, outside of the typical range of 2% to 6%.
    - In SFA 11, total salmon returns to Conne River and Little River were the lowest in each time series in 2019. Poor marine survival is a likely factor behind the

observed declines in in these rivers as estimates were <3% for Garnish River in 2018 and 2019 and <1% for Conne River in 2018.

- In SFA 14A, Western Arm Brook total returns in 2019 were the lowest observed since 1992 and marine survival estimates continued to fluctuate between 4% and 10% annually.

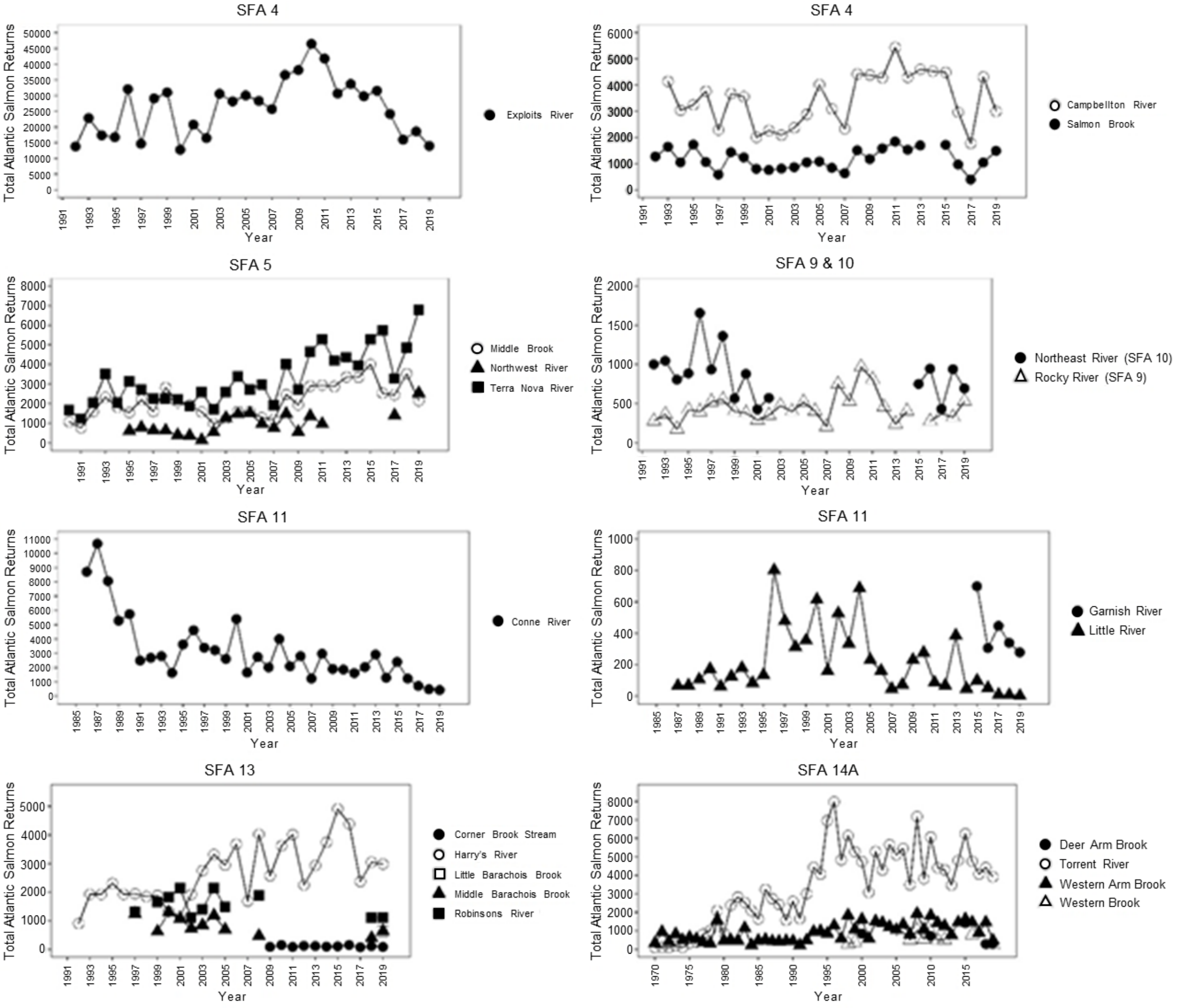

Figure 7.3-33. Total Atlantic Salmon returns to monitored rivers in the northeast coast (SFA 4 and 5), south coast (SFA 9, 10, and 11), west coast (SFA 13) and northern peninsula (SFA 14A) of Newfoundland until 2019. See Figure 7.3-32 for map of SFAs and locations for each monitored river.

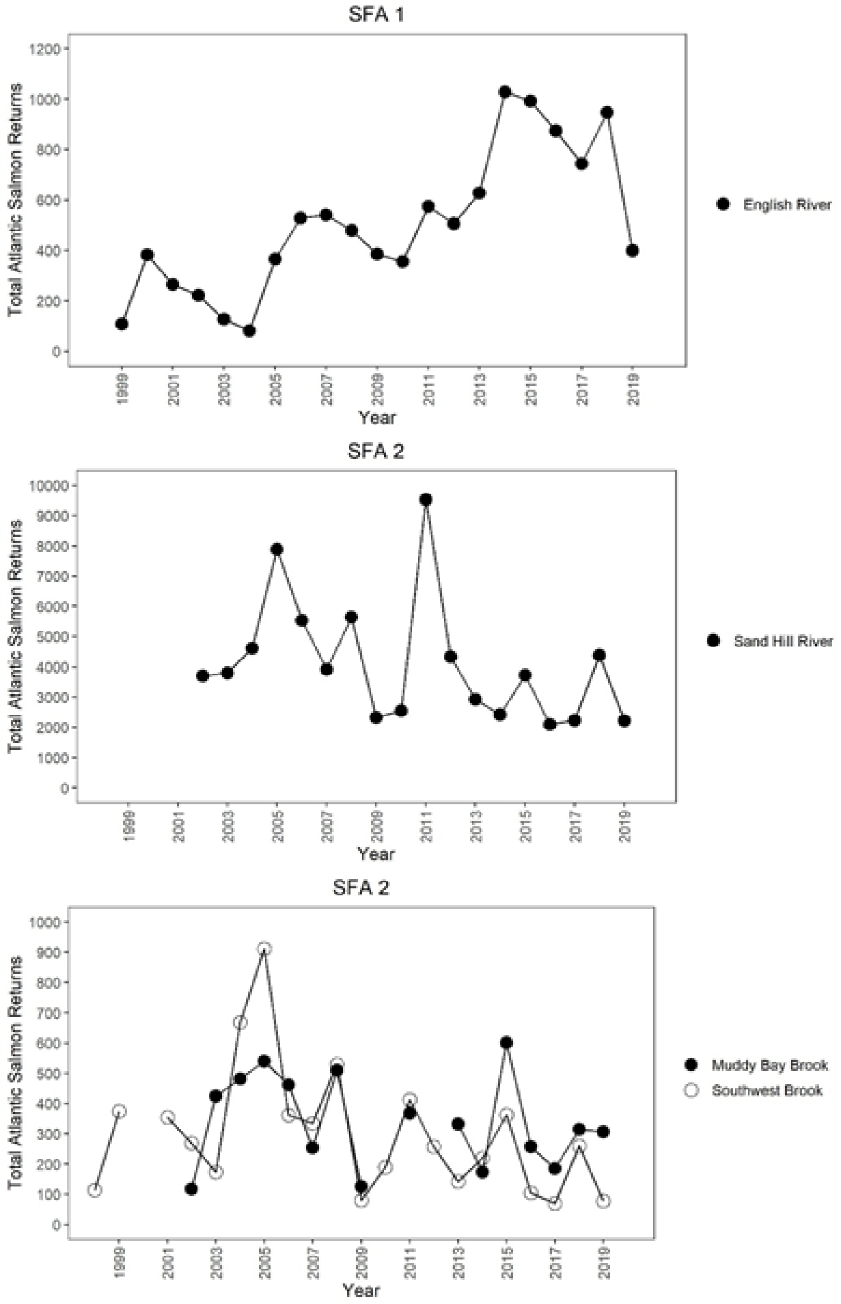

Figure 7.3-34: Total Atlantic Salmon returns to monitored rivers in northern Labrador (SFA 1) and southern Labrador (SFA 2) from 1999 to 2019. No Atlantic Salmon rivers in SFA 14B have been monitored in recent decades. See Figure 7.3-32 for map of SFAs and locations for each monitored river.

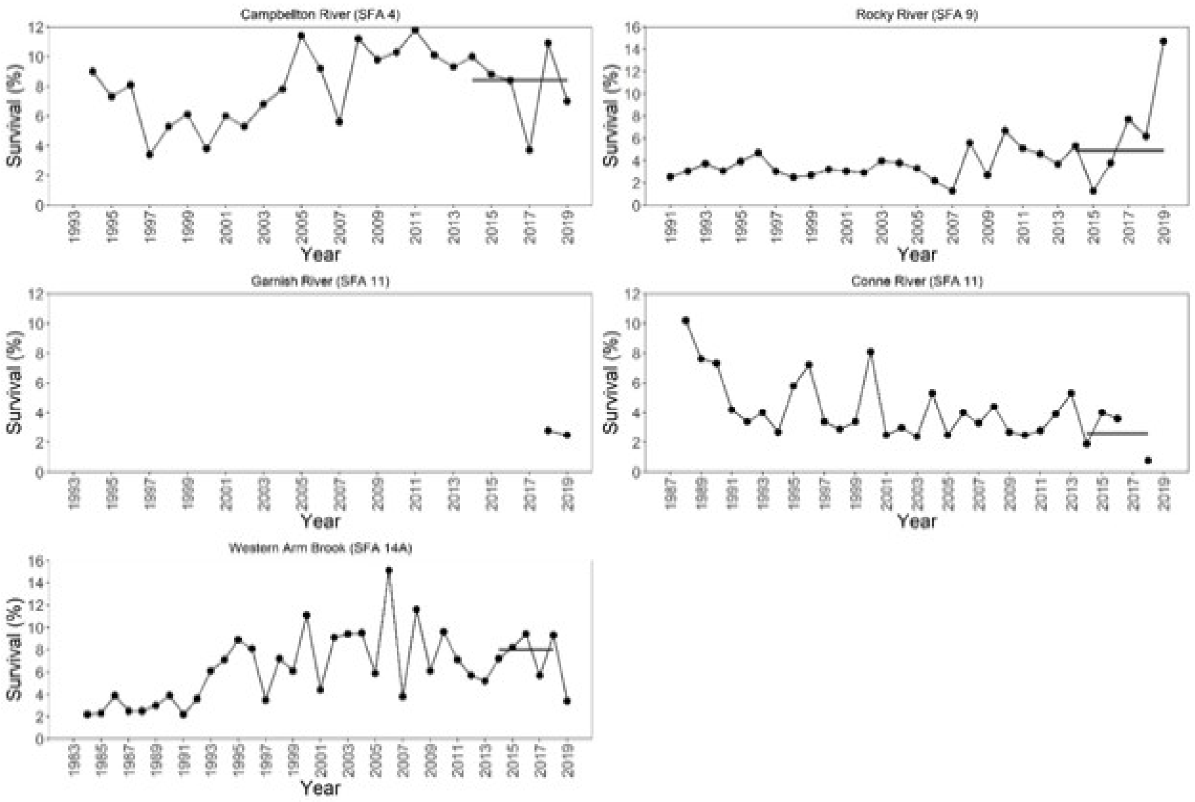

Figure 7.3-35: Marine survival rates of smolt-to-adult small Atlantic Salmon for monitored Newfoundland rivers. Year reflects the adult return year (migrating smolt left the river the year before). The commercial salmon moratorium was implemented for Newfoundland in 1992. Marine survival estimates prior to 1992 have not been adjusted for marine exploitation during the commercial salmon fishery and therefore represent survival of salmon back to the river. Horizontal dashed lines illustrate the previous generation average (2014–2018). See Figure 7.3-32 for map of SFAs and locations for each monitored river.

## 7.4 Drivers of Change

Although fish communities show some common trends and similar drivers across bioregions, there are also many important differences. Several changes in fish species that were documented are thought to be brought about by a long history of overfishing, a rapidly changing environment, and changing trophic interactions, but many of these trends remain to be fully explained.

In the sGSL, high natural mortality of commercial-sized individuals has been found to be the most important factor limiting the recovery of many demersal fish including the once abundant Atlantic Cod (Swain et al. 2011; Swain and Benoît 2015), White Hake (Swain et al. 2016), and American Plaice (Ricard et al. 2016). Predation by rapidly growing populations of Grey Seal (*Halichoerus grypus*) population in the sGSL has been shown to be an important source of natural mortality for these demersal species (Benoît et al. 2011; Hammill et al. 2014; Swain et al. 2015; Neuenhoff et al 2019; Rossi et al. 2021). In contrast, spring- and fall-spawning Atlantic Herring continue to decline. These trends are largely driven by increasing natural mortality on large herring, which is correlated to the rise of its key predators: Atlantic Bluefin Tuna (*Thunnus thynnus*) and Grey Seals (Turcotte et al. 2021).

The primary threat to Thorny, Winter, and Smooth skates in the sGSL is elevated natural mortality (COSEWIC 2012a, b, 2015; Swain and Benoît 2015; Swain et al. 2019). In addition to a decline in abundance, Thorny and Winter skates have also experienced severe constriction in range size due to predation avoidance (Swain et al. 2015, 2019). Historically, bycatch of Smooth and Winter skates (COSEWIC 2012a, 2015) may have played a role in the initial declines; however, fishing mortality on these stocks is currently quite low (Swain and Benoît 2015). Fishing mortality is also an identified threat to Thorny Skate due to both a directed fishery and bycatch (COSEWIC 2012b).

In the nGSL from the late 1990s to 2010, the abundance of demersal fish in offshore waters improved little since their collapse in the early 1990s. This collapse has been attributed to overfishing and unfavourable environmental conditions (cold period), particularly for Atlantic Cod and redfish (Chouinard and Fréchet 1994; Dutil et al. 1999; Dutil and Lambert 2000), and with the exception of Greenland Halibut, a cold-water species associated with deep channels (Bourdages et al. 2017; DFO 2018c, d). The increase in redfish in the nGSL is concomitant with an increase in deep water temperature (Galbraith et al. 2021).

The fish communities on the NLS were historically dominated by demersal fish, particularly Atlantic Cod. By the late 1980s and early 1990s, changing environmental conditions, combined with overfishing of many important fish stocks, resulted in major declines in commercial and non-commercial demersal and pelagic fish species (Koen-Alonso et al. 2010, 2013; Dawe et al. 2012; Buren et al. 2014; Dempsey et al. 2017; Pedersen et al. 2017). While the effects of this abrupt shift in community structure were felt throughout the bioregion, changes were observed earlier and were more dramatic on the Newfoundland Shelf than in Southern Newfoundland.

In recent years, demersal fish stock dynamics have been linked to bottom-up processes, whereby the success of demersal fish stocks appears related to the availability of food, and starvation-induced mortality may be limiting the recovery of some stocks (Regular et al. 2022). Capelin is a primary food source (Koen-Alonso et al. 2021) as well as other pelagic fish species, so declines in pelagic fish may influence the recovery of demersal species. Specifically, the continued low abundance of Capelin may be inhibiting the production of other finfish (e.g. Atlantic Cod). The important ecological role of forage fish under a changing climate is discussed further in the previous *State of the Atlantic Ocean Synthesis Report* (Koen-Alonso et al. 2018).

Fisheries continue to be identified as the primary threat to shark populations in the North Atlantic; however recent management actions have reduced the potential for shark mortality from Canadian fisheries (see Section 11.2.4 in *Multiple Stressors*). There is still a strong need to understand bycatch, particularly given the diversity of fisheries that intercept sharks.

Diadromous fish face varying threats in both freshwater and marine environments across SFAs/watersheds and marine bioregions, resulting in varying degrees of negative impacts on Atlantic Canadian populations. For Atlantic Salmon, marine threats include impacts due to ecosystem change, salmonid aquaculture, and diseases/parasites, and poor survival during their marine migration due to high predation and/or low prey availability. Impacts from hydroelectric dams, illegal fishing/poaching, and lack of adequate fish passages are threats of high concern in the freshwater environment (see Section 11.2.2 in *Multiple Stressors*). Threats to Striped Bass include overfishing, habitat loss and degradation, pollution, and migration barriers (COSEWIC 2012c). Climate change will likely exacerbate these pressures on diadromous fish populations.

## 7.5 Research Gaps and Uncertainties

Conservation and management of the fish communities in Atlantic Canadian waters requires monitoring (including in the coastal zone) as well as research aimed to understand the impacts of a complex set of ecosystem drivers such as fishing, climate, and species interdependencies.

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 community. To compensate, scientific surveys (e.g. multi-species trawl surveys, 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 using bottom trawl gear. For diadromous species, such as Atlantic Salmon, populations in assessed rivers may be unique and not necessarily representative of other rivers within an SFA.

There is an ongoing need to understand the ecosystem-level effects of commercial fisheries to minimize harm to non-target species (i.e. bycatch). The majority of information on non-target catches comes from at-sea observer programs, which typically sample a low number of trips in a given fishery (Gavaris et al. 2010). For species that are captured sporadically and/or from a wide variety of fisheries (e.g. pelagic sharks), there is a need to address data limitations caused by variable observer coverage rates to estimate total fishing mortality (Bowlby et al. 2020). Several additional reporting mechanisms have been implemented, including mandatory logbooks for species listed on Schedule 1 of the *Species at Risk Act* (e.g. wolffishes, sea turtles) as well as supplementary discard logbooks for select fleets. However, integration of these information sources with data from established dockside monitoring and at-sea observer programs continues to be challenging. Future research is needed to quantify fleetwide bycatch of particular species from a particular fishery and to aggregate these estimates to understand total fishing mortality from all fleets.

It is currently unknown how large-scale environmental shifts associated with ocean acidification or climate change will influence shark distributions and/or abundance in Canadian waters (Bowlby et al. 2020). There is the expectation that the distribution of several semi-tropical species will shift northward and become more prevalent in Canada. The impact of other systematic changes to marine ecosystems such as underwater noise or marine pollution are unknown.

## 7.6 Technical Notes

In 2018, the SS and Bay of Fundy research vessel survey coverage was limited to the west (4X), while most of the survey area, including all of 4V, most of 4W, and depths <183 m in 5Zj, were not sampled due to mechanical issues with the research vessel. This was the first time since the survey began in 1970 that there was insufficient coverage of 4VW. Similarly, spatial coverage in 2021 was also limited to the west (4X) due to mechanical issues with the research vessel.

In 2021, sampling was conducted onboard the new Canadian Coast Guard research vessel, CCGS *Capt. Jacques Cartier*, using different trawl gear referred to as the NEST (Northeast Fisheries Science Center Ecosystem Survey Trawl). Biomass estimates based on catches from the CCGS *Capt. Jacques Cartier* are not comparable to the time series until comparative fishing between the new and old vessel/gear combinations is completed and conversion factors are calculated for each species. Comparative fishing is expected to be completed in 2022.

Pelagic sharks are not intercepted by DFO's annual multi-species bottom trawl surveys. Historically, indices of abundance were generated from catch-per-unit effort (CPUE) data. This involved dividing total catch weight of a species by a standardized metric of fishing effort. Now that pelagic shark catches are almost exclusively bycatch, CPUE is not as reliable and new methods to estimate incidental catch from at-sea observer data are required.

For Atlantic Salmon in the Maritimes Region, the river-specific CER is based on an egg deposition of 2.4 eggs/m$^2$ multiplied by the amount of accessible fluvial rearing habitat that is of suitable gradient. An egg deposition of 2.4 eggs/m$^2$ is considered to be a Limit Reference Point in the context of DFO's PA framework (DFO 2012; Gibson and Claytor 2013) for the DFO Maritimes Region.

In the NLS, juvenile Atlantic Salmon predominantly remain in freshwater habitats for three to four years in Newfoundland and four to five years in Labrador prior to undergoing smoltification and migrating to sea as smolts (DFO 2020d). For the majority of rivers in Newfoundland (SFAs 3–12 and 14A), the small (<63 cm fork length) adult salmon population is predominantly grilse (one-sea-winter, 1SW salmon), that have spent one year at sea before returning to spawn for the first time. The large (63 cm+) adult salmon population in Newfoundland rivers is composed mainly of repeat-spawning grilse which are either consecutive or alternate spawning fish. In contrast, populations in Labrador (SFAs 1, 2 and 14B) and southwestern Newfoundland (SFA 13) consist of important large salmon components that contain maiden fish that have spent two (two-sea-winter, 2SW) or more years (multi-sea-winter, MSW) at sea before returning to spawn.

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# 8. MARINE MAMMALS

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## 8.1 Key Messages

- Climate change is impacting marine mammals either directly through changes in the habitat or indirectly through changes in the abundance and/or distribution of their prey.
  - Changes in sea ice conditions are impacting pup survival for ice-obligatory pinniped species such as harp seals.
  - North Atlantic Right Whales are following changes in the relative abundance of their prey, whose distributions have shifted as a result of recent ocean warming.
- After a period of stability, the Northwest Atlantic Harp Seal population appears to be increasing in recent years. However, unusual sea ice conditions during the pupping season in 2017 led to the lowest pup production estimates in decades.
- The Grey Seal population in Canadian waters continues to increase but the rate of increase is slowing. The 2021 survey showed a decrease in the estimated number of pups born on Sable Island for the first time since the 1960s.
- Between 2010 and 2019 the Northern Bottlenose Whale population has increased on the eastern Scotian Shelf. This is reversal of a long term declining trend for the population observed between 1990 and 2004.
- Since 2015, a substantial proportion of the known population of North Atlantic Right Whales currently summers in the Gulf of St. Lawrence. Population estimates for this endangered species continue to decline.
- Recent efforts to identify important habitats for large baleen whales (Blue, Minke, Fin, Humpback, and North Atlantic Right whales) and the Northern Bottlenose Whale, have provided insight into their occurrence and foraging activities throughout Atlantic Canadian waters. The identification of these priority areas allows for the effective monitoring of cetacean species and aids in efforts to mitigate the impacts of human activities on their population recovery.

## 8.2 Background

Marine mammals are important predators throughout the Northwest Atlantic (NWA) due to either their large population size (i.e. Harp Seals *Pagophilus groenlandicus*) or high biomass (i.e. large whales). They are important consumers of a range of trophic levels from zooplankton (e.g. Blue Whales *Balaenoptera musculus)* to fish (e.g. seals, dolphins, Humpback Whales *Megaptera novaeangliae*) and provide an important top-down influence on the structure and function of the ecosystems of which they are a part. Given their positions near the top of their respective food chains, marine mammals can also act as ecosystem sentinels as changes in their abundance, distribution and diet can signal changes occurring in the ecosystem that may be harder to detect otherwise (Moore 2008; DFO 2012; Hazen et al. 2019).

The NWA marine mammal community is represented by a mix of Arctic and temperate pinnipeds (7 species) and cetaceans (23 species) with the relative species composition varying regionally and seasonally. A few additional species are vagrants that occur rarely in the NWA. Some species (e.g. Grey Seals *Halichoerus grypus*, Harbour Seals *Phoca vitulina*, St. Lawrence Estuary Beluga Whales *Delphinapterus leucas*, Northern Bottlenose Whales *Hyperoodon ampullatus*) spend the entire year within the NWA while other species (e.g. North Atlantic Right Whale *Eubalaena glacialis*, Fin Whale *Balaenoptera physalus*, Humpback Whale) migrate from more southerly areas to take advantage of summer foraging opportunities. Seasonal migrants to the NWA generally return to southern areas during the winter for breeding, although an unknown proportion of the population may remain in the NWA year round for some species (e.g. Common Minke Whale *Balaenoptera acutorostrata*, Blue Whale, Humpback Whale; Stenson et al. 2018).

Our understanding of distribution, habitat use, population size and trends in abundance varies significantly by species. Some species are harvested commercially (e.g. Harp Seals, Hooded Seals *Cystophora cristata*, Grey Seals), taken for subsistence (e.g. Beluga Whales, Ringed Seals *Pusa hispida*, Bearded Seals *Erignathus barbatus*) or are SARA-listed species of high public interest (e.g. North Atlantic Right Whale, St. Lawrence Estuary Beluga Whale, Northern Bottlenose Whale). As a result, there is a greater research effort and more data available for these species.

The ability to effectively monitor marine mammals and mitigate the impacts of human activities requires knowledge of population abundance and trends as well as frequently-used habitats, their periods of use, and the features of those habitats that make them suitable for vital functions such as socializing, breeding, or foraging (Hoenner et al. 2012). In Atlantic Canadian waters, abundance and trend information have been updated for Harp Seals, Grey Seals, Northern Bottlenose Whales, and North Atlantic Right Whales.

Recent habitat studies have included the broad scale identification of important habitats for Blue Whales (Section 11.3.2 in *Habitat*), an analysis of the habitat use of large baleen whales in the St. Lawrence Estuary (Section 11.3.3 in *Habitat*), an assessment of the connectivity among previously identified important habitats for Northern Bottlenose Whales (Section 11.5.1 in *Scientific Innovations to Advance Ecosystem Understanding*), and the identification of suitable foraging habitat for North Atlantic Right Whales in the Gulf of St. Lawrence (Section 11.4.1 in *Predator–Prey Interactions*).

## 8.3 Status and Trends

Abundance estimates are available for approximately half of the pinniped (3/7) and cetacean species (13/23) in the NWA, although most of these data are outdated. Fourteen of the marine mammals in the NWA have either unknown or approximate population sizes and nine species have population estimates that are more than ten years old. Information on population trends are not available for approximately three-quarters of the marine mammal species in the NWA. Abundance and population trends of recently updated pinnipeds and cetaceans are presented below with reference to bioregions as applicable: Gulf of St. Lawrence (GSL), Scotian Shelf (SS), and Newfoundland and Labrador Shelves (NLS). A summary of most recent assessment data for all marine mammals is included in Appendix 1.

### *8.3.1 Pinnipeds*

The NWA population of Harp Seals summers in the Arctic and then migrates south along the Canadian continental shelf in the autumn to overwinter and reproduce in the GSL and off northeastern Newfoundland on medium-to-thick first year pack ice (Stenson and Hammill 2014). Total population size is estimated using pup counts obtained from aerial surveys of the whelping patches combined with data on reproductive rates, anthropogenic removals, and mortality due to poor ice conditions (Hammill et al. 2021).

- The estimated population size of Harp Seals was 6.8 million (95% CI: 5.8–8.0) individuals based on the 2017 survey (Hammill et al. 2021).
- The population has been increasing in recent years likely due to higher reproductive rates and lower removals (Hammill et al. 2021) after being relatively stable since the mid-1990s.
- The 2017 pup production estimate was the lowest since 1994 (Stenson et al. 2020a); continued decreases in sea ice in this area may affect the future population trend (see Section 11.1.3 in *Climate Change*).

Grey Seals form a single population that is divided into two herds in Canada based on the location of breeding sites: SS (Sable Island and Coastal Nova Scotia) and GSL (Gulf). The Grey Seal population size is estimated using pup counts obtained from aerial photographic and visual surveys of all known breeding colonies combined with data on reproductive rates, survival rates and anthropogenic removals. The Grey Seal population in the NWA has been increasing since the 1960s. The Grey Seal Sable Island breeding colony is the largest in the world and currently accounts for 78% of the total pup production in Canadian waters (DFO 2022).

- Grey Seals have an estimated population size of 366,400 (95% CI: 317,800–409,400) in Canadian waters based on a 2021 survey (DFO 2022).
- The population continues to increase in the NWA but the rate of increase is slowing.
- There was a decrease in the estimated number of pups born on Sable Island for the first time since the 1960s (DFO 2022).

### *8.3.2 Cetaceans*

The abundance of the SS population of Northern Bottlenose Whales has been estimated using mark–recapture modelling from photo-identification surveys for the last 30 years (Gowans et al. 2000; Whitehead and Wimmer 2005; O'Brien and Whitehead 2013).

- In 2019, the SS population of Northern Bottlenose Whales was estimated to be between 179 (95% CI: 68–253) and 181 (95% CI: 80–260) (Feyrer 2021), an increase from an estimated 143 (95% CI: 129–156) individuals in 2011 (O'Brien and Whitehead 2013).
- Between 2010 and 2019, the Northern Bottlenose Whale population has increased on the eastern SS. This is reversal of a long term declining trend for the population observed between 1990 and 2004 (Feyrer 2021).

North Atlantic Right Whales have been observed in the GSL for many decades. However, based on opportunistic sightings, their numbers in the GSL were considered to be low and dispersed (DFO 2019). Since 2015, observations of North Atlantic Right Whales in the GSL between May and November have increased substantially. Results from recent systematic aerial surveys and visual surveillance efforts indicate that a substantial proportion of the known population currently summers in the GSL. Although the majority of North Atlantic Right Whales in Atlantic Canadian waters are observed in the GSL, there have been a limited number of sightings and acoustic detections in other areas of Atlantic Canada, including in the Bay of Fundy, on the SS and along the coast of Newfoundland.

- In 2019, North Atlantic Right Whales had a total estimated population of 356 (95% CI: 345–369) (Crowe et al. 2021; Pettis et al. 2021). In 2019, 128 different individual whales were identified in Atlantic Canadian waters, and mark–recapture results provided an abundance estimate of 137 (95% CI: 135–147; Pettis et al. 2021). Systematic aerial surveys estimated a maximum abundance of 204 (95% CI: 96–433) individuals in the GSL in 2019 (Simard et al. 2019; DFO 2020).

## 8.4 Drivers of Change

The NWA is undergoing a period of tremendous change with modifications occurring in temperature, ocean circulation, pH balance, sea ice cover, and sea level (see Chapter 2 *Physical Oceanography*). The most rapid environmental changes due to climate change globally are occurring in adjoining Arctic areas (McCarthy et al. 2001; Walsh 2008; IPCC 2014; Comiso and Hall 2014; Haug et al. 2017). The potential impacts of climate change on marine mammals, particularly in Arctic and subarctic areas, have been reviewed by a number of authors (e.g. Kovacs and Lydersen 2008; Laidre et al. 2008, 2015; Kovacs et al. 2011; Stenson et al. 2020b). The impacts may be either through direct changes in the habitat required for vital functions (e.g. pupping on pack ice) or indirect through changes in the abundance and/or distribution of prey. For some species the associated changes may be positive. For example, the expectation that a warmer (more ice-free) ocean will lead to higher primary productivity could result in higher concentrations of zooplankton, to the benefit of some marine mammals such as Blue Whales. However, the loss of prey species that depend on sea ice, especially Arctic Cod (*Boreogadus saida*) and amphipods, could have negative impacts on other marine mammals that feed extensively upon them, such as Harp Seals (Eamer et al. 2013). The negative consequences of climate change are likely to be most severe for ice-dependent species, particularly those that inhabit the southern ice edge of the rapidly changing Arctic pack ice (Walsh 2008). Recent research on Harp Seals (see Section 11.1.3 in *Climate Change*) and North Atlantic Right Whales (see Section 11.4.1 in *Predator–Prey Interactions*) illustrate some of the impacts climate change is having on marine mammals in the NWA.

Marine mammals in the NWA face a variety of additional stressors and threats. Human-induced stressors include (but are not limited to) shipping (i.e. noise, vessel strikes, disruption of pupping and nursing platforms of ice-breeding seals), oil and gas exploration and production (i.e. noise, contaminants, disruption of movements and foraging behaviour), commercial fishing (i.e. bycatch, entanglements, competition for prey), military activities (i.e. noise, disturbance), tourism (i.e. noise, disturbance), and pollution (i.e. contaminants) (Heide-Jørgensen et al. 2013; Wilson et al. 2017; Bröker et al. 2019; Sharp et al. 2019; Nelms et al. 2021).

## 8.5 Research Gaps and Uncertainties

Numerous gaps in our knowledge of marine mammals remain despite decades of research effort. Abundance data are not available for almost half of the pinniped and cetacean populations that regularly occur in the NWA and the majority of species have unknown trends in their population sizes. Even when trend data are available, given that most marine mammals range over large distances, it can be difficult to determine if changes are due to changes in population abundance or distribution.

There are also considerable knowledge gaps related to species' distributions and habitat use. Habitat modelling, based either on biotelemetry data or sightings from vessel or aerial surveys, has greatly increased our understanding of where some of these species are found throughout the NWA and what habitat characteristics might influence their distribution (e.g. Andersen et al. 2013; Lesage et al. 2016; Gomez et al. 2017, 2020). However, in most cases, the variables used in habitat models are selected based on available data (e.g. water depth, chlorophyll *a*) rather than on what might directly underpin a species' distribution such as the relative concentration of prey or predators.

The response of marine mammals to ecosystem change and the additional effect of anthropogenic stressors on individuals, populations, and communities remains unclear. This is especially concerning as uncertainties remain in future changes in sea-surface temperature, ocean currents, and prey distribution (Shackell et al. 2015; Alexander et al. 2020; Gonçalves Neto et al. 2021). Ecosystems are complex and multiple stressors may act independently, cumulatively, and/or sequentially but this remains an important knowledge gap.

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# 9. SEA TURTLES

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## 9.1 Key Messages

- There is uncertainty in the population size estimates for sea turtles in Atlantic Canadian waters. Only a small fraction of the habitat used by sea turtles is surveyed, and detection probabilities for sea turtles are not established. Instead, indices for subpopulations of sea turtles are estimated from nesting data surveyed on tropical beaches outside of Canada.
- Leatherback Sea Turtles in the Northwest Atlantic subpopulation are in decline. A regional decline in nest abundance has been observed since the 1990s in long term datasets.
- The Loggerhead Sea Turtle Northwest Atlantic subpopulation had declines in the past, but the current trajectory is unclear with findings of both increasing and decreasing estimates in long term studies.
- Bycatch remains the largest threat to sea turtles in Canadian waters. Fixed gear fisheries pose an entanglement risk to leatherbacks, and pelagic longline fisheries interact with both Leatherback and Loggerhead sea turtles.

## 9.2 Background

Four species of sea turtles occur in Atlantic Canadian waters: Leatherback Sea Turtles (*Dermochelys coriacea*), and three cheloniid sea turtles: Loggerhead Sea Turtle (*Caretta caretta*), Green Sea Turtle (*Chelonia mydas*), and Kemp's Ridley Sea Turtle (*Lepidochelys kempii*). Sea turtles are broadly distributed through offshore and coastal waters in Atlantic Canada. They mainly use Atlantic Canadian waters in the summer and fall from around June to October.

Leatherbacks are the most regularly observed sea turtle in Atlantic Canada, in part due to their large size and coastal foraging behaviour. They have been documented in the Canadian Exclusive Economic zone in all months of the year but are mainly present in the summer and fall. Adult and subadult leatherbacks undertake annual migrations from reproductive areas in the tropical and subtropical Atlantic to northern foraging habitat, which includes coastal waters of Atlantic Canada (James et al. 2007).

Cheloniid sea turtles found in Atlantic Canadian waters are typically juvenile. Loggerheads are the most common cheloniid, encountered by pelagic longline fisheries (Brazner and McMillan 2008; DFO 2017). Green and Kemp's Ridley sea turtles are less frequently encountered, with the majority of sightings as cold-stunned, stranded turtles found along the coast in the late autumn and winter months (James et al. 2004; McAlpine et al. 2007).

## 9.3 Status and Trends

Distributions of sea turtles in Atlantic Canada have largely been delineated by satellite telemetry (DFO 2020c), bycatch records, and opportunistic sightings. These data are used as a proxy to identify foraging habitat for sea turtles as it is not possible to directly measure prey abundance (DFO 2020c). Using telemetry data to identify important habitat can introduce biases due to tagging location and potential tagging effects.

Sea turtles are broadly distributed through pelagic and coastal waters, but they neither nest nor come ashore for any other purpose in Atlantic Canadian waters. Together, these factors make it difficult to assess population size in Atlantic Canada, and as such, population estimates have not been derived for any sea turtle species in Canadian waters. Instead, the status and trends provided are for subpopulations of sea turtles as observed from nesting beaches in the Northwest Atlantic (NWA). Status and trends are also summarized in Appendix 1. Nesting data are used as an index for estimating trends at site, stock, and regional levels. Only a subset of these subpopulations use Atlantic Canadian waters for foraging. Although estimating trends with nesting data facilitates collection of long-term nesting datasets, variations in female breeding behaviour exist (e.g. clutch frequency, nest location, and remigration intervals). Variability in breeding periodicity and monitoring protocols can lead to overestimating sea turtle population size (Casale and Ceriani 2020).

Leatherbacks using Atlantic Canadian waters belong to the NWA subpopulation, which has been the subject of several population analyses. The NWA Leatherback Working Group (NALWG 2018) assessed Leatherback Sea Turtle nesting data from 23 sites in 14 different countries throughout the NWA. The analyzed data represented nesting sites with at least 10 years of data employing consistent nest count methods. The National Marine Fisheries Service (NMFS) and the US Fish and Wildlife Service (USFWS) conducted a status review of Leatherback Sea Turtles in 2020. This review included the evaluation of extinction risk for seven different leatherback turtle Distinct Population Segments (DPS), including the NWA.

- For Leatherback Sea Turtles of the NWA population, negative trends of nest abundance were observed across three time frames (1990–2018, 1998–2018, and 2008–2018) and at site, stock, and regional levels (NALWG 2018). The most recent decline was 60% from past estimates to 2017 (NALWG 2018).
- The amount of time it would take for nesting females in the NWA DPS to decline by 50% was estimated to occur in less than one generation (8–28 years) (NMFS and USFWS 2020).
- Leatherback Sea Turtles are listed as Endangered under Canada's *Species at Risk Act* (COSEWIC 2012) and the United States *Endangered Species Act* (Tiwari et al. 2013). The IUCN assessed the NWA subpopulation as Endangered (NALWG 2019).

Loggerhead Sea Turtles found in Atlantic Canada belong to the NWA subpopulation. In 2017, the IUCN analyzed the NWA subpopulation, assessing 86 nesting sites with over 10 years of annual nest counts, using an estimated generation time of 45 years (Ceriani and Meylan 2017).

- The NWA subpopulation of Loggerhead Sea Turtles was estimated to have increased relative to its size three generations ago, laying approximately 83,717 nests annually (Ceriani and Meylan 2017). However, earlier analyses of an 18-year time series of nesting on index beaches in Florida indicated a net decrease in nesting from 1989 to 2006, which is indicative of a decline in the number of nesting females in the population (Witherington et al. 2009).

- Loggerhead Sea Turtles are listed as Endangered under Canada's *Species at Risk Act* (COSEWIC 2010), and the NWA DPS is listed as Threatened under the United States *Endangered Species Act* (Conant et al. 2009). The IUCN assessed the Northwest Atlantic subpopulation as Least Concern (Ceriani and Meylan 2017).
- Globally, the IUCN lists Green Sea Turtles as Endangered (Seminoff et al. 2004) and Kemp's Ridley Sea Turtles as Critically Endangered (Wibbels and Bevan 2019). Neither species are listed as Endangered under Canada's *Species at Risk Act*.

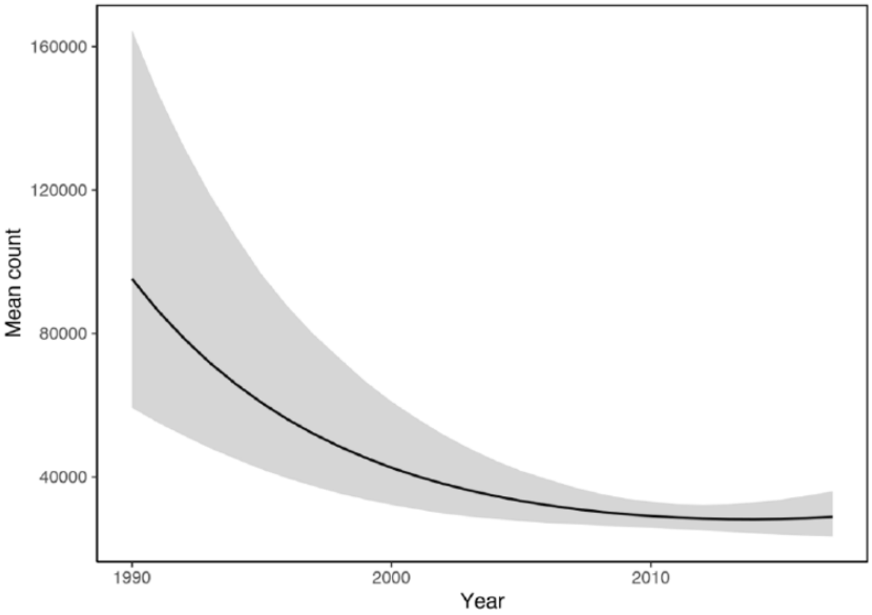

Figure 9.3-1. Annual geometric mean change in Leatherback Sea Turtle nest counts for 1990–2017. Line indicates geometric annual mean trend weighted by relative site-level abundance and shaded area is 95% credible intervals. Reproduced with permission from NALWG (2018).

## 9.4 Drivers of Change

Threat assessments have recently been conducted for both Leatherback Sea Turtles (DFO 2020a) and Loggerhead Sea Turtles (DFO 2017) in Atlantic Canada. These assessments identified and categorized threats both in Atlantic Canadian waters and throughout the broader NWA.

Bycatch in fixed gear fisheries remains a principal threat to Leatherback Sea Turtles (Hamelin et al. 2017; DFO 2020a, b). From 2001 to 2017, 205 Leatherback Sea Turtle interactions with fixed gear fisheries were publicly reported. Most turtles were released alive and 15.1% were reported dead in gear (Hamelin et al. 2017). However, these numbers are likely a gross underestimate of true interaction rates (Hamelin et al. 2017) and may not be reflective of true mortality rates due to public reporting biases and unknown rates of post-release mortality. Bycatch of Leatherback Sea Turtles has also been documented by fishery observers (DFO 2020b) and mandated fisher logbook records (Hurtubise et al. 2020) in pelagic longline fisheries targeting swordfish (*Xiphias gladius*) and tunas. For Loggerhead Sea Turtles, the only anthropogenic cause of mortality documented in Atlantic Canadian waters is bycatch in pelagic longline fisheries targeting swordfish and tunas (DFO 2010, 2017), which catch an estimated 1,200 individuals annually (DFO 2010). Although turtle–fishery interactions regularly occur in Atlantic Canada, these interactions are not expected to significantly contribute to the decline of NWA subpopulation. Ongoing or emerging monitoring programs incorporating fisheries observers, electronic monitoring, and biotelemetry would be beneficial for quantifying the threat of incidental capture of sea turtles in Atlantic Canada.

Other threats to both Leatherback and Loggerhead sea turtles include marine pollution such as plastic, oil, and contaminants. Leatherbacks rely on a diet of gelatinous zooplankton and consume an average of 20 kg of jellyfish a day while in Atlantic Canadian waters (Wallace et al. 2018). As visual predators (Wallace et al. 2015), they have a high likelihood of ingesting floating plastics in the water column (DFO 2020a). In Atlantic Canada, 40% of Leatherback Sea Turtles necropsied from 2004 to 2018 had evidence of plastic in their digestive tracts, although ingestion of such material was not identified as the cause of death (DFO 2020b). Additional studies are required to understand the prominence of this threat in Atlantic Canada. Threats such as vessel strikes, underwater noise, and entanglement in ghost fishing gear are also known to occur in areas where sea turtles are seasonally present. However, the corresponding risk to sea turtles in Atlantic Canada remains unknown (DFO 2017, 2020a).

The extent to which climate change may impact sea turtle populations in Atlantic Canada is not well defined. The time sea turtles spend foraging in Atlantic Canadian waters is seasonal and related to foraging habitat quality (DFO 2020c). Changes in ocean temperature may influence prey species and, therefore, the temporal and spatial distributions of sea turtles. Active monitoring is required to evaluate any changes in sea turtle spatial or temporal distribution. Such shifts may result in new patterns of turtle–fishery interactions and increased frequency of incidental capture and accompanying injury or mortality.

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# 10. SEABIRDS

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## 10.1 Key Messages

- Overall, populations of breeding seabirds in Atlantic Canada have increased by an average of 4% relative to 1970.
- Since 1970, Great Black-backed Gull, Herring Gull, Arctic Tern, and Northern Fulmar have shown declines of more than 50%. Razorbill, Northern Gannet, Double-crested Cormorant, and Atlantic Puffin have shown increases of more than 100%.
- Threats to seabirds in Atlantic Canadian waters include changing ocean conditions, overfishing, and various forms of pollution, which impact both breeding birds and non-breeding visitors.

## 10.2 Background

Seabirds are a visible component of the marine landscape. As top predators that sample the marine environment, seabirds can be used as indicators of the general health of the ocean environment, including changes in the abundance and distribution of the forage fish on which they rely (Davoren and Montevecchi 2003; Gaston et al. 2003). See Section 11.4.2 on *Predator–Prey Interactions* for a discussion of the response of seabird populations to reduced forage fish.

Canadian seabirds include species that nest in Canada and species that nest elsewhere but rely on our waters to feed. The eastern Canadian coastlines bordering the Atlantic Ocean and Gulf of St. Lawrence are host to approximately 10 million breeding seabirds of over 16 different species from five families: Alcidea (auks), Phalacrocoracidae (cormorants), Sulidae (gannets), Hydrobatidae (storm-petrels), and Laridae (gulls and terns). Colonies of national and international importance for several species are found in this region. Northern Fulmars (*Fulmarus glacialis*) of the family Procellariidae occur in Atlantic Canada but nest in the remote Arctic. The productive waters of the Northwest Atlantic (NWA) also attract millions of non-breeding seabirds, with many migrants coming from the Arctic, Europe, and even the Southern hemisphere.

## 10.3 Status and Trends

Population trends for nesting seabirds are estimated using nest counts or counts of individuals attending colonies. Species that are widely dispersed, nest in low-density colonies, or only use the area during the non-breeding season (e.g. Arctic-nesting populations of Thick-billed Murres *Uria lomvia*) are more difficult to monitor. For these reasons, 62% of Canadian seabirds have unknown trends (NABCI Canada 2019). Of the species with accessible colonies, multiple survey methods are used to generate estimates of colony-level abundance, tailored to each species and its habitat. Methods include visual and photographic surveys of colonies for cliff-nesting species, counts of active nests or individuals by aircraft for ground-nesting species, and surveys of plots to estimate burrow density and occupancy for burrow-nesting species. Expert opinion is used to determine if historical data are reliable enough (i.e. from complete and replicable surveys) to include.

The overall population trend for nesting seabirds is informed by 16 seabird species with available data spanning from 2020 to the 1970s, when systematic population monitoring of the major seabird colonies in Canada's NWA began. Status and trends are also summarized in Appendix 1.

- A global assessment shows that 55 of the 58 seabird species that use Canadian waters are of conservation concern (Panjabi et al. 2019).
- The breeding population of all seabirds in eastern Canada has increased by an average of 4% since the 1970s (NABCI Canada 2019; Fig. 10.3-1).
- Surface-feeding species, such as Herring Gulls (*Larus argentatus*), Great Black-backed Gulls (*Larus marinus*), Arctic Terns (*Sterna paradisaea*), and Northern Fulmars, have shown moderate to large population declines since the early 1990s and have declined by more than 50% since 1970.
- Leach's Storm-Petrels (*Oceanodroma leucorhoa*) have declined since the mid-1980s, including at the world's largest colony on Baccalieu Island, NL (Wilhelm et al. 2020).
- Razorbills (*Alca torda*) and Atlantic Puffins (*Fratercula arctica*) have had moderate to large population growth since the 1990s and have increased by more than 100% since 1970, along with Northern Gannet (*Morus bassanus*) and Double-crested Cormorant (*Phalacrocorax auratus*).
- Since 2010, Northern Gannet populations have stabilized or started showing signs of decline (Rail et al. 2021).

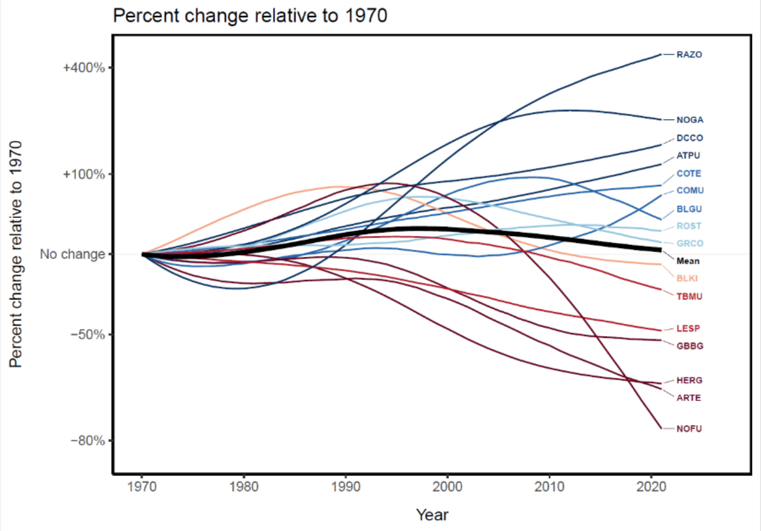

Figure 10.3-1. Average percent change in population size since 1970 of 16 breeding seabird species in Atlantic Canada for which data are available. See Section 10.6 *Technical Notes* for a description of graphic methods. See Table 10.3-1 for species codes and rates of change. The colours correspond to the change categories shown in Figure 10.3-2.

Table 10.3-1. Estimated change in Atlantic seabird populations since 1970. Lower (LCI) and upper credible intervals (UCI) represent 2.5 and 97.5 quantiles of Bayesian posterior distribution. See Section 10.6 *Technical Notes* for explanation of calculations.

| **Species Name** | **Nesting** | **Status** | **% Change since 1970** | **LCI** | **UCI** |
|---|---|---|---|---|---|
| Razorbill (RAZO) | cliff, ground | Large increase | +462 | +168 | +1105 |
| Northern Gannet (NOGA) | cliff | Large increase | +219 | +173 | +277 |
| Double-crested Cormorant (DCCO) | cliff, ground | Large increase | +157 | +22 | +435 |
| Atlantic Puffin (ATPU) | cliff, burrow | Large increase | +118 | +13 | +304 |
| Common Tern (COTE) | ground | Moderate increase | +81 | -25 | +306 |
| Common Murre (COMU) | cliff, ground | Moderate increase | +67 | -81 | +2171 |
| Black Guillemot (BLGU) | cliff | Moderate increase | +35 | -79 | +486 |
| Roseate Tern (ROST) | ground | Small increase | +22 | -97 | +2626 |
| Great Cormorant (GRCO) | cliff | Small increase | +11 | -55 | +170 |
| Black-legged Kittiwake (BLKI) | cliff | Small decrease | -8 | -66 | +106 |
| Thick-billed Murre (TBMU) | cliff | Moderate decrease | -26 | -85 | +219 |
| Leach’s Storm-Petrel (LESP) | burrow | Moderate decrease | -48 | -81 | +55 |
| Great Black-backed Gull (GBBG) | cliff, ground | Large decrease | -52 | -90 | +98 |
| Herring Gull (HERG) | cliff, ground | Large decrease | -67 | -84 | -39 |
| Arctic Tern (ARTE) | ground | Large decrease | -69 | -95 | +99 |
| Northern Fulmar (NOFU) | cliff, ground | Large decrease | -78 | -95 | -13 |
| **Mean** | **-** | **Small increase** | **+4** | **-27** | **+49** |

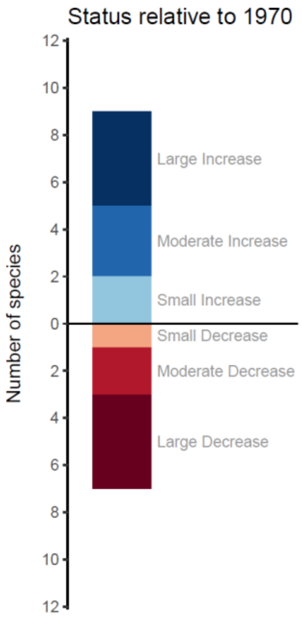

Figure 10.3-2. The number of seabird species that have experienced large (>100%), moderate (33–100%), or small (0–33%) increases or large (>50%), moderate (25–50%), or small (0–25%) decreases in population size in Atlantic Canada since 1970.

## 10.4 Drivers of Change

In Canada, direct threats to seabirds include fisheries bycatch, oil pollution, climate change, light pollution, disease, and plastic pollution (NABCI Canada 2019). Globally, the main threats to seabirds are invasive species, bycatch in fisheries, and climate change, which is leading to more frequent storms, rising sea levels, and declining prey availability due to changing ocean conditions (Dias et al. 2019). Oil spills, overfishing, hunting/trapping, and disturbance are also identified as important threats to global seabird populations (Dias et al. 2019).

In Atlantic Canada, direct threats caused by fisheries bycatch and chronic oil pollution have been greatly reduced in Atlantic Canada since 2000 (Wilhelm et al. 2009; Lucas et al. 2012, Regular et al. 2013). Unfortunately, many species are now being affected by changes in the availability of high quality prey fish due to a combination of climate change impacts and over-fishing (Fitzsimmons et al. 2017; d'Entremont et al. 2022). Climate change also increases the occurrence of extreme weather conditions, such as hurricane-force winds (Diamond et al. 2020). Other threats known to be prevalent in the coastal and marine environments that may be negatively impacting populations, include light pollution, which can attract birds to collide with human-made structures (Gjerdrum et al. 2021; Wilhelm et al. 2021), and plastic pollution, which many seabirds ingest and may affect their survival or reproduction (Krug et al. 2021). Leach's Storm-Petrel faces many threats in its breeding area, including predation by large gulls and mammals, colliding or stranding at onshore and offshore industrial sites due to light attraction, and other threats while at sea (e.g. plastic pollution, changes in ocean conditions due to climate change) in both Canadian and international waters (COSEWIC 2020).

In 2022, the incursion and subsequent transmission of the highly pathogenic avian influenza (HPAI) virus at many breeding colonies resulted in high mortality rates for some species. Large numbers of mortalities were reported in Northern Gannets, Common Murres (*Uria aalge*), and Common Eiders (*Somateria mollissima*). HPAI outbreaks were observed at 5 of 6 Northern Gannet colonies in 2022, but the population level impact has yet to be assessed.

Increases in Razorbills and Atlantic Puffins may be due to fewer gillnets in inshore waters since the closure of the large-scale groundfish fishery in 1992, which was formerly responsible for high levels of seabird mortality (Gaston et al. 2009; Regular et al. 2013).

Northern Gannet populations have grown since the 1970s following the ban of the insecticide DDT, which had caused lower hatching success due to eggshell thinning (Elliott et al. 1988; Chardine et al. 2013). The more recent stable/declining trend is linked to poor breeding success, which is thought to be the result of reduced availability of their key prey, Atlantic Mackerel *Scomber scombrus* (see Section 11.4.2 in *Predator–Prey Interactions*), due to warming ocean temperatures and overfishing (Van Beveren et al. 2020; Montevecchi et al. 2021; d'Entremont et al. 2022).

Declines in surface-feeding species since the 1990s are likely caused by two factors: lower prey fish availability from large-scale changes in oceanographic conditions and reduced availability of fish discards due to the closure of the groundfish fishery (Mallory 2011; Wilhelm et al. 2016; Descamps et al. 2017; Langlois Lopez et al. 2022).

## 10.5 Research Gaps and Uncertainties

Systematic population monitoring in Atlantic Canada is designed to monitor select species or locations to detect changes in population trends should they occur; it has therefore traditionally focused on the major seabird colonies. Species that are widely dispersed and nest in low-density colonies are much more difficult to monitor as are seabirds that use the area in the non-breeding season, such as Arctic-nesting populations of Thick-billed Murres and several species of shearwaters. 62% of Canadian seabirds have unknown trends as they nest outside Canada or in remote areas of the Arctic (NABCI Canada 2019).

There is also some uncertainty in the colony monitoring results due to the inherent challenges and costs in counting colonial seabirds. Burrow-nesting species are difficult to count, and revisit periods of many colonies are irregular and often very long, especially in remote areas, increasing uncertainty in trends.

## 10.6 Technical Notes

Trajectories in Figure 10.3-1 were estimated using hierarchical generalized additive models (*sensu* Smith and Edwards 2021) that share information among colonies to the degree supported by data. Briefly, colony-level intercepts are estimated independently, but spline coefficients describing patterns of temporal change are treated as colony-level random effects. When the data indicate trajectories are similar among colonies, estimates of spline coefficients are partially pooled and precision is increased. Models were fit using Bayesian methods, implemented with JAGS v4.3.0 interfaced with R v3.6.2 using the jagsUI package. R code is available on GitHub at https://github.com/davidiles/Status_of_Birds_seabird_analysis_2022.

The overall “mean” trajectory and trend among species (Table 10.3-1) was calculated by converting species-level estimates of percent change to a log-scale value, calculating the arithmetic mean of those estimates, then converting back to a percent scale. This ensures that measures of proportional population change are symmetric around zero before calculating the mean (see methods in Environment and Climate Change Canada 2019).

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# 11. ECOSYSTEM PERSPECTIVES

Ocean ecosystems are dynamic, influenced by both natural processes (e.g. seasonality and climate) and human activities (e.g. fishing, coastal development, and resource exploitation). Atlantic Canadian ecosystems are no exception, currently experiencing changes in their physical, chemical, and biological components at different rates and scales. These changes vary within and across bioregions. Climate change is considered the key driver for many of these changes, but it also interacts with other historical and contemporary drivers. Climate change pressures are a negative influence in many cases, but some species may benefit from ecosystem changes, in part due to habitat conditions becoming more favourable and/or reductions in anthropogenic stressors (i.e. reduced fishing pressure).

Understanding the influence of multiple drivers of change requires a multidisciplinary, ecosystem-based approach to research and monitoring, which can be used to improve management and conservation measures for the future. Establishing marine ecosystem connections to develop tools and approaches for improved management of marine resources is a complex undertaking which requires knowledge of the many links between ecosystem components (e.g. Leslie and McLeod 2007; Mills et al. 2013; Painting and Forster 2013; Armoškaite et al. 2020; Dahlin et al. 2021). Although DFO continues to work towards a more comprehensive ecosystem-based perspective, this remains difficult, as current knowledge of status and trends information is uneven across species groups.

Many uncertainties remain in understanding and predicting the indirect effects of climate change on the ecology of Atlantic ecosystems: predator–prey interactions (i.e. in demersal food webs due to changes in the abundance of redfish, lobster, shrimp, and crab), competition among species as distributions shift, changes in the primary and secondary productivity of pelagic habitats, the expansion of aquatic invasive species, and the subsequent changes in ecosystems services (carbon storage and export, coastal erosion). Advances in our understanding of species' ecology, increased availability of relevant environmental data, and advanced modelling frameworks will improve our knowledge, leading to more accurate predictions of how species will likely respond to anthropogenic stressors and climate change driven alterations in their ecosystems.

In this chapter, case studies are presented that highlight connections among different ecosystem components in Atlantic Canada. These focused research sections examine several broad themes related to the direct effects on marine species from climate change or the interplay among multiple anthropogenic stressors, quantifying the location or ecological role of important habitats, and the indirect effects of environmental change on predator–prey relationships and food webs. Also included is a section on innovative applications of modern technological methods to generate new understanding and discoveries and better provide scientific advice in Atlantic Canadian waters.

## 11.1 Climate Change

Consequences of climate change on marine biota may be profound, directly affecting growth, reproduction, and survival of species and their habitat conditions. Altered environmental conditions may lead to range expansions or contractions with further changes in community composition and altered predator–prey interactions and food webs.

Alterations in Atlantic Canadian ecosystems from climate change are evidenced by warming surface and bottom waters; reductions in sea ice duration, areal coverage, and/or volume; declines in CIL thickness; increasing acidity; and declining oxygen. Some metrics (i.e. sea-surface temperature) track climate change–driven warming trends observed in the atmosphere, while others (i.e. bottom water temperatures) result from basin-scale changes in circulation within the NWA, which vary the relative proportions of source waters, altering habitat conditions.

Effects of climate change, whether direct or indirect, have been observed for marine biota across all trophic levels and functional groups. This section highlights in depth some of the responses of selected individual species to the changes in their physical and chemical environment directly linked to climate change.

- Warming of coastal waters and summer sea-surface temperatures throughout Atlantic Canadian waters has led to increased productivity and biomass of American Lobster, resulting in record landings for this important fishery in recent years.
- Snow Crab may increase in the short term as bottom waters warm but decline over the long term when warming bottom temperatures exceed their narrow range of thermal tolerance.
- The loss of sea ice is increasing Harp Seal pup mortality, leading to potential impacts on population abundance and changes in the distribution of pupping. The impact of climate change on other seal species is mixed.

### *11.1.1 Warmer coastal temperatures are leading to increased productivity of American Lobster*

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American Lobster (*Homarus americanus*) is a temperate species. Although it can inhabit waters below 0°C and as warm as about 25°C, it prefers temperatures of 13–19°C (Chabot et al. 2013). For this reason, the recent warming trend described by Galbraith et al. (2021) for coastal waters of the northern Gulf of St. Lawrence (nGSL) is considered to be one explanation for the gain in lobster productivity in this area, particularly in the previously coldest parts (e.g. the North Shore and around Anticosti Island, DFO 2019a–c). Similarly, summer sea-surface temperature has increased since 1981 on the Newfoundland and Labrador Shelves and this has led to more favourable oceanographic habitat conditions for lobster (DFO 2021a).

Another possible reason for the increase in productivity of American Lobster in the nGSL is the increase in minimum legal size that took place in the late 1990s and early 2000s. This resulted in an increase in the average size of commercial lobsters (DFO 2019a–c) and likely resulted in an increase in the proportion of American Lobster that participate in at least one reproduction event before being removed by the fishery. Despite this measure, there are some questions around long-term sustainability of the fishery in other areas as very few new recruits escape the fishery to become large individuals that may contribute to the next generation such as in the sGSL (Rondeau et al. 2015). However, in 2022, the minimum legal size of carapace allowed for lobster commercial fishery in some parts of the GSL increased from 77 mm to 79 mm and is set to be increased to 81 mm in 2023, thus reducing the removal of smaller lobsters in the commercial fishery in this area.

The development and moulting rates of lobster larvae from a northern, historically colder-water region in the nGSL exhibited a different response to temperature than those from other southern, historically warmer-water regions (Quinn et al. 2013), suggesting possible local thermal adaptation or acclimation in lobsters; these differences were subsequently shown to influence the potential impacts of variation in water temperature, including warming, on lobster larval development (Quinn and Rochette 2015) and potential larval dispersal and connectivity among subpopulations (Quinn et al. 2022). A genetic study has confirmed that lobsters do exhibit variation in molecular markers associated with cold adaptation across their range (Benestan et al. 2016). American Lobster is fished using baited traps which is a gear type considered to have low to moderate impact on the ecosystem. There is little knowledge, however, of the fishery's impact on non-target species which are caught in the traps, including those that may also legally be retained for bait or sale (e.g. Shorthorn Sculpin *Myoxocephalus scorpius*, Rock Crab *Cancer irroratus*, and Cunner *Tautogolabrus adspersus* in the sGSL) (Rondeau et al. 2015).

Global change has been mostly associated with increasing American Lobster production in the Atlantic Basin until now, this may change in the future, in particular at the southern edge of its distribution or in areas that are particularly warm (Rheuban et al. 2017; Goode et al. 2019; Greenan et al. 2019). Warming waters negatively affect the survival, performance, and moulting of lobster larvae (Quinn 2017), while leading to smaller sizes at maturity for adults (Le Bris et al. 2017). Warming waters increase susceptibility of lobsters to diseases, cause serum imbalance, and reduce immunocompetence (Chabot et al. 2013; Shields 2017). Further, there are observed and projected negative impacts of ocean acidification and warming on larvae, juveniles, and adults of the American Lobster, with consequences for recruitment and fisheries catch potential and abundances (Waller et al. 2016; Menu-Courey et al. 2019; Klymasz-Swartz et al. 2019; Noisette et al. 2021; Tai et al. 2021).

### *11.1.2 Short versus long-term impacts of warming temperatures on Snow Crab*

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Snow crab is a cold stenothermal species preferring temperatures of less than 4°C (Dionne et al. 2003; Dawe et al. 2012). Temperature has a profound effect on its production, early survival, and subsequent recruitment to fisheries (Foyle et al. 1989; Dawe et al. 2008; Marcello et al. 2012). Within the acceptable range, warmer temperatures result in larger adults of both sexes, likely due to a decrease in intermoult interval. Snow Crabs can then reach one or more additional instars in warm water (3°C) than in cold (0°C) water (Sainte-Marie et al. 2008; Burmeister and Sainte-Marie 2010; Dawe et al. 2012; Sainte-Marie et al. 2021). However, Snow Crab is expected to be negatively affected where bottom waters warm to more than 3 or 4°C, as demonstrated by an important population decrease accompanying an incursion of warm water on the western part of the Scotian Shelf (SS) in 2011 and 2012 (Zisserson and Cook 2017). Thus, biomass estimates may improve with warming of bottom temperatures until they collapse when the species tolerance is exceeded.

The cyclical nature of this fishery, with periods of good recruitment to the fishery interspersed with periods of poor recruitment, makes it difficult to establish links between temperature and abundance or biomass. For instance, there are no ecosystem-level indications of change that would temper the recent increasing trend in landings for the SS (DFO 2021b). Recent climate conditions and pre-recruit abundance indices suggest favourable prospects for recruitment into the exploitable biomass over the next 2 to 4 years in most assessment zones on the Newfoundland and Labrador Shelves. The current trend of the North Atlantic Oscillation suggests improved environmental prospects for Snow Crab in the short term for the same region (DFO 2022a). On the other hand, the warming trend in the deep channels of the Gulf of St. Lawrence (GSL) (Galbraith et al. 2021) has resulted in shrinking of the surface area of bottom favourable to Snow Crab in some nGSL assessment zones (DFO 2021c). The narrow temperature range that Snow Crab can tolerate suggests this fishery will be negatively impacted by the long-term warming trend expected with climate change (Chabot et al. 2013; DFO 2022a).

### *11.1.3 Variability in ice conditions negatively impacts Harp Seal reproduction*

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The Harp Seal (*Pagophilus groenlandicus*) is a medium-sized, migratory pinniped found in the continental shelf regions of the north Atlantic. In summer, Harp Seals are found in the eastern Canadian Arctic and Greenland, migrating southward in fall to the Gulf of St. Lawrence (GSL) or northeastern Newfoundland to overwinter and pup (Stenson and Hammill 2014). Harp Seals require medium to thick first year ice from late February through mid-March (Stenson et al. 2020a), and as an ice-obligatory species, changes in ice conditions can have a large impact on Harp Seals. If the ice cover or thickness is not sufficient during the 12-day nursing period or during the subsequent 3–4 week post-weaning period when the young seals are developing the physiological capacity for diving, the ice can break up during storms and the young of the year seals may drown (Fig. 11.1-1; Stenson and Hammill 2014). Hammill et al. (2021) found that although ice cover varied considerably among years, there was a major change in sea ice conditions by the late 1990s with a significant declining trend in annual ice cover in the GSL. The extent of ice off southern Labrador/northeast Newfoundland has also declined but the impact was considered to be less due to the larger area. However, Hammill et al. (2021) estimated that total ice-related pup mortality was as high as 50% in 2010 and 75% in 2011, as a result of reduced ice cover in both areas (Fig. 11.1-2). Repeated years with increased ice-related mortality could have serious consequences on the overall population that might go unnoticed for over a decade given the current frequency of pup production surveys.

Harp Seals only pup on ice; thus, changes in ice conditions are expected to change the distribution of breeding Harp Seals. For example, Stenson and Hammill (2014) found that females pupped in areas with suitable ice outside of their traditional whelping areas if no ice was present within the traditional areas. However, if any amount of ice was present in the traditional areas, females gave birth even if the ice was too thin to sustain the pups, resulting in increased pup mortality. In 2017, poor ice in the southern GSL resulted in an almost complete collapse of pupping with only 2% of the total Northwest Atlantic (NWA) pup production occurring in an area that traditionally accounts for 25–30% of pup production. Evidence suggested that some of the females moved to the ice off of southern Labrador and northeast Newfoundland to give birth (Stenson et al. 2020a). Whether these females will continue to use this area or move back to the GSL is unknown (Stenson et al. 2020a). Increasing frequency of years with poor ice conditions could result in the disappearance of the most southern breeding component in the GSL.

Figure 11.1-1. Young-of-the-year Harp Seals that drowned after a storm destroyed the ice on which they had been born in the northern Gulf of St. Lawrence in March 2010. (Photo credit: G. Stenson)

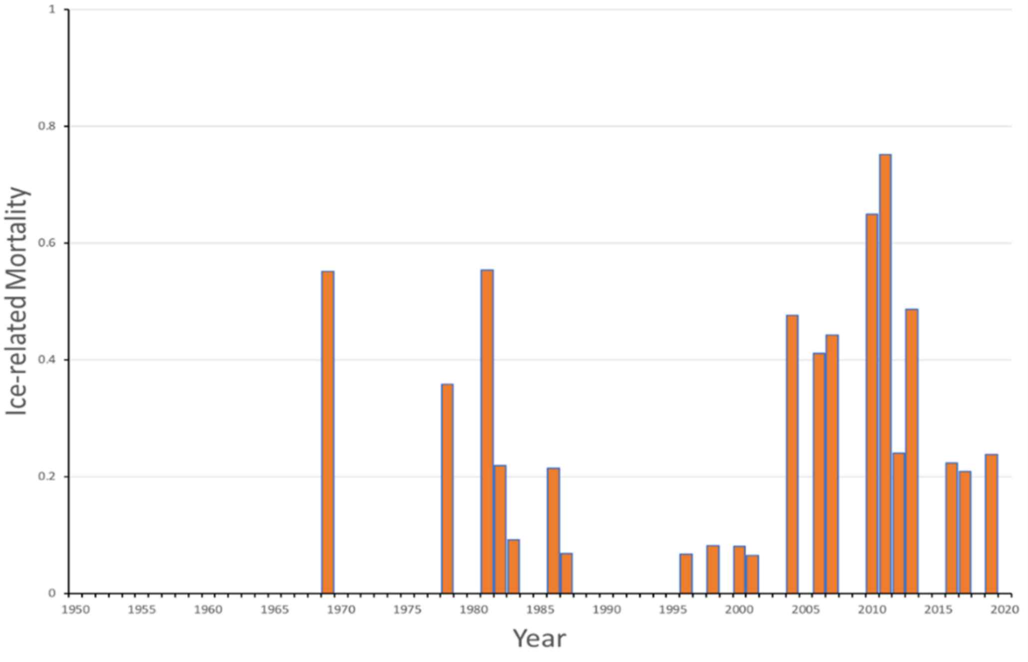

Figure 11.1-2. Estimated ice-related mortality of Northwest Atlantic Harp Seal young of the year (1952–2019) based upon ice conditions in the Gulf of St. Lawrence and off Newfoundland. Adapted from Hammill et al. (2021).

Ecosystem changes in the NWA have also impacted population dynamics of Harp Seals through changes in body condition and subsequent reproductive rates. Harp Seals appear to gain some of their energy stores during the summer feeding in Arctic regions but reach their maximum weight in February after feeding in southern areas in the fall (Chabot et al. 1996; Chabot and Stenson 2002; Stenson 2013). Approximately 50% of consumption by NWA Harp Seals has been shown to occur on the Newfoundland Shelf south of 55°N (Stenson 2013). Therefore, changes in prey availability in both Arctic and southern areas can impact the ability of NWA Harp Seals to obtain the energy needed for successful reproduction. Since the early 1980s, late-term pregnancy rates among mature females declined while inter-annual variability increased, ranging from 20% to over 80%. Beginning in the late 1980s, females aborted their foeti prematurely in some years (Stenson et al. 2016). During this same period, Harp Seals underwent a more than three-fold increase in abundance and showed declines in growth rates (Chabot et al. 1996; Hammill and Sauvé 2017; Hammill et al. 2021). Stenson et al. (2016) found that while the general decline in fecundity is a reflection of density-dependent processes associated with increased population size, the large inter-annual variability in fecundity was due to varying rates of late term abortions which were linked to changes in Capelin (*Mallotus villosus*) abundance and mid-winter ice coverage. Biomass of Capelin on the Newfoundland Shelf is influenced by changes in the timing of ice retreat which, in turn, results in changes in the timing of the primary productivity bloom (Buren et al. 2014; Lewis et al. 2019). This suggests that mid-winter ice extent reflects environmental conditions that influence a variety of species Harp Seals prey upon. Hammill et al. (2021) found that the fit of their population model to the observed pup production was improved by assuming that annual reproductive rates were a function of an index consisting of a variety of environmental variables (e.g. sea-surface temperature, ice extent, bottom temperature, air temperature) (Colbourne et al. 2016) that reflect a changing carrying capacity in the ecosystem.

In their examination of changes in body condition over the past 40 years, Stenson et al. (2020b) found that the average relative condition of pregnant females has remained consistently high, while that of non-pregnant and immature females varied considerably and showed a general decline since 2000. While body condition did not appear to influence fecundity rates directly, it affected the rate of late term abortions; relatively small reductions in average condition resulted in much higher abortion rates. Stenson et al. (2020b) also found that body condition was related to Capelin abundance and mid-winter ice extent. They proposed that as overall condition in the population declines, females that are able to attain sufficient energy (i.e. body condition) maintain their pregnancy while those that cannot attain sufficient energy reserves will terminate their pregnancy prematurely.

For the other pinniped species in Atlantic Canada, the implications of changes in ice conditions are mixed. In contrast to Harp Seals, the observed declines in ice cover have had limited impacts on Grey Seals (*Halichoerus grypus*). In the GSL, the majority of Grey Seal pupping historically occurred on the drifting pack ice between Prince Edward Island and Nova Scotia. Although the initial changes in the availability of suitable ice for pupping led to higher mortality rates for young-of-the-year seals that were born on the ice, over the last decade there has been a significant shift in the distribution of pupping, with the majority of Grey Seal pups now born on islands in the southern GSL (den Heyer et al. 2021). Thus, for this species, the decline in ice has not had a significant long-term impact. For Hooded Seals (*Cystophora cristata*) and Ringed Seals (*Pusa hispida*), the decline in stable ice is expected to have a negative impact on both the survival of pups and on the abundance and/or distribution of their prey. In contrast, changes in winter ice cover are not expected to have a major impact on Harbour Seal breeding, since they normally reproduce in spring (May–July). The decline in ice cover may open up new habitat for them and lead to a northward expansion of their range (Woollett et al. 2000; Bajzak et al. 2013).

## 11.2 Multiple Stressors

Anthropogenic drivers of change include land- or ocean-based human activities that generate stressors with measurable impacts on coastal and offshore environments or species. Stressors vary across spatial and temporal scales, ultimately changing the quality and/or quantity of valued ecosystem components and impacting ecosystem structure and functioning. Species' responses to multiple interacting stressors can be complex, combining in different and unexpected ways (i.e. additive, antagonistic, synergistic) making resulting impacts difficult to assess. Regardless, the ecological consequences of multiple stressors can be profound, including potential impacts to species' life histories and habitats, shifts in distribution or abundance, altered interactions with predators and prey, and energy flow through food webs.

Atlantic ecosystems are impacted by many historical and contemporary drivers (e.g. nutrient enrichment, invasive species, pollution, land-use alterations, and habitat fragmentation), but fishing remains one of the most widespread and dominant. Climate change itself represents a complex mix of stressors (e.g. change in temperatures, acidification, sea ice cover, sea level rise, ocean circulation, ocean chemistry) that are superimposed on an increasingly anthropogenic seascape.

Describing and understanding the complex network of human activities and their subsequent stressors is key to successful mitigation of their harmful effects. This section highlights recent research that identifies or quantifies some of the direct and indirect impacts of anthropogenic marine stressors, the interplay among these stressors, or the ongoing management and conservation efforts that aim to reduce their impacts throughout Atlantic Canadian ecosystems.

- Declines in Northern Shrimp stocks in the northern Gulf of St. Lawrence are linked to the concurrent effects of environmental changes (i.e. warming bottom waters, declining oxygen, increasing acidification) and food web alterations (i.e. increasing predation pressure, declining abundance and nutritional value of prey species).
- Atlantic Salmon face threats in both freshwater and marine environments, including overfishing, habitat loss and degradation, migration barriers, salmonid aquaculture, diseases and parasites, and poor marine survival, which results in varying degrees of negative impacts on Atlantic Canadian populations.
- Loss of Eelgrass coverage and kelp biomass in the Gulf of St. Lawrence and on the Scotian Shelf due to the combined effects of climate warming and invasive species—as well as nutrient enrichment from land-use change for Eelgrass—may reduce nearshore habitat quality and quantity for associated commercially important species.
- Implementing various management actions to alleviate multiple stressors from Canadian commercial fishing activities (e.g. bycatch, entanglement, over-harvesting) has reduced the potential for excessive mortality on pelagic shark populations.

### *11.2.1 Northern Shrimp stocks in the Gulf of St. Lawrence in an increasingly stressful environment*

Denis Chabot

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From 2017 to 2020, Northern Shrimp (*Pandalus borealis*) landings were at or well below average across all bioregions. Survey indices followed the same trends as for landings, where available, reaching values at or below historic lows on the northern Gulf of St. Lawrence (nGSL) and the Newfoundland and Labrador Shelves (NLS) (see Fig. 6.3-2). Direct environmental effects as well as indirect effects from ecosystem changes (e.g. changes in predation pressure, abundance and nutritional value of prey species) are thought to have contributed to these declines.

In 2018, environmental changes were thought to have already begun to negatively impact Northern Shrimp in the nGSL (Bourdages et al. 2022). Northern Shrimp are a cold stenothermic species (narrow thermal range) preferring temperatures of 0–5°C (Shumway et al. 1985; Garcia 2007). Water in the deep channels of the St. Lawrence Estuary (SLE) and the GSL are low in dissolved oxygen (Gilbert et al. 2005) and have become warmer and more hypoxic in recent years (Mucci et al. 2011; Blais et al. 2021a; Galbraith et al. 2021). It is likely that a recent shift of fishing effort in the SLE to shallower bottoms bathed in colder and better oxygenated waters was caused by the deterioration of habitat quality in the deep channel of the SLE fishing area of the nGSL (Bourdages et al. 2022), in particular the very severe hypoxic conditions observed since 2010 in this area (Blais et al. 2021a). The warming itself is also thought to negatively affect Northern Shrimp (Bourdages et al. 2022), and although they are tolerant of severe hypoxia (the lethal threshold of females is 16% saturation at 5°C and 22% saturation at 8°C, Dupont-Prinet et al. 2013), worsening hypoxia combined with further warming and acidification is expected to have a negative impact on their mortality rate, distribution, and abundance (Stortini et al. 2017; Chemel et al. 2020).

The impact of predation by redfish was likely minor before 2018; however, the recent massive increase in redfish biomass in the nGSL (Fig. 7.3-6) has likely played a role in the recent declining survey biomass. Redfish are known predators of Northern Shrimp, although only large fish (>25 cm) feed on them heavily (Brown-Vuillemin et al. 2022). Other predators may have had an impact on shrimp abundance in recent years (see Section 6.5 *Research Gaps and Uncertainties*).

Redfish are long-lived species and the very abundant 2011–2013 redfish cohorts are now large enough to eat shrimp, so predation is likely to be an important source of shrimp mortality for many years. Changes in the zooplankton community may also change the quality and timing of food availability for upper trophic levels, including Northern Shrimp (DFO 2021d). Further warming, acidification, and worsening of hypoxia are expected by the second half of the century (Loder et al. 2013) and are expected to continue to impact Northern Shrimp in the GS L (Dupont-Prinet et al. 2013; Stortini et al. 2017).

### *11.2.2 Atlantic Salmon in the southern Gulf of St. Lawrence and Scotian Shelf bioregions threatened by multiple stressors in both marine and freshwater habitats*

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A detailed list of marine and freshwater threats for Atlantic Salmon populations in Atlantic Canada was provided in DFO and MRNF (2009) and COSEWIC (2010). Atlantic Salmon populations in rivers flowing into the southern Gulf of St. Lawrence (sGSL) face similar threats although the levels of impact may differ among populations. In contrast, each of the four designatable units in the Scotian Shelf (SS) bioregion (Inner Bay of Fundy, Outer Bay of Fundy, Southern Uplands, and Eastern Cape Breton) have unique threats with varying degrees of negative impacts to Atlantic Salmon populations.

Threats of particular importance for the sGSL in freshwater include poor fish passage (roads and culverts), elevated summer water temperatures and low streamflow, invasive species, and forestry practices. Many streams in the sGSL have impediments to fish passage blocking diadromous fish from reaching spawning areas in headwater streams (Breau 2012). In the rapidly warming environment, elevated water temperatures and periods of low streamflow lead to physiological stress in Atlantic Salmon and even mortalities (Breau 2013). Invasive species such as Chain Pickerel (*Esox niger*) and Smallmouth Bass (*Micropterus dolomieu*) have been found in some rivers and Smallmouth Bass are established in the Miramichi and Margaree River systems (Biron 2018). Although forestry practices have followed provincial regulations, the activities have greatly altered the landscape in the region leading to changes in hydrological processes, water quality, and nutrient regime alterations which can result in adverse water conditions such as eutrophication, hypoxia, and anoxia (Hardy et al. 2012).

For the Endangered Inner Bay of Fundy Atlantic Salmon population, ecosystem change within the marine environment is of the highest concern and likely the main threat restricting recovery, however, if marine survival was to improve, freshwater threats may also become more concerning (Amiro et al. 2008).

There are numerous threats to Atlantic Salmon populations within the Outer Bay of Fundy (DFO 2014a). Hydroelectric dams and illegal fishing/poaching pose the largest threat within the freshwater environment. Within the marine environment, environmental/ecosystem shifts, salmonid aquaculture, depressed population phenomenon, and disease/parasites are considered high concern threats.

In the Southern Upland (Southwestern Nova Scotia, SFA 21), acidification, altered hydrology, invasive fish species, habitat fragmentation, and illegal fishing/poaching are considered high concern threats within the freshwater environment (Bowlby et al. 2014; DFO 2013). Invasive species such as Chain Pickerel and Smallmouth Bass have become widely distributed and abundant throughout the Southern Uplands (DFO 2013). Within the marine environment, ecosystem change and salmonid aquaculture are considered high concern threats. Due to climate change there is evidence of an entire ecosystem shift along the eastern SS and it is believed a similar shift is occurring in the western portion also (Bowlby et al. 2014).

For Eastern Cape Breton, illegal fishing/poaching within the freshwater environment and salmonid aquaculture, ecosystem change, and disease/parasites within the marine environment were deemed high level of concern threats. Within Eastern Cape Breton there have been reports of illegal fishing and poaching occurring with gillnets and recreational fishing gear (Gibson et al. 2014). Aquaculture production in this region is predominantly Rainbow Trout (*Oncorhyncus mykiss*), so there is less risk of genetic introgression of farmed Atlantic Salmon into wild populations. However, escapees from other regions can migrate into the region and could have a negative impact given low population numbers. In addition, predator abundances are higher around marine pens, which leads to increased predation rates and transfer of disease/parasites to wild fish. Escapee aquaculture Rainbow Trout can also compete with Atlantic Salmon and prey on juvenile life stages putting further stress on the populations (Bowlby et al. 2014). Given the evidence of marine ecosystem change inducing mortality across the Atlantic Salmon species range, it is likely that Eastern Cape Breton populations are also experiencing increased marine mortality (Gibson et al. 2014).

### *11.2.3 Natural and anthropogenic factors influence Eelgrass habitat quality*

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Nutrient loading remains one of the leading human threats to Eelgrass (*Zostera marina*) beds in Atlantic Canada, specifically those located in the Gulf of St. Lawrence (GSL). Eelgrass coverage within southern GSL estuaries has been linked to nitrogen loading (specifically nitrate), with significant Eelgrass declines in estuaries with high nitrate-N (van den Heuvel et al. 2019; Coffin et al. 2021). A separate field study in the sGSL did not observe reduced Eelgrass cover and biomass with higher total nitrogen loading, however, other signs of eutrophication (e.g. increased algal cover and Eelgrass tissue nitrogen) were present in sites with higher nitrogen loading estimates (McIver et al. 2019). Eelgrass beds on the Scotian Shelf (SS) are generally at lower risk of decline from excess nutrient input as total nitrogen loading estimates modelled for the region are much lower than for the GSL (Nagel et al. 2018; Kelly et al. 2021).

Excess nutrients can come from many sources including land runoff, atmospheric deposition, industrial pollution, and finfish aquaculture operations. Recent estimates of the extent of dissolved nutrients released from finfish aquaculture farms in Nova Scotia and whether these inputs negatively affect eelgrass have been mixed. McIver et al. (2018) estimated that the nitrogen contribution from a finfish farm in Port Mouton Bay could be up to double the background concentration in the bay and increase the annual human-derived nitrogen loading to the bay by 14%. A field study from the same bay found that Eelgrass cover significantly decreased at locations closer to the finfish farm (Cullain et al. 2018). In contrast, Filgueira et al. (2021) suggests that excess nutrient input from the finfish farm in Port Mouton Bay is unlikely to have impacted Eelgrass cover, and they estimated nutrient loading from the farm to be below the threshold that would be toxic to Eelgrass. Given that these studies have all been conducted in the same bay, further research to assess Eelgrass responses to finfish aquaculture across Atlantic Canada are needed to determine general trends. Notably, marine finfish aquaculture is absent in the GSL, and in areas where it is present (e.g. southern Newfoundland, Bay of Fundy, SS) potential overlap is limited as aquaculture typically occurs in waters too deep for Eelgrass growth.

Recent studies have examined the link between environmental factors related to nutrient loading and both Eelgrass cover and the trophic status (i.e. whether an estuary is considered oligotrophic or eutrophic) of Eelgrass inhabited estuaries (Coffin et al. 2018; van den Heuvel et al. 2019; Coffin et al. 2021). The amount of dissolved oxygen in an estuary has been identified as a reliable indicator that can be used in cost-effective nutrient loading monitoring programs by ecosystem managers to estimate trophic status and inform decision-making (Coffin et al. 2018, 2021). Furthermore, nitrogen loading thresholds that provide estimates of how much Eelgrass is expected to decline at different amounts of nitrate-N have been developed for the GSL (Coffin et al. 2021). Such thresholds will be useful for ecosystem management to identify at-risk areas and ensure nitrogen loading remains below the amounts necessary to reduce Eelgrass loss.

Recent studies in Atlantic Canada have also investigated the physical processes that influence Eelgrass distribution and bed structure. Water temperature, light availability, nutrient dynamics, and water motion have all been strongly linked to Eelgrass growth and productivity (Cullain et al. 2018; Namba et al. 2018; van den Heuvel et al. 2019; Krumhansl et al. 2021; Vercaemer et al. 2021), similar to Eelgrass in other Canadian and global locations. Eelgrass beds in warm, shallow, protected waters that experience warming events from solar heating typically have lower productivity and resilience relative to beds in deeper, cooler waters that are well flushed (Krumhansl et al. 2021). Temperatures that remain elevated above 23°C are particularly problematic for Eelgrass because respiration begins to outpace photosynthesis, negatively affecting Eelgrass growth, survival, and overall carbon balance. These temperatures are common in shallow, poorly flushed Eelgrass beds in Atlantic Nova Scotia and the sGSL (van den Heuvel et al. 2019; Krumhansl et al. 2020; Coffin et al. 2021; Wong and Dowd 2021b). Furthermore, Eelgrass beds throughout Atlantic Canada inhabit a wide range of underwater light conditions related to water depth, winter sea ice, and water turbidity from wind events, sediment resuspension, runoff, or plankton blooms (Namba et al. 2018; Murphy et al. 2021; Krumhansl et al. 2020; Wong and Dowd 2021b). Eelgrass plants typically respond to reduced light by altering their growth, physiology, and morphology to enhance photosynthesis and reduce respiratory burden (Wong et al. 2021).

### *11.2.4 Reducing potential shark mortality from Atlantic Canadian fisheries*

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Relative to bony fishes, sharks have a long lifespan, mature at older ages, and have relatively few offspring. These characteristics make them vulnerable to fishing pressure, and populations are comparatively slow to increase once reduced in size (DFO 2017). Recent management actions have reduced the potential for shark mortality from Canadian fisheries, including regulations that ban finning (removing fins and discarding the shark carcass; Campana et al. 2004) and trade in fins under the modernized *Fisheries Act* [Bill C-68], additional gear restrictions and changes to reporting requirements for species listed on Schedule 1 of the *Species at Risk Act* (White Shark *Carcharodon carcharias*), as well as landings restrictions for shark bycatch because the majority of captures can be released alive (Bowlby et al. 2021). However, there is still a strong need to understand bycatch, particularly given the diversity of fisheries that intercept sharks.

The commercial fishery for Spiny Dogfish (*Squalus acanthias*) was small prior to 1955 but increased with expanded directed fishing during the 1960s (Campana et al. 2007). Foreign fleets fishing in Canadian waters landed substantial amounts of Spiny Dogfish during the 1970s, peaking just less than 10,000 mt in 1974 (DFO 2020b). Since 1977, US commercial landings have accounted for most of the reported catch in the North Atlantic. From 1998 to 2008, Spiny Dogfish landings by Canadian fleets increased by an order of magnitude, peaking at 3,578 mt in 2001 and averaging 2,300 mt (DFO 2020b). Most of these were taken in the directed longline fishery for Spiny Dogfish, with lesser amounts from gillnets and otter trawl. The directed fishery for Spiny Dogfish has been inactive since 2012, and landings from all Canadian fisheries have been very low (<100 mt; DFO 2020b; Fowler and Bowlby 2022).

Porbeagle Sharks (*Lamna nasus*) were heavily harvested along the Atlantic coast by international fleets in the 1960s. Canadian participation in the fishery started in 1994, with quotas established in 1998. In 2016, a license condition was added to the pelagic longline fleet requiring all live Porbeagle Sharks to be released in the manner that causes the least amount of harm to the shark. Porbeagle Shark landings remained well below the quota of 185 mt after the fishery closed in 2013 (Campana et al. 2015). Landings fell to less than 1,000 mt by 1970 as the fishery collapsed (Campana et al. 2015) after rising sharply from 1,900 mt in 1961 to over 9,000 mt in 1964.

In 1995, a non-restrictive quota of 250 mt annually was implemented for Shortfin Mako (*Isurus oxyrinchus*), which was reduced to 100 mt due to conservation concern (Campana et al. 2006; Showell et al. 2017). Only Canadian, Japanese, and Faroese vessels are known to have caught significant quantities of Shortfin Mako in Canadian waters, although the contribution of foreign vessels to catches has been negligible since 1999 (Campana et al. 2004). As of 2020, all landings of Shortfin Mako by large pelagic fleets were prohibited and all bycatch must be discarded at sea (Bowlby et al. 2020). In 2021, this prohibition was extended to apply to all groundfish and fixed gear fisheries in Atlantic Canada.

### *11.2.5 Kelp dynamics in an altered ecosystem state*

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Increased water temperature is predicted to affect the distribution, structure, productivity, and resilience of kelp forests worldwide (Harley et al. 2012). Warming seawater temperatures affect kelps directly by causing cellular damage that decreases blade strength (Simonson et al. 2015) and reducing growth and survival (Simonson et al. 2015; Wilson et al. 2015). Increasing temperature also impacts kelps indirectly by facilitating higher settlement (Saunders and Metaxas 2007, 2008) and growth of an invasive bryozoan (*Membranipora membranacea*) on kelp blades (Saunders and Metaxas 2009a). These lead to greater cover and more severe outbreaks (Saunders and Metaxas 2008; Scheibling and Gagnon 2009) by the bryozoan, which decreases blade strength and increases blade breakage during storms (Krumhansl et al. 2011). Kelp defoliation driven by *M. membranacea* and warming also facilitate colonization by kelp competitors, including turf algae (O'Brien and Scheibling 2018a) and invasive seaweeds such as *Codium fragile fragile* and *Fucus serratus* (Scheibling and Gagnon 2006; Filbee-Dexter et al. 2016). Once these competitors become established, it is very difficult to reverse changes in ecosystem structure.

Following large-scale defoliation of kelp forests, various feedback mechanisms lead to anemic recovery of kelp and favour persistence of the degraded ecosystem state (O'Brien 2018). In degraded habitats, low density of reproductive adults restricts the supply of kelp spores (O'Brien and Scheibling 2016), and pervasive turf mats trap large quantities of inorganic sediment (Filbee-Dexter et al. 2016) and inhibit the early-life history stages of kelp (O'Brien and Scheibling 2018a). Dense meadows of *C. fragile* also can preempt recolonization by kelp (Scheibling and Gagnon 2006). As a consequence, chronically low levels of recruitment of young kelp sporophytes may persist (O'Brien and Scheibling 2018b). The proliferation of turf algae has led to a dramatic overall change in habitat architecture of the kelp ecosystem defined by a reduction in the height, biomass, and scale of habitat space of the seaweed canopy (Pessarodona et al. 2021). With the limited availability of hard rocky substratum in turf-dominated habitats, kelp spores that settle and establish to a macroscopic size are frequently directly attached loosely to turf algae (Burek et al. 2018). Turf-attached kelps are at increased risk of dislodgement during fall and winter storms as they attain a larger size due to lower attachment strength (Burek et al. 2018). Juvenile kelps in turf-dominated habitats also experience high mortality and tissue loss related to the effects of encrustation by *M. membranacea* and grazing by the abundant snail *Lacuna vincta* (O'Brien and Scheibling 2018a). Similar to *M. membranacea*, grazing perforations by *L. vincta* weaken kelp tissue and increase the rate of blade breakage and erosion (Krumhansl and Scheibling 2011a, b; Krumhansl et al. 2011). As kelp becomes more sparse, snails graze their preferred source more intensively (O'Brien et al. 2015). Moreover, preferential grazing of reproductive tissues by *L. vincta* may further exacerbate kelp spore supply constraints (O'Brien and Scheibling 2016).

Models generally predict contraction of the southern range edge and some northward expansions of kelp in the Northwest Atlantic (Assis et al. 2018; Khan et al. 2018; Wilson et al. 2019) with overall range contractions predicted for the two dominant species of kelps under a business-as-usual scenario (34% for *Laminaria digitata* and 21% for *Saccharina latissima*, Wilson et al. 2019). Southern range limits for *L. digitata* and *S. latissima* are expected to shift northward to the Gulf of Maine, Bay of Fundy (Wilson et al. 2019), or as far north as Newfoundland (Assis et al. 2018). Models agree that habitat suitability for kelps is at least likely to decrease along the Atlantic coast of Nova Scotia and in the Gulf of St. Lawrence (Assis et al. 2018; Khan et al. 2018; Wilson et al. 2019). Under strong climate change mitigation scenarios, losses of kelp are projected to be significantly reduced (Assis et al. 2018; Wilson et al. 2019).

Projected increases in ocean temperature are also expected to increase population growth of *M. membranacea*, which negatively influences the abundance of kelp (Denley et al. 2019). The predominant kelp species in the region are differentially susceptible to defoliation from the effects of *M. membranacea* (Saunders and Metaxas 2009b) and warming-induced tissue degradation and loss (Simonson et al. 2015). If such species-specific responses result in changes in the relative composition of kelp communities, this may enhance the reproductive potential and severity of outbreaks of the bryozoan due to higher fecundity on the more resistant species (Denley and Metaxas 2017; Denley et al. 2019). Projected warming and associated increases in abundance of *M. membranacea* and grazing activity alongside increases in significant wave height are anticipated to reduce kelp biomass with long-term impacts on detrital production and export from kelp ecosystems in the region (Krumhansl et al. 2014).

## 11.3 Habitat

Habitat contains the array of resources and physical and biological factors present in an area necessary to support the survival and reproduction of a species. From intertidal sedimentary flats to open ocean pelagic areas to deep-sea rocky canyons, Atlantic Canada contains diverse coastal and offshore habitats. Some species are themselves biogenic habitat (i.e. kelp, eelgrass, sponges, corals), providing shelter, food, and refuge for other species. Research that identifies and delineates key habitats can promote marine biodiversity, assist conservation and recovery efforts for SARA-listed species and lead to the development of Ecological or Biological Significant Areas (EBSAs).

Generally, information to assess status and trends of habitats across broad spatial scales throughout Atlantic Canadian waters is limited. This section highlights research on the importance and identification of subtidal and offshore habitats for Atlantic Canadian species.

- Kelp forests and Eelgrass beds provide many ecosystem functions and services and are important biogenic habitats in the life-cycle of commercially important fish and crustaceans.

- Important transit corridors and year-round foraging and socializing areas for Endangered Blue Whales have been identified in the Gulf of St. Lawrence and along the continental shelf edge.
- To reduce the risk of vessel strikes in the St. Lawrence Estuary for Fin, Humpback, Minke and Blue Whales, the implementation of additional management measures should consider areas in and around the Laurentian Channel within the St. Lawrence Estuary.

### *11.3.1 Kelp and Eelgrass as biogenic habitat providers*

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Kelp forests and Eelgrass (*Zostera marina*) beds provide many ecosystem functions and services, acting as key ecosystem engineers in coastal areas. For kelp, the most valuable services include support of commercial fisheries, carbon sequestration, and nutrient removal, which were recently valued at $165,200 per hectare per year in the Northwest Atlantic (Eger et al. 2023). Eelgrass habitats filter seawater, 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. 2008). The perturbation of Eelgrass has been shown to have substantially greater ecological consequences than the loss of any other habitat-forming species in Atlantic Canada, as the ecosystem services provided by its biogenic structure in soft sediments cannot easily be replaced. Accordingly, DFO (2009) has designated Eelgrass an Ecologically Significant Species in Atlantic Canada.

Kelp and Eelgrass habitats are both highly productive environments. Kelp forests have high rates of primary productivity as well as secondary productivity locally and in adjacent habitats through the provision of habitat and export of carbon (Krumhansl and Scheibling 2012). Eelgrass beds provide high secondary production from associated macrobenthic infaunal and epifaunal invertebrates as well as epiphytes (Wong 2018); secondary production and diversity of benthic invertebrates (infauna and epifauna ≥500 µm) are typically higher in Eelgrass beds than adjacent bare sediments (Wong 2018; Wong and Dowd 2021a).

Eelgrass beds also typically support high densities and diversity of fish and invertebrates when compared to nearby unvegetated habitats (Joseph et al. 2013; Cote et al. 2013; Wong and Dowd 2015; Wong et al. 2016). When compared between Eelgrass and macroalgal (*Ulva* spp.) beds, invertebrate diversity was higher in Eelgrass, which had more stable environmental conditions (Coffin et al. 2018). Eelgrass also performs a nursery function to important commercial and recreational species, such as juvenile Atlantic Cod (*Gadus morhua*), Greenland Cod (*Gadus macrocephalus*), White Hake (*Urophycis tenuis*), forage species such as Cunner (*Tautogolabrus adspersus*), and invertebrates such as Rock Crab (*Cancer irroratus*) (Laurel et al. 2003; Wong and Dowd 2015; Lunzmann-Cooke et al. 2021). The structural complexity of Eelgrass provides cover from predation (Gorman et al. 2009) and enriched food supply. Kelp forests are also important to commercial fish and crustaceans, which use them during juvenile stages or throughout their lifetime. These species include Atlantic Cod, Atlantic Tomcod (*Microgadus tomcod*), White Hake, American Lobster (*Homarus americanus*), Rock Crab, and Jonah Crab (*Cancer borealis*).

Kelp and other seaweeds are also harvested from the wild and grown in aquaculture in Atlantic Canada by several companies for use in seaweed-based products for human consumption, animal feed, and agricultural use. Most animals do not eat live Eelgrass in Atlantic Canadian waters; however, the Canada goose (*Branta canadensis*) and other brants graze on significant quantities, and their numbers correlate with its availability (Seymour et al. 2002).

### *11.3.2 Important habitat identified for the Endangered Atlantic Blue Whale*

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The Atlantic population of Blue Whale (*Balaenoptera musculus*) is listed as Endangered by COSEWIC and under the *Species at Risk Act* with an estimated abundance in the low hundreds (Sears and Calambokidis 2002). Until recently, little was known about their range or critical habitat within Canadian waters, the determination of which were listed as important objectives in their Recovery Strategy (Beauchamp et al. 2009). The main activity of Blue Whales in Canadian waters is foraging, with Arctic Krill (*Thysanoessa* spp.) and Northern Krill (*Meganyctiphanes norvegica*) as their main prey (Gavrilchuk et al. 2014). Important habitats were recently identified in Atlantic Canadian waters by combining historical and current distributions of Blue Whales with areas of observed or predicted krill aggregations (Lesage et al. 2018).

Results identified four important foraging and/or socializing areas that appear to be exploited nearly year-round (Fig. 11.3-1). Satellite tagging data also identified important transit corridors with strong connectivity among areas of concentrated activity (Fig. 11.3-1; Lesage et al. 2017). Analyses of recordings from passive acoustic monitoring instruments deployed in Atlantic Canadian waters are expected to provide additional insights into Blue Whale occurrence in areas where research efforts have previously been limited but where significant krill aggregations have been detected (Lesage et al. 2018). The relative importance of deep waters off the shelf break and the location and boundaries of wintering areas remain uncertain.

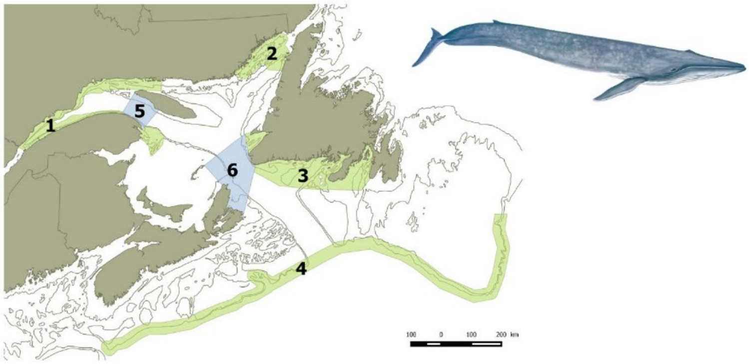

Figure 11.3-1. Areas in Atlantic Canadian waters identified as important Blue Whale habitats. Foraging/socializing areas (green): 1) lower St. Lawrence Estuary/northwestern Gulf of St. Lawrence, 2) Mecatina Trough/head of Esquiman Channel, 3) south and southwestern Newfoundland, 4) continental shelf edge. Transiting areas (blue): 5) Honguedo Strait, 6) Cabot Strait. Adapted from Lesage et al. (2018).

### 11.3.3 Identifying important areas for baleen whales in the St. Lawrence Estuary

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The St. Lawrence Estuary (SLE) is both an important habitat for marine mammals and a major seaway. Thousands of commercial vessels transit the estuary each year as well as ferries, pleasure boats, and whale-watching vessels (Chion et al. 2009). This overlap of vessels and whale activities creates an increased risk to marine mammals to vessel strikes, which are a significant source of mortality and injury for many species of whales (Jensen and Silber 2003). To reduce the risk of collisions in the SLE, provisional voluntary protection measures (including Speed Reduction, No-Go, and Caution Areas) were implemented in and around the Saguenay–St. Lawrence Marine Park in 2013 to complement existing park regulations (Chion et al. 2018). To determine the adequacy of these protective measures and inform future marine spatial planning efforts, data from over 25 years of systematic surveys, whale watching activities, and citizen science programs were used to identify important areas within the SLE for Fin, Humpback, Minke, and Blue whales (Martins et al. 2022; Mosnier et al. 2022).These analyses indicated the head of the Laurentian Channel and its northern and southern submarine slopes as important areas for Fin, Humpback, and Minke whales and that the Laurentian Channel between Les Escoumins and Forestville as an important area for Blue Whales (Figs. 11.3-2 and 11.3-3). Results will be used to help define future protected areas and to develop additional regulations aimed at avoiding the risk and severity of vessel strikes in the SLE.

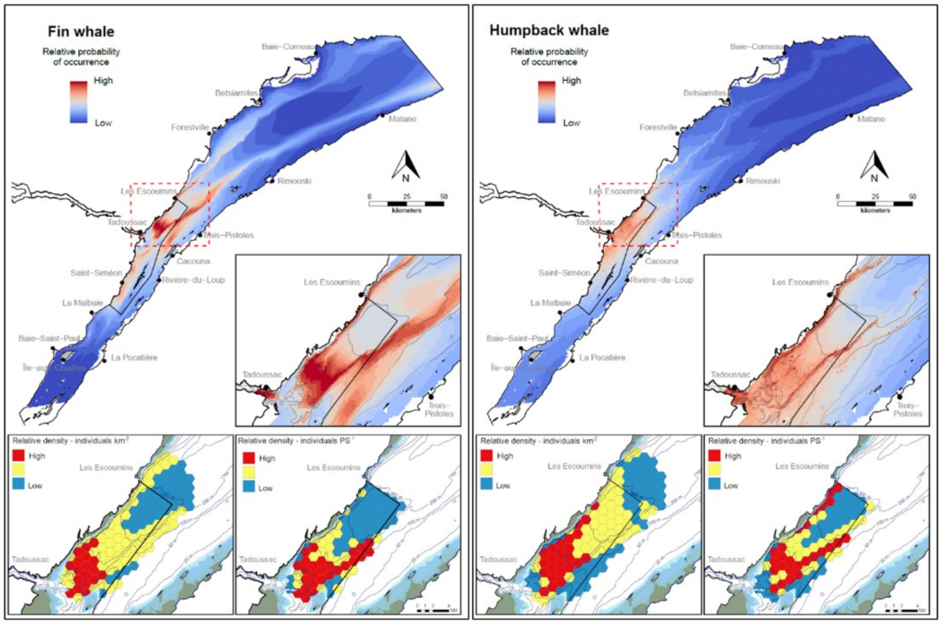

Figure 11.3-2. Upper panels for Fin Whale (left) and Humpback Whale (right) show relative probability of occurrence in the St. Lawrence Estuary from a spatial model incorporating information from DFO vessel and aerial surveys (1995–2017). Lower panels show predicted relative density from a spatial model incorporating information from Parks Canada’s systematic boat surveys (2006–2011) (left) and whale watching activities monitoring program (1994–2018) (right). The Saguenay–St. Lawrence Marine Park limits are indicated by the thick black line. Adapted from DFO (2022b).

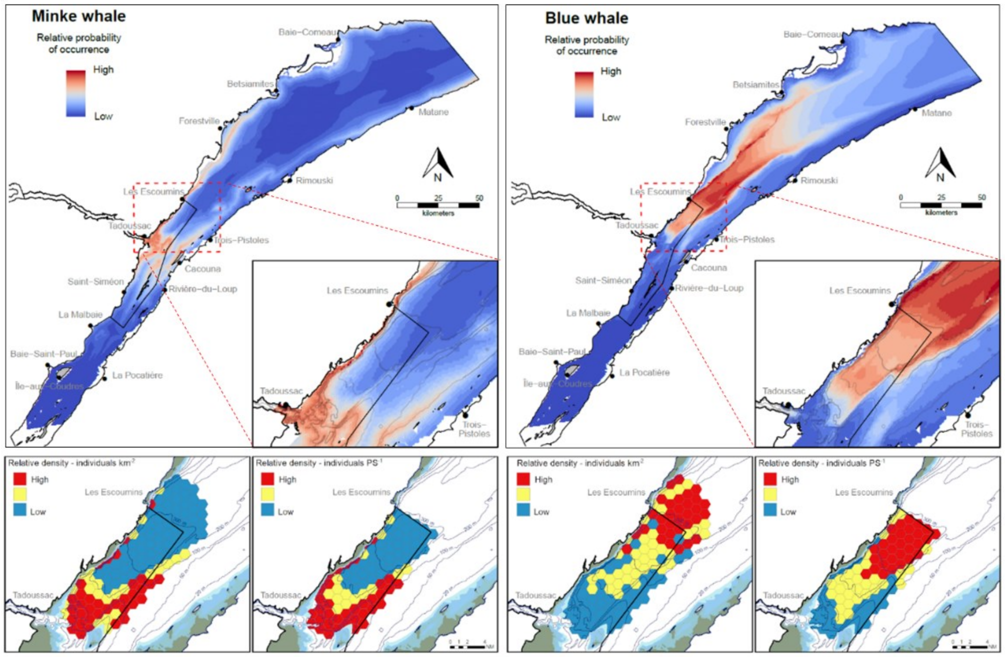

Figure 11.3-3. Upper panels for Minke Whale (left) and Blue Whale (right) show relative probability of occurrence in the St. Lawrence Estuary from a spatial model incorporating information from DFO vessel and aerial surveys (1995–2017). Lower panels show predicted relative density from a spatial model incorporating information from Parks Canada's systematic boat surveys (2006–2011) (left) and whale watching activities monitoring program (1994–2018) (right). The Saguenay–St. Lawrence Marine Park limits are indicated by the thick black line. Adapted from DFO (2022b).

## 11.4 Predator–Prey Interactions

Predator–prey relationships play an important role in structuring ecosystems. Predators affect the dynamics of their prey directly by reducing the number of individuals or indirectly by influencing risk-mitigating behaviours that alter how prey interact with their environment. The dynamics between predators and prey thus cascade through communities, affecting productivity, biodiversity, nutrient cycling, carbon storage, and other ecosystem processes.

Growing evidence suggests climate and anthropogenic influences on marine ecosystems can alter the dynamics of prey populations, shifting species distributions and predator–prey overlap. This section highlights two situations identified in Atlantic Canadian waters where predator–prey interactions have shifted in recent years.

- Interannual and decadal variability in zooplankton community composition—*Calanus* spp. in particular—altered the distribution of the planktivorous North Atlantic Right Whale across Atlantic Canadian waters. North Atlantic Right Whales shifted from their traditional feeding grounds in the Gulf of Maine and on the Scotian Shelf into the Gulf of St. Lawrence, putting them at increased risk of injury or death from entanglements in fishing gear or vessel strikes.
- Declines in the abundance and shifts in the distributions of forage fish, such as Atlantic Mackerel and Atlantic Herring, have been linked to poor breeding conditions, low reproductive success, and reduced adult survival for their seabird predators.

### *11.4.1 Changes in distribution of the North Atlantic Right Whale and its prey in the western North Atlantic*

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The North Atlantic Right Whale (*Eubalaena glacialis*) (NARW; Fig. 11.2-8) uses Atlantic Canadian waters for foraging, nursing calves, mating, and socializing. Serious injury and death from vessel strike and entanglement in rope from fishing gear have hindered the recovery of this endangered species and threatened its remaining population (Knowlton and Kraus 2001; van der Hoop et al. 2017; Moore et al. 2021; Knowlton et al. 2022). There is an urgent need to identify processes that influence the distribution of NARW throughout the known range of this species, including waters off the southeastern US to Atlantic Canada. This information will help to identify priority areas for implementation of management measures to reduce anthropogenic risks from fishing and vessel activity.

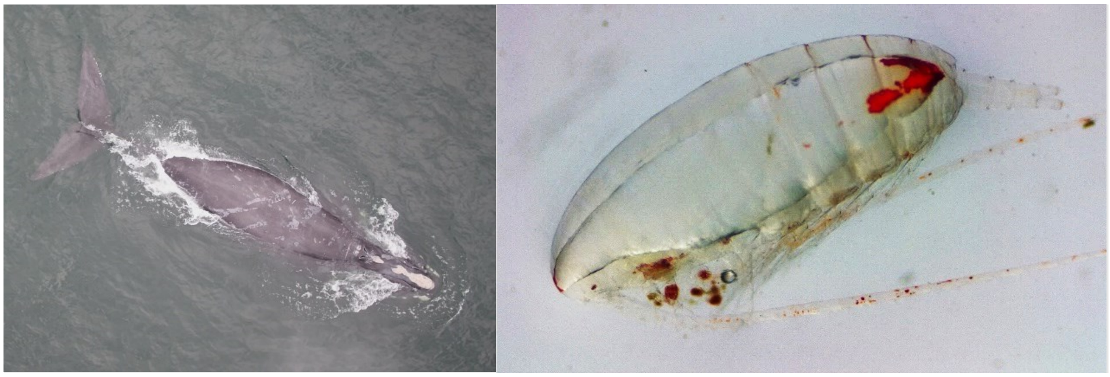

Figure 11.4-1. North Atlantic Right Whale (left) and late-stage *Calanus hyperboreus* copepod with prosome length of 4.8 mm (right). Photo credits: Dr. Andrew J. Wright, DFO Maritimes, taken under all relevant permits (left), and DFO Quebec (right).

One important source of variation in the distribution of NARW off the northeastern US and Atlantic Canada is the distribution of its prey (Pendleton et al. 2009; Plourde et al. 2019; Record et al. 2019). NARW feed on zooplankton and copepods of the genus *Calanus* are an important food source (Pershing and Stamieszkin 2020; Fig. 11.4-1). The subarctic species *Calanus finmarchicus* is abundant in and north of the Gulf of Maine (GoM), whereas the Arctic species *Calanus hyperboreus* and *Calanus glacialis* are abundant mainly north of the Scotian Shelf (SS; Conover 1988; Sorochan et al. 2019). Several studies have indicated that NARW feed on late life stages of *C. finmarchicus* in the GoM and on the western SS (Mayo and Marx 1990; Beardsley et al. 1996; Baumgartner et al. 2003; Davies et al. 2013). Late stages of *C. hyperboreus* are likely an important prey item for NARW in the Gulf of St. Lawrence (GSL) due to their abundance and relatively high energy content (Lehoux et al. 2020). NARW requires the presence of high densities of prey that occur in localized patches for foraging to be profitable (Kenney et al. 1986; Baumgartner and Mate 2003; Gavrilchuk et al. 2021). The dynamics of prey patches, which are governed by the interaction of biological and physical processes (e.g. Sorochan et al. 2021), likely influence the distribution of NARW.

The distribution of NARW detections changed substantially on western North Atlantic shelves in the 2010s (Davis et al. 2017; Davies et al. 2019; Record et al. 2019; Meyer-Gutbrod et al. 2022; Fig. 11.4-2). In the late 2010s, acoustic detections increased in the southern GSL (Simard et al. 2019) and photographic identification of NARW from aerial surveys indicated that the GSL was an important habitat for ~40% of the population (Crowe et al. 2021). The change in distribution of NARW was associated with an increase in the number of anthropogenic mortalities (Davies and Brillant 2019), with multiple deaths in 2017 and 2019 in the GSL (Daoust et al. 2018; Bourque et al. 2020). The foraging ecology of NARW in the GSL has not been studied as intensively as in other known foraging areas in the GoM and western SS. Initial studies on the spatial distribution of *Calanus* spp. and bioenergetics of NARW have indicated that the sGSL is likely suitable foraging habitat for NARW (Plourde et al. 2019; Gavrilchuck et al. 2021) although it may be insufficient to support lactating and pregnant females in some years (Gavrilchuck et al. 2021; Fig. 11.4-3). The presence of potentially suitable foraging habitat in the sGSL is consistent with high numbers of NARW sightings in this subregion in recent systematic surveys (DFO 2019d, 2020a). Gavrilchuck et al. (2021) reported substantial annual variation in the coverage of potentially suitable foraging habitat for NARW in the sGSL. These variations are influenced by regional population level upstream of the sGSL and transport of *Calanus* spp. (Brennan et al. 2019, 2021). At the scale of the western North Atlantic, the change in distribution of NARW has been linked to a shift in environmental conditions (Record et al. 2019; Sorochan et al. 2019; Meyer-Gutbrod et al. 2021). In comparison to the 2000s, waters on western North Atlantic shelves in the 2010s were generally characterized by higher ocean temperatures, lower abundance of *C. finmarchicus*, higher abundance of non-copepod zooplankton, and lower zooplankton biomass (e.g. DFO 2021e). Several studies have linked climate-driven variation in the oceanography of the western North Atlantic, including shifting dominance of cool and fresh Labrador Slope Water (associated with the Labrador Current) and warm and salty Warm Slope Water (associated with the Gulf Stream), to interannual and decadal-scale variation in population levels of *C. finmarchicus* in the GoM (Licandro et al. 2001; Greene et al. 2003; MERCINA 2004, 2012; Meyer-Gutbrod et al. 2021). Annual and decadal scale shifts in prey abundance can influence NARW reproduction (Meyer-Gutbrod and Greene 2014; Meyer-Gutbrod et al. 2021), and during periods of low reproduction, anthropogenic NARW mortality can result in a substantial decline in overall population numbers (Meyer-Gutbrod and Greene 2018).

Interannual variation in the abundance of *C. finmarchicus* in the GoM and on the SS has been shown to be negatively correlated with ocean temperature (Licandro et al. 2001; Record et al. 2019; Sorochan et al. 2019). The relatively high ocean temperatures observed in the western North Atlantic in the 2010s resulted from rapid warming since around 2005 (Brickman et al. 2018; Seidov et al. 2021). Recent warming has been attributed to changes in the positioning and meandering of the Gulf Stream (Chen et al. 2020; Meyer-Gutbrod et al. 2021; Gonçalves Neto et al. 2021) and an increase in the prevalence of subsurface warm anomalies that appear to have propagated westward from the tail of the Grand Banks (Brickman et al. 2018). Interdecadal variation in temperature can be attributed to natural variability and anthropogenic global warming. Observed ocean warming and a northward shift in the position of the Gulf Stream in the late 2000s and 2010s (Seidov et al. 2021) are consistent with the hypothesis that weakening of the Atlantic Meridional Overturning Circulation (AMOC), associated with increasing global atmospheric $CO_2$, has contributed to enhanced warming in the western North Atlantic (Saba et al. 2016). Although the exact mechanisms that lead to variation in the physical environment and population level of *C. finmarchicus* are not yet fully understood, changes in environmental conditions, including warming ocean temperature, may influence the distribution and abundance of zooplankton and NARW suitable habitat in the coming decades (Grieve et al. 2017; Ross et al. 2021). If prey distribution continues to shift northward in the North Atlantic (e.g. Reygondeau and Beaugrand 2011; Chust et al. 2014), the distribution of NARW could also continue to change. This could result in more NARW detections at higher latitudes, including the Newfoundland and Labrador Shelves. While NARW has been reported only occasionally in waters off Newfoundland (e.g. Lien et al. 1989), multiple NARW detections occurred off Newfoundland in the summer and fall of 2021 (J. Lawson, *pers. comm.*).

Interannual and decadal variability in circulation, hydrography, and zooplankton community composition can have significant consequences for planktivores, including the NARW. Sustained DFO ocean monitoring of these environmental variables and NARW occurrence are critical for assessment and mitigation of future environmental change on NARW and other higher trophic level species.

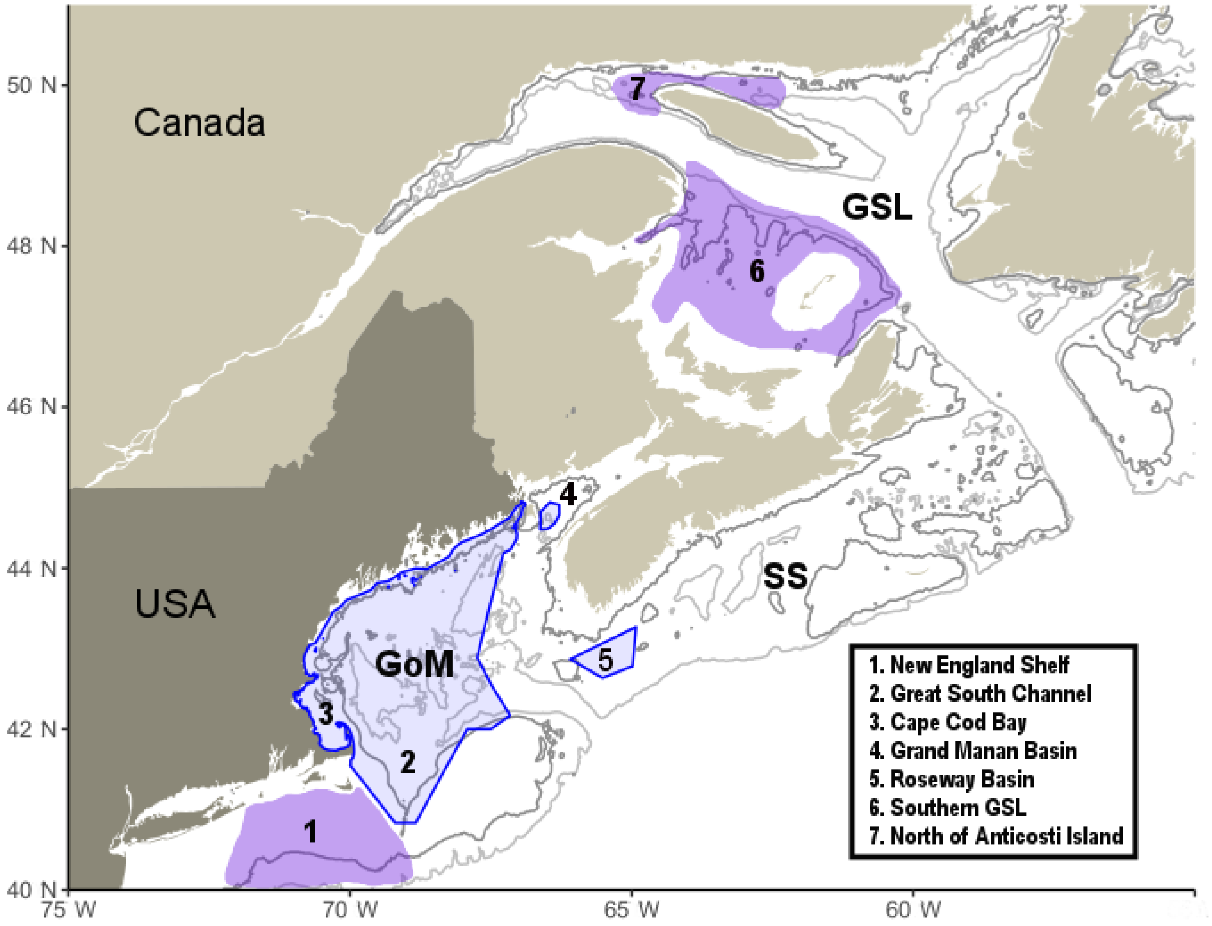

Figure 11.4-2. Foraging areas of the North Atlantic Right Whale (*Eubalaena glacialis*) including “traditional” foraging areas in designated critical habitat (blue areas 2 to 5) and schematic of areas of frequent *E. glacialis* detection from 2017 through 2021 (purple areas 1, 6, and 7).

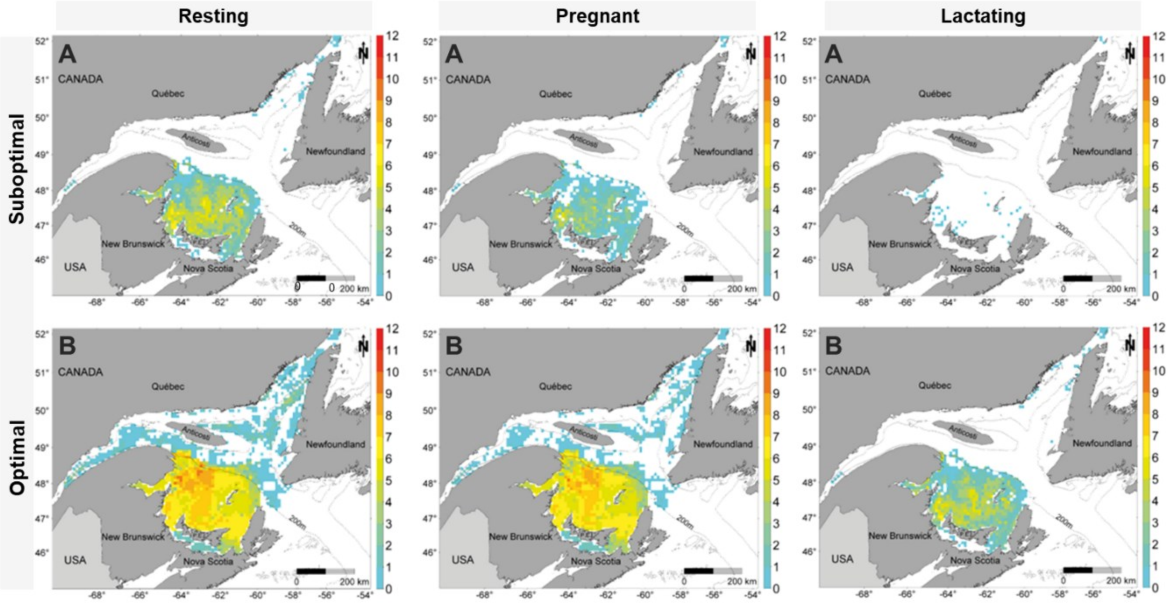

Figure 11.4-3. Persistent suitable foraging habitat in the Gulf of St. Lawrence from June to September 2006−2017 for resting, pregnant, and lactating North Atlantic Right Whales under A) suboptimal (low energy gain for high energy expenditure) and B) optimal (high energy gain for low energy expenditure) foraging scenarios. Scale shows the number of years a given grid cell had at least one 10 m depth bin with suitable prey density. Adapted from Gavrilchuk et al. (2021).

### *11.4.2 Seabird populations respond to reduced forage fish availability*

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As top predators, seabirds are an integral part of a healthy ecosystem and serve as important indicators of changes in the abundance and distribution of the forage fish on which they rely (e.g. Fig. 11.4-4) (Davoren and Montevecchi 2003; Gaston et al. 2003). For example, Northern Gannet (*Morus bassanus*) chicks reared on Bonaventure Island, QC, the largest colony in North America, obtain most of their nutritional energy from Atlantic Mackerel (*Scomber scombrus* L.; Rail et al. 2013). Northern Gannets have experienced low reproductive success since 2009—below the level required to maintain a stable population—marking the end of a period of population growth (Guillemette et al. 2018). Poor breeding conditions are attributed to low food availability linked to recent stock declines and changes in the distribution of Atlantic Mackerel in the Gulf of St. Lawrence (GSL) (DFO 2021f; Smith et al. 2020). The 2022 closure of the commercial and bait fishery for Atlantic Mackerel provides a unique opportunity to study the impact of the closure on stock recovery by tracking the health of Northern Gannet populations, well documented indicators of the health of the GSL.

Figure 11.4-4. Given their heavy reliance on fish populations, seabirds like this Razorbill (*Alca torda*) are excellent indicators of the general health of the ocean environment. Photo credit: Christina Petalas.

Further south in the Bay of Fundy, declining Atlantic Herring (*Clupea harengus*) stocks are impacting the most important seabird breeding colony in the Gulf of Maine (GoM): Machias Seal Island. Alcids and terns at this site rely on Atlantic Herring to successfully raise their young, but since the early 2000s, they have shifted their diets to lower quality prey (such as juvenile Sand Lance *Ammodytes dubius*, euphausiid crustacea, and other larval fish) leading to reduced breeding success (Gaston et al. 2009). Consequently, attendance at the largest tern colony in the GoM collapsed in 2006 and remains low (Gaston et al 2009; Scopel and Diamond 2017). Furthermore, the decline in Atlantic Herring abundance has been linked to reduced adult survival in Atlantic Puffins (*Fratercula arctica*), causing general concern for the sustainability of their breeding in the GoM (Breton and Diamond 2014). Rising water temperatures in the Bay of Fundy and some levels of allowable catch are raising alarms for the long-term persistence of spawning Atlantic Herring populations (Melvin et al. 2009). No-take zones around important seabird colonies can be effective at reducing forage fish competition between seabirds and commercial fisheries (Soanes et al. 2016; Bogdanova et al. 2014; Guillemette et al. 2018). However, 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; Guillemette et al. 2018).

## 11.5 Scientific Innovations to Advance Ecosystem Understanding

Scientists are continually improving how they learn and study Atlantic Canadian ecosystems. New sampling and sensing methods and tools have allowed researchers to gain more detailed and more frequently collected data to provide new kinds of observations that improve our understanding of species and habitats. These complementary and collaborative approaches can provide researchers with high-resolution data with less effort, making information more complete and more accurate, increasing the efficiency of analysis, and even detecting new species.

This section highlights the application of technologies to provide enhanced scientific advice for conservation and protection of marine species and habitats or to improve large-scale and long-term monitoring.

- Passive acoustic monitoring, vessel-based visual and acoustic surveys, and modelling of individual movements were combined to identify important year-round inter-canyon foraging and transiting areas for Northern Bottlenose Whales along the continental slope.
- FlowCam® Imaging particle analysis technology and environmental DNA metabarcoding approaches will improve detection and quantification of the impact of human stressors on the coastal food web.
- Applying DNA barcoding and complementary spicule analysis on hard-to-identify specimens led to the identification and naming of new sponge species in the Gulf of St. Lawrence, which will identify key habitats requiring protection from bottom-contact activities and promote biodiversity.
- A new climate index aims to describe the environmental conditions on the Newfoundland Shelf, providing continuity in the production of advice for fisheries management and ecosystem status.

### *11.5.1 Determining Northern Bottlenose Whale habitat connectivity on the eastern Scotian Shelf with a multi-method approach*

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The endangered Scotian Shelf (SS) population of Northern Bottlenose Whales (*Hyperoodon ampullatus*) occurs primarily along the eastern edge of the SS off Nova Scotia (Wimmer and Whitehead 2004), and the Gully, Shortland, and Haldimand Canyons were identified as critical habitat for the population in 2016 (Fig. 11.5-1; DFO 2016). Although individuals were known to move among these canyons (Wimmer and Whitehead 2004; O'Brien and Whitehead 2013), little was known about the extent to which they used the areas in between these three canyons. Passive acoustic monitoring, vessel-based visual and acoustic surveys, and modelling of individual movements were used to examine the distribution and habitat use of Northern Bottlenose Whales within and between the designated critical habitats (Stanistreet et al. 2021). Northern Bottlenose Whales are present year-round in the inter-canyon areas, which represent important habitat for foraging and frequent transiting between the canyons (Fig. 11.5-1). Acoustic monitoring efforts have been expanded along the edges of the SS and the Grand

Banks off Newfoundland and species distribution models are under development for this population. Together, these efforts will provide further insights into the occurrence and foraging activities of this endangered population throughout its range.

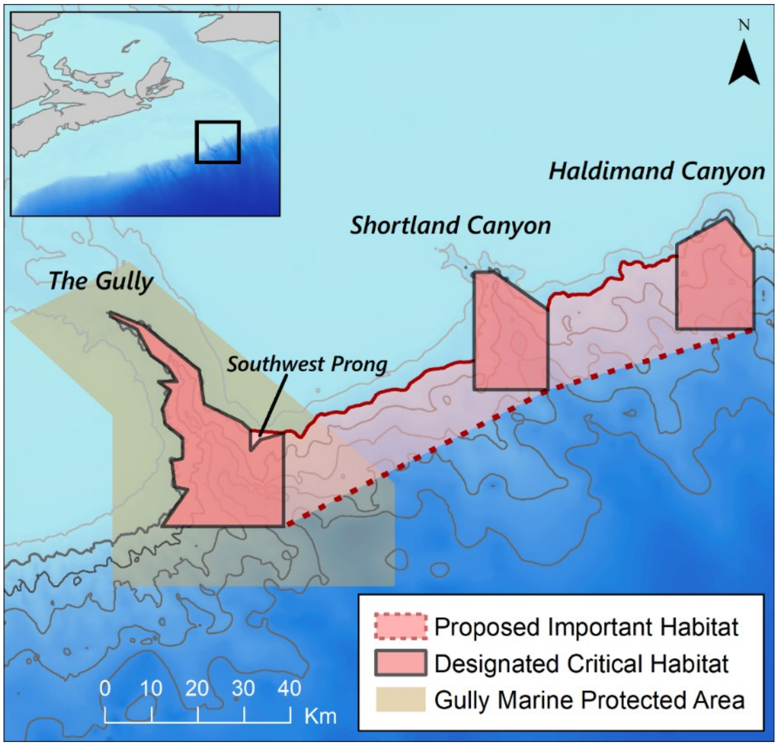

Figure 11.5-1. Current Designated Critical Habitat for Northern Bottlenose Whales and Proposed Important Habitat in the inter-canyon areas on the eastern Scotian Shelf. Adapted from Stanistreet et al. (2021).

### *11.5.2 Optimizing environmental DNA metabarcoding and imaging particle systems to monitor zooplankton dynamics in Canada’s sensitive coastal ecosystems*

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Plankton are the base of marine food webs, so understanding the impact of human activities on plankton dynamics is crucial for sustaining aquaculture, fisheries, and other marine life. The food chain can be perceived as an engine transferring energy or biomass between trophic levels (Lindeman 1942). The impact at higher trophic levels (i.e. fish, birds, mammals) requires understanding the local energy flows through pelagic communities, where predator–prey interactions and physiological limitations scaled with body size are critical information to define the length of marine food chains and the trophic efficiency (Andersen 2019).

Zooplankton are the main link between primary producers and fish. However, characterizing the food web dynamics requires monitoring the biomass, size, and community structure of zooplankton. This is achieved through intensive sample collection; however, this can be challenging due to the high natural variability of water column properties and seasonal cycles of zooplankton communities. Understanding ocean dynamics to inform sustainable marine decision-making thus requires characterizing zooplankton at high frequency, which is often associated with higher costs due to increased labour and time.

The DFO Aquaculture Monitoring Program (AMP) is aiming to relate long-term variability in zooplankton biomass size spectra to environmental drivers in order to understand how shellfish aquaculture and climatic variability impact energy flow though the marine food web. Little is known about potential direct and indirect impacts of shellfish aquaculture on zooplankton. Enumeration, identification, and size measurement by traditional methodology (i.e. microscopy) is too resource demanding for routine application and there have therefore been a number of efforts to develop more efficient methodologies. AMP is thus currently testing and optimizing a combination of new technologies to ensure an efficient and cost-effective monitoring approach for zooplankton and to determine the risk of impact from shellfish aquaculture on higher trophic levels. In addition to using traditional biomass metrics and flow cytometry (nanoplankton and bacterioplankton, 2–20 µm), AMP is currently testing and optimizing two recent and complementary technologies for Canadian coastal waters: environmental DNA (eDNA) metabarcoding and imaging particle systems (micro- and macro-FlowCam®, 50–600 µm and 250 µm–5 mm).

eDNA monitoring is a method that can detect traces of DNA from organisms in cellular or extracellular form in seawater from sources such as feces, secreted mucous membranes, gametes, and skin cells (Thomsen et al. 2012; Lacoursière-Roussel and Deiner 2021). It is different from DNA or metagenomics, which typically refer to genetic material extracted from organisms. eDNA metabarcoding can complement—and overcome the limitations of—conventional methods by targeting different species, sampling greater diversity, and increasing the resolution of taxonomic identifications (see the review Deiner et al. 2018). eDNA has also the potential to characterize biodiversity from the tiniest to the largest marine animals by sampling only a few litres of seawater. Integrating eDNA analysis in monitoring of coastal biodiversity could help standardize biodiversity monitoring and early detection of species shifts (Abbott et al. 2021). eDNA concentrations in water vary greatly temporally, likely due to biological and physical processes (Leduc et al. 2019; Sevellec et al. 2021). Understanding eDNA temporal dynamics is thus essential for optimizing monitoring strategies and for interpreting long-term biodiversity patterns. We are evaluating the eDNA metabarcoding approach as a potential tool to monitor zooplankton community composition and species relative abundance by pairing it with direct sampling surveys (e.g. taxonomy on plankton net tow samples). We are also studying temporal variations in the eDNA detectability at multiple temporal scales (seasonally, annually) in different Canadian regions to infer regional biotic and abiotic factors altering the detection of zooplankton eDNA indices. These results will contribute to our general knowledge of eDNA temporal dynamics.

Using automated imaging technologies allows the generation of unprecedented volumes of plankton image data. FlowCam® provides a fast alternative to manual microscopy for monitoring plankton physical measurements, biovolume calculations, size distribution, and semi-automated classification of organisms. The FlowCam® Imaging particle analysis technology combines the benefits of digital imaging and microscopy into a single instrument to measure the size and shape of microscopic particles in a fluid medium (Fig. 11.5-2). The accuracy of physical measurements is powerful and can be applicable for large samples if the software is well trained for local diversity. The classification of organisms requires an initial phase of image library construction to train the algorithms recognizing specific taxa. In an effort to develop a long-term monitoring program, AMP has developed more than 125 libraries since 2019, covering four bays in Nova Scotia, three bays in Prince Edward Island, one bay in Newfoundland, and one bay in

British Columbia. Of the four locations, more than 165 samples have been collected and run through the FlowCam® for processing. In order to differentiate the size spectra by taxa and/or life stages, AMP has currently developed libraries by DFO Region (49 libraries in Maritimes, 45 in Gulf, 33 in Newfoundland, and 46 in Pacific). Each library is first developed by imaging specimen collection identified by taxonomists. To improve rapidity and accuracy of the classification system overtime, we implemented a standard procedure where libraries can be updated over time as samples are accrued. The improvement of images in libraries has the potential to improve the efficiency of this tool and reduce hand sorting of images. International effort is currently growing to collaboratively improve the accuracy of existing automated plankton imaging and classification systems (e.g. Kerr et al. 2020), in turn, improving our ability to detect and quantify potential impact of human stressors on the coastal food web.

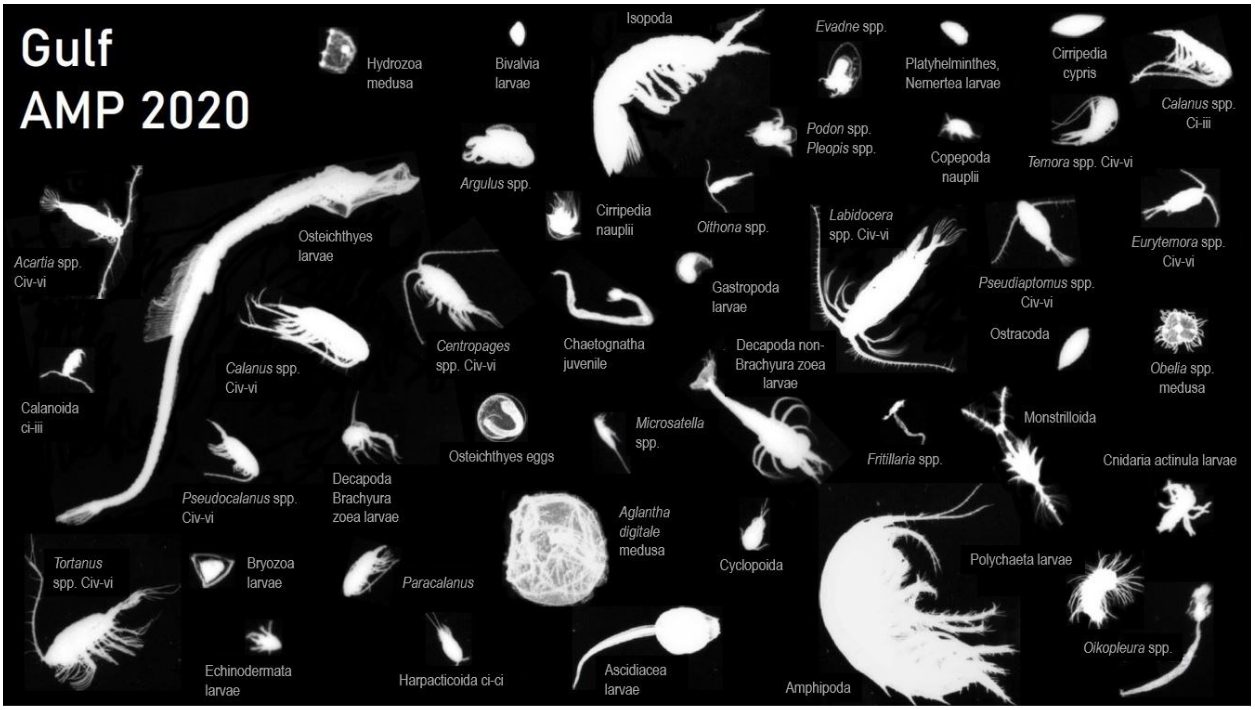

Figure 11.5-2. Species richness identified using FlowCam® images in the Gulf of St. Lawrence.

### *11.5.3 Enriching sponge taxonomic knowledge in the Gulf of St. Lawrence using morphology and DNA analyses*

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Sponges (Phylum Porifera) are relatively simple animals that lay a strong foundation for many marine ecosystems. Sponges, like corals, can create complex living habitat (Miller et al. 2012; Hawkes et al. 2019), and several species in eastern Canada have recently been identified as important ecosystem engineers that are vulnerable to fishing damage (Beazley et al. 2013; Kenchington et al. 2015). Sponges also filter small organic material from their surrounding water to feed. As an example of the important role of sponges in aquatic ecosystems, theoretical removal of sponges from the Flemish Cap region off Newfoundland and Labrador has been likened to the removal of the filtering capacity of a large water treatment plant, which is suggested to have a monetary value of hundreds of millions of dollars annually (Pham et al. 2019).

There are more than 9,000 species of sponge globally (de Voogd et al. 2022) with varied growth forms and life histories (Hooper and Van Soest 2002). Since sponge species differ markedly in physiology (Leys and Meech 2006), growth rate (Schippers et al. 2012), and filtering capacity (Weisz et al. 2008; Leys et al. 2011), the importance of understanding where different sponge species are distributed is critical to better understand how to prevent damage to the ecosystem due to fishing and industrial activity.

While most animal species can be easily identified by size and shape, sponges grow without symmetry or predictable patterns. As filter feeding animals, sponges can grow to take advantage of currents and water flow (Bidder 1923; Vogel 1977; Palumbi 1984). This leads to growth forms that differ even within a single species. For this reason, sponges are considered particularly difficult to identify at the species level by visual means alone. Most sponges do, however, have unique mineral skeletons that often differ between species. These skeletons are formed by silica (glass) or calcium carbonate, and the individual skeletal pieces are called spicules. Isolating and measuring spicules can help a taxonomist to identify many sponge species. Spicule measurements require a microscope—sometimes high-powered scanning election microscopes are required to view microscopic spicules.

Annual fishery-independent surveys carried out by DFO have been occurring in the Gulf of St. Lawrence (GSL) since 1971, but sponges collected during these surveys have largely been recorded at the phylum level. Some sponge species are notoriously difficult to identify in the field (Hooper and Van Soest 2002) and it is difficult to identify many trawl collected specimens without detailed guides or effort in the lab. As a result, much of the data available for sponge catches in these surveys is reduced to the catch weight of the phylum as a whole. Although sponge biomass is an important indicator to delineate important sponge habitat, a better understanding of species-specific distributions and species associations is critical to better understand how sponges affect local ecosystem functioning, nutrient turnover, and resilience to disturbance.

Starting in 2018, DFO Gulf's Marine Conservation group led a project to identify sponge species collected in several surveys in the GSL. Sponges were photographed, pieces were processed for spicule measurements, and DNA barcoding was conducted on hard-to-identify specimens. From this work, a field guide of the sponges of the GSL was created that includes 46 different sponge taxa (e.g. Fig. 11.5-3) (Dinn 2020a). This work has also led to the naming of new species, including two encrusting sponges from the family Crellidae (Goodwin et al. 2021) and a new species of the recently described sub-genus *Haliclona* (*Flagellia*) (Dinn 2020b). Additionally, four Atlantic fan-shaped sponges that occur throughout eastern Canada were compared to prevent further confusion between those species (Dinn et al. 2020). One of the four fan-shaped sponges was renamed as it was previously placed in the wrong genus, which was revealed from spicule and DNA analysis. Additional sponges are being described, including a new species of sponge with a wide Northwest Atlantic distribution. A report on the history of sponge identifications in the region from 1971 to present is also being prepared to describe the need for species-level identifications moving forward.

This work contributes to the marine conservation targets program, which has set a goal to protect 30% of Canada's oceans by 2030. Currently coral and sponge areas represent 38 of 59 other effective area-based conservation measures (OECMs) in Canadian waters (DFO 2021g). The identification of important coral and sponge habitat is key to deciding which additional areas should be protected from bottom-contact activities to ensure continued use of our valuable marine ecosystems.

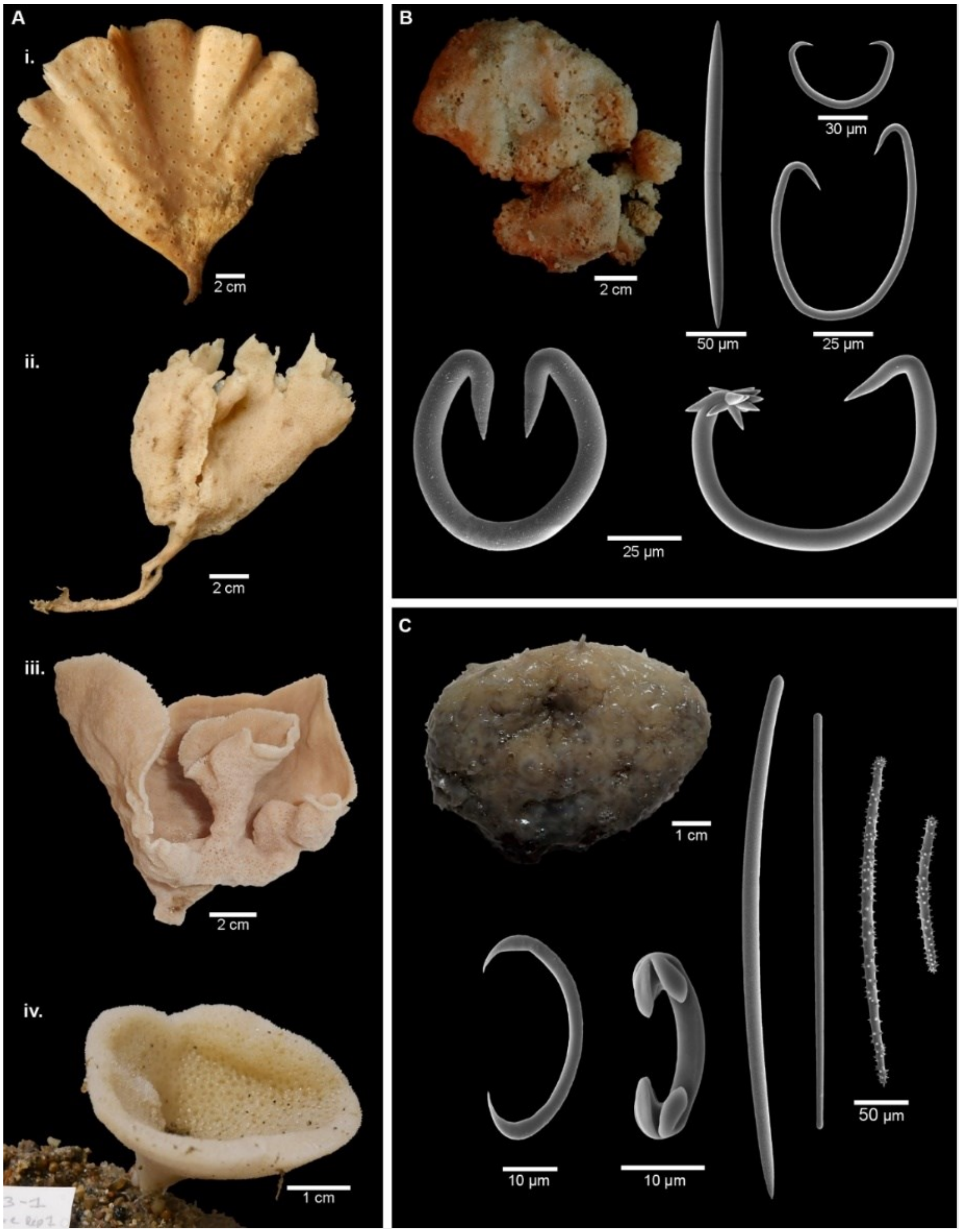

Figure 11.5-3. Example sponge species identified from 2018 to 2021. A) Fan-shaped sponges from eastern Canada described in Dinn et al. (2020): i. *Cladocroce spatula*, ii. *Semisuberites cribrosa*, iii. *Plicatellopsis bowerbanki*, and iv. *Axinella arctica*. B) *Haliclona* (*Flagellia*) *xenomorpha* specimen and spicules, a new species described in Dinn (2020b). C) *Crella* (*Pytheas*) *cutis* specimen and spicules, one of two new species described in Goodwin et al. (2021).

### *11.5.4 A new climate index for the Newfoundland and Labrador Shelf*

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Climate indices are simple descriptors of the state of the environment within a certain region or ecosystem. They generally integrate a number of contributions from different variables or aspects of the climate of the region of interest. Useful and accessible climate indices are key pieces of information for ecological and environmental studies and climate and fisheries research. Climate indices are also useful pieces of information for the implementation of an ecosystem approach to fisheries management.

At DFO, climate indices (also referred to as composite indices; see Chapter 2 *Physical Oceanography*) are often found in annual reports of the state of the ocean produced as part of the Atlantic Zone Monitoring Program (AZMP) (e.g. DFO 2021). In the Newfoundland and Labrador (NL) Region, such indices are used, for example, during various stock assessments of commercial marine resources (Koen-Alonso et al. 2010; DFO 2014b), to assess marine mammal stock fluctuations (DFO 2020; Hammill et al. 2021; Stenson et al. 2020c), or to evaluate the ecosystem productivity as a whole (NAFO 2017, 2018).

Cyr and Galbraith (2021) introduced a new climate index for the NL Shelf (available online, see Cyr and Galbraith 2020). The NL climate index (NLCI) aims to describe the environmental conditions on the NL Shelf and in the Northwest Atlantic (NWA) as a whole (Figs. 11.5-4 and 11.5-5). It consists of the average of 10 standardized anomalies, or subindices, derived annually: winter North Atlantic Oscillation (NAO), air temperature, sea ice season severity, iceberg count, seasonal sea-surface temperature, vertically averaged temperature and salinity at the AZMP Station 27, summer cold intermediate layer (CIL) core temperature at AZMP Station 27, summer CIL area on three AZMP hydrographic sections, and bottom temperature on the NL Shelf. The index runs from 1951 to 2020 and will be updated annually. It also provides continuity in the production of advice for fisheries management and ecosystem status on the NL Shelf, for which a similar but recently abandoned index was used.

The NLCI highlights the different regimes prevailing on the NL Shelf and the NWA since 1951. For example, the 1960s stands out as the warmest decade of the entire 1951–2020 period, although it is heavily driven by CIL anomalies. The following few decades were gradually cooling until the early 1990s, with 1991 being the coldest year on record since 1951. The warming trend that followed the early 1990s peaked in 2010–2011 (depending on the record) and was followed by recent cooling that culminated in 2015. This recently observed cold period on the NL Shelf (roughly 2014–2017) was the coldest period since the early 1990s and coincided with the intensification of convection in the Labrador Sea that created the largest volume of Labrador Sea Water since the early 1990s (Yashayaev and Loder 2017).

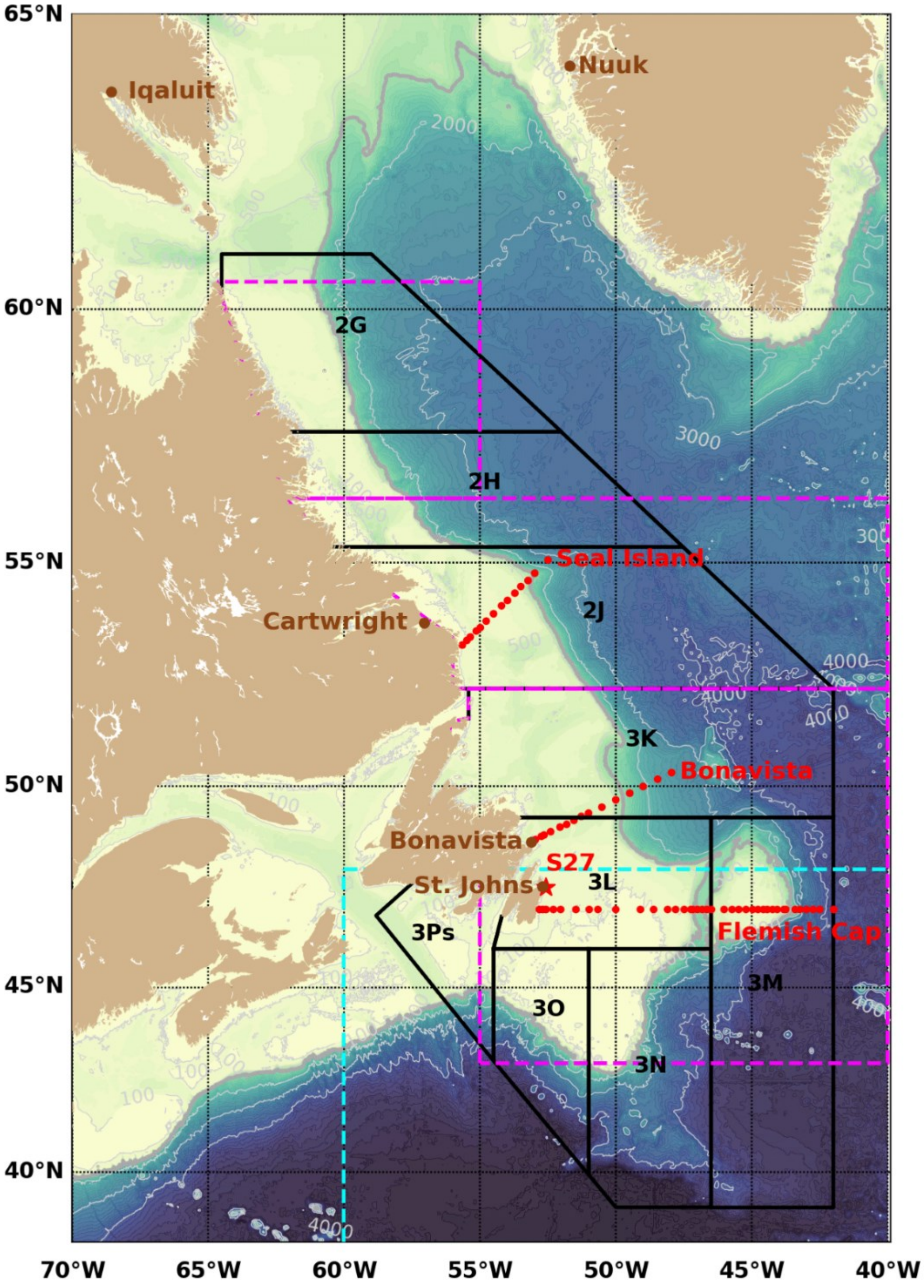

Figure 11.5-4. Map and main bathymetric features of the western North Atlantic ocean. NAFO Divisions (sub-areas 2 and 3) on the Newfoundland and Labrador (NL) shelf are drawn. The AZMP hydrographic sections Seal Island, Bonavista Bay and Flemish Cap are shown with red dots. Long-term AZMP hydrographic Station 27 is highlighted with a red star. The five stations used for the air temperature time series are shown in brown. The three regions used for sea ice calculations are drawn with dashed magenta lines: northern Labrador shelf, southern Labrador shelf, and Newfoundland shelf, respectively, from north to south. The region used by the International Ice Patrol (IIP) for iceberg sightings south of 48°N is drawn in dashed cyan. The shelf break is delimited by a thicker and darker contour corresponding to the isobath 1000 m (used to clip the sea-surface temperature and bottom temperature). Adapted from Cyr and Galbraith (2021).

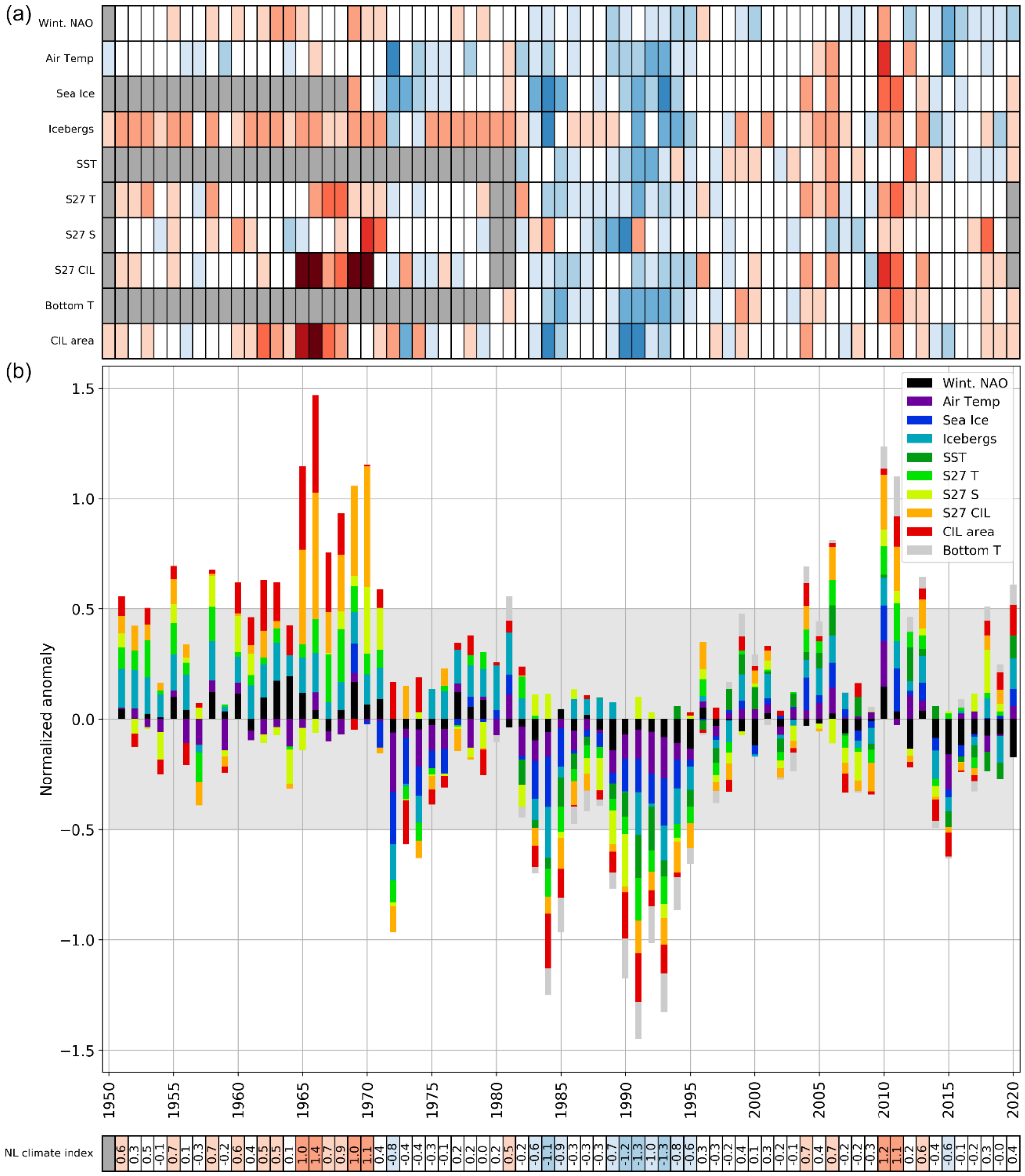

Figure 11.5-5. The Newfoundland and Labrador climate index (NLCI). The scorecard in panel (a) represents the 10 subindices used to construct the NLCI, colour coded according to their value (blue=negative, red=positive, white=neutral). These time series are the following: winter NAO index (starts in 1951), the air temperature at five sites (starts in 1950), the sea ice season duration and maximum area for the northern Labrador, southern Labrador, and Newfoundland Shelves (starts in 1969), the number of icebergs (starts in 1950), sea-surface temperatures (SST) in NAFO Division 2GHJ3KLNOP (starts in 1982), vertically averaged temperature and salinity at Station 27, CIL core temperature at Station 27 (starts in 1951), the summer CIL areas on the hydrographic sections of Seal Island, Bonavista Bay, and Flemish Cap (starts in 1950), and the spring and fall bottom temperature in NAFO Divisions 3LNOPs and 2HJ3KLNO, respectively (starts in 1980). The sign of some indices (NAO, ice, icebergs, salinity, and CIL volume) has been reversed when positive anomalies are generally indicative of colder conditions. Gray cells in the scorecards indicate the absence of data. Panel (b) represents the NLCI as a stacked bar in which the total length of the bar is the average of the respective subindices and their relative contribution to the average is adjusted proportionally. The scorecard at the bottom of the figure shows the colour-coded numerical values of the NLCI. Adapted from Cyr and Galbraith (2021).

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# 12. KEY MESSAGES AND SYNTHESIS

Climate change—through increases in air temperature and alterations in global ocean circulation patterns—continues to drive changes in Atlantic Canadian waters. Warmer ocean conditions were reflected in all metrics, resulting in record values for temperature, sea ice, and the cold intermediate layer, particularly in 2021. There is still considerable interannual variability, but the long-term warming trend remains clear. Acidity is also increasing across the Atlantic, and at rates faster than the global average. Oxygen saturation has also been declining and is most prevalent in the northern Gulf of St. Lawrence near the head of the Laurentian Channel.

Warming surface and deep waters as well as shifts in ocean circulation are important drivers of change in nutrients, phytoplankton, and zooplankton. There has been a recent shift to higher deep-water nitrate and near or above-normal phytoplankton biomass in the Gulf of St. Lawrence and on the Newfoundland and Labrador Shelves. Recent changes in zooplankton community structure also suggest a gradual return to average abundances of *Calanus finmarchicus* with potentially beneficial consequences on the flow of energy toward higher trophic levels. However, long-term declines in these lower trophic level indices may be indicative of lower ecosystem production potential compared to previous decades.

Coastal macrophyte habitats of kelp and Eelgrass have been reduced from historical levels in many areas of the Atlantic zone, although some healthy areas persist and are increasing where conditions are favourable. The combined effects of multiple stressors, like warmer waters, invasive species, and excess nutrient input, on macrophytes are also impacting their associated species and disrupting the ecosystem services that kelp and Eelgrass provide.

Fish and invertebrate communities in the Atlantic zone continue to feel the impacts of historical overfishing. However, in combination with rapidly changing environmental conditions, additional ecological and anthropogenic pressures continue to hinder the recovery of many species and perpetuate significant changes in community structure. Communities now feature American Lobster and redfish more prominently, with continued low numbers of forage fish, many demersal fish, and Atlantic Salmon. However, the dynamics of species with high interannual variability or those that are data poor—such as large invertebrates of small-scale fisheries, demersal sharks and skates, and pelagic sharks—remain unexplained.

Important habitats for whales have recently been identified, providing key insights into their occurrence and foraging activities throughout Atlantic Canadian waters. The identification of these priority areas allows for the effective monitoring of cetacean species and aids in efforts to mitigate the impacts of human activities on their population recovery, including implementing various management actions to alleviate multiple stressors and provide advice for fisheries management and ecosystem status.

The consequences of climate change on marine biota may be profound, affecting growth, reproduction, and survival of species, altering habitat conditions, and driving range expansions or contractions with further changes in community composition and altered predator–prey interactions and food webs. The interaction of increased acidity, low oxygen saturation, and warming bottom waters in some areas of the northern Gulf of St. Lawrence has created a particularly stressful environment for commercially important invertebrates. Effects of these environmental changes have been observed for marine biota across all trophic levels and functional groups.

In response to changes in prey availability (e.g. *Calanus* copepods and forage fish) and habitats (e.g. sea ice, macrophytes), many larger fish, seabirds, and mammals have adapted by varying their behaviour or diet, with consequences for their overall health. A diverse array of species in Atlantic Canada remain at risk from across taxonomic groups—fish, sea turtles, pelagic sharks, seabirds, and whales—and most have not been able to recover in the face of multiple stressors. In contrast, for a handful of Atlantic species, observed increases in abundance or documented recovery provides cautious optimism for marine life in the face of mounting pressures.

DFO continues to work towards a more comprehensive ecosystem-based perspective, including more consistent approaches among bioregions. Although this remains difficult, new technologies and new methods continue to improve our understanding of the status and trends of Atlantic ecosystems. These applications have led to more efficient monitoring, new species discoveries, and the identification of key habitats for various marine species. Advances in our understanding of species' ecology, increased availability of relevant environmental data, and advanced modelling frameworks will improve our knowledge, leading to more accurate predictions of how species will likely respond to anthropogenic stressors and climate change–driven alterations in their ecosystems.

# 13. ACKNOWLEDGEMENTS

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# APPENDIX 1. STATUS AND TRENDS SUMMARY TABLE

Table A1. List of environmental variables and species included in this report. Bioregions: Newfoundland and Labrador Shelves (NLS), Scotian Shelf (SS), Gulf of St. Lawrence (GSL) sometimes reported as northern (nGSL) and southern (sGSL). ATL indicates a species assessed across the Canadian Atlantic. Summary statements of status and trend information presented in this report or obtained directly from references. Full citations are listed within the respective chapters.

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| | | | Chapter 2. Physical Oceanography | | |
| **Ocean Temperature** | | | | | |
| Sea surface | - | ATL | variable; third-warmest year in series 2021 | 2021 | DFO 2022 |
| Sea surface | - | GSL | warmest year in series 2016 | 2021 | DFO 2022 |
| Deep/Bottom | - | nGSL | normal to above normal | 2021 | DFO 2022 |
| Deep/Bottom | - | SS | normal to above normal | 2021 | DFO 2022 |
| Deep/Bottom | - | NLS | normal to above normal; 2021 series record | 2021 | DFO 2022 |
| **Sea ice** | | | | | |
| Sea ice index | - | GSL | lower than normal / 2021 record low | 2021 | DFO 2022 |
| Sea ice index | - | SS | lower than normal / 2021 record low | 2021 | DFO 2022 |
| Sea ice index | - | NLS | lower than normal | 2021 | DFO 2022 |
| **North Atlantic Oscillation (NAO)** | | | | | |
| NAO index | - | ATL | 2021 negative after positive (cooler) anomaly streak (2016–2020) | 2021 | DFO 2022 |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| **Cold Intermediate Layer (CIL)** | | | | | |
| CIL volume | - | GSL | warmer than normal / 2021 record low in series | 2021 | DFO 2022 |
| CIL volume | - | SS | warmer than normal | 2021 | DFO 2022<br>*data not collected in 2021 |
| CIL volume | - | NLS | warmer than normal | 2021 | DFO 2022 |
| **Runoff** | | | | | |
| - | - | GSL | highly variable | 2021 | DFO 2022 |
| **Stratification** | | | | | |
| Stratification index | - | GSL | highly variable | 2021 | DFO 2022 |
| Stratification index | - | SS | mostly normal | 2021 | DFO 2022 |
| Stratification index | - | NLS | variable | 2021 | DFO 2022 |
| **Mean Sea Level** | | | | | |
| RSL | - | nGSL | rising in some areas and falling in others; overall trend small | 2021 | Hebert et al 2021; Han et al. 2014 |
| RSL | - | SS | rising 20 to 40 cm/century | 2021 | Hebert et al. 2021; Han et al. 2014 |
| RSL | - | NLS | rising in south (22 cm/century); falling in north (20 cm/century) | 2021 | Hebert et al. 2021; Han et al. 2014 |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Chapter 3. Carbonate Chemistry, pH, and Dissolved Oxygen | | | | | |
| **Ocean Acidity** | | | | | |
| pH | - | ATL | decreasing 0.03–0.04/decade | 2020 | DFO 2022 |
| pH | - | GSL | <7.6 in the SLE; increase since 2019; Gulf decreasing 0.04 pH units/decade; 2020 record low in series | 2020 | DFO 2022 |
| pH | - | SS | 7.8 to 8; decreasing 0.03 pH units/decade | 2020 | DFO 2022 |
| pH | - | NLS | 7.8 to 8; Labrador Sea decreasing 0.03 pH units/decade | 2020 | DFO 2022 |
| **Carbonate Saturation State (Ω)** | | | | | |
| Carbonate saturation state | - | GSL | bottom waters undersaturated for aragonite; deep waters in SLE undersaturated for calcite and aragonite | 2020 | DFO 2022 |
| Carbonate saturation state | - | SS | slightly undersaturated on eastern SS | 2020 | DFO 2022 |
| Carbonate saturation state | - | NLS | slightly undersaturated in deeper areas | 2020 | DFO 2022 |
| **Dissolved Oxygen** | | | | | |
| Dissolved oxygen | - | GSL | deep channels consistently hypoxic (below 30% saturation) | 2020 | DFO 2022 |
| Dissolved oxygen | - | SS | generally high | 2020 | DFO 2022 |
| Dissolved oxygen | - | NLS | generally high | 2020 | DFO 2022 |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Chapter 4. Nutrients and Plankton | | | | | |
| **Nutrients** | | | | | |
| Deep nitrate | - | ATL | record lows in 2017/2018; increased to near normal in 2019–2020 | 2020 | DFO 2022 |
| Deep nitrate | - | GSL | shift from below normal to above normal | 2020 | DFO 2022 |
| Deep nitrate | - | SS | mostly below normal | 2020 | DFO 2022 |
| Deep nitrate | - | NLS | shift from below normal to mostly above | 2020 | DFO 2022 |
| **Phytoplankton** | | | | | |
| Chlorophyll *a* index | - | ATL | near or above normal | 2020 | DFO 2022 |
| Chlorophyll *a* index | - | GSL | near or above normal since 2017 | 2020 | DFO 2022 |
| Chlorophyll *a* index | - | SS | near or below normal | 2020 | DFO 2022 |
| Chlorophyll *a* index | - | NLS | near or above normal since 2017 | 2020 | DFO 2022 |
| **Zooplankton** | | | | | |
| Copepods | *Calanus finmarchicus* | ATL | rebounding and near normal after 2015 record low | 2020 | DFO 2022 |
| Copepods | *Pseudocalanus* spp. | ATL | decline to near normal after 2015 maximum | 2020 | DFO 2022 |
| Copepods | *Pseudocalanus* spp. | GSL | generally near or above normal since 2014 | 2020 | DFO 2022 |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Copepods | *Pseudocalanus* spp. | SS | generally near or below normal since 2014 | 2020 | DFO 2022 |
| Copepods | *Pseudocalanus* spp. | NLS | generally near or above normal since 2013 | 2020 | DFO 2022 |
| Non-copepods | - | ATL | gradual decline after 2015 peak | 2020 | DFO 2022 |
| Non-copepods | - | GSL | mainly above average | 2020 | DFO 2022 |
| Non-copepods | - | NLS | mainly above average | 2020 | DFO 2022 |
| Chapter 5. Marine Macrophytes | | | | | |
| **Macroalgae** | | | | | |
| *Red Algae* | | | | | |
| Irish Moss | *Chondrus crispus* | SS | - | - | Bundy et al. 2014 |
| *Brown Algae* | | | | | |
| Wrack | *Fucus* sp. | SS | - | - | Bundy et al. 2014 |
| Rockweed | *Ascophyllum nodosum* | SS | - | - | Bundy et al. 2014 |
| Kelp spp. | - | GSL/NLS | no recent data | - | Merzouk and Johnson 2011 |
| Kelp spp. | - | SS | biomass declined 85–99% over last 4–6 decades; some replacement by turf algae | 2016 | Filbee-Dexter et al. 2016 |
| Kelp* | *Alaria esculenta* | - | - | - | *included in kelp spp. trends |

| **Environmental Variable/Common Name** | **Scientific Name** | **Bioregion** | **Status/Trend Information** | **Most Recent Data** | **References/Notes** |
|---|---|---|---|---|---|
| Kelp* | *Saccharina latissima* | - | - | - | *included in kelp spp. trends |
| Kelp* | *Agarum clathratum* | - | - | - | *included in kelp spp. trends |
| Kelp* | *Hedophyllum nigripes* | - | - | - | *included in kelp spp. trends |
| Kelp* | *Laminaria digitata* | - | - | - | *included in kelp spp. trends |
| **Marine Plant** | | | | | |
| Eelgrass | *Zostera marina* | GSL | more than half of beds decreasing others stable or increasing | 2020 | ECCC 2020; Murphy et al. 2021 |
| Eelgrass | *Zostera marina* | SS | half of the beds stable or increasing and half decreasing | 2020 | ECCC 2020; Murphy et al. 2021 |
| Eelgrass | *Zostera marina* | NLS | most stable or expanding; fewer decreasing | 2020 | ECCC 2020; Murphy et al. 2021 |
| Charge 6. Large Marine Invertebrates | | | | | |
| **Crustaceans** | | | | | |
| American Lobster | *Homarus americanus* | nGSL | increasing landings | 2020 | DFO 2019a–c, e |
| American Lobster | *Homarus americanus* | sGSL | Healthy Zone | 2020 | DFO 2014a, 2019e |
| American Lobster | *Homarus americanus* | SS | Healthy Zone; high landings | 2020 | DFO 2021f–k |
| American Lobster | *Homarus americanus* | NLS | increasing landings | 2020 | DFO 2021l |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Northern Shrimp | *Pandalus borealis* | nGSL | 3 Healthy Zone, 1 Cautious Zone but improving; landings at or well below average 2017–2020;<br>survey indices at or below historic lows | 2020 | DFO 2021d |
| Northern Shrimp | *Pandalus borealis* | SS | Eastern SS stock Healthy Zone in 2020 but Cautious Zone in 2021;<br>landings at or well below average 2017–2020 | 2021 | DFO 2021p, 2022a |
| Northern Shrimp | *Pandalus borealis* | NLS | three stocks from south to north: Critical Zone, Healthy Zone, Cautious Zone; landings at or well below average; survey indices at or below historic low 2017–2020 | 2020 | DFO 2021e |
| Snow Crab | *Chionoecetes opilio* | sGSL | Healthy Zone; survey indices high but variable; landings high 2017–2018 | 2020 | DFO 2014b, 2021m |
| Snow Crab | *Chionoecetes opilio* | nGSL | landings high in 2017 but very low by 2020 | 2020 | DFO 2021a |
| Snow Crab | *Chionoecetes opilio* | SS | declined to very low values in 2017–2018 then increased 2019–2020 but well below average | 2020 | DFO 2021o |
| Snow Crab | *Chionoecetes opilio* | NLS | above limit reference point<br>survey indices low but increasing<br>declined to very low values in 2017–2018 then increased 2019–2020 but well below average | 2020 | DFO 2021n, 2022b |
| Jonah Crab | *Cancer borealis* | SS | low and/or declining landings 2017–2020 | 2020 | - |
| Rock Crab | *Cancer irroratus* | nGSL | low and/or declining landings 2017–2020 | 2020 | DFO 2018a |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Rock Crab | *Cancer irroratus* | sGSL | low and/or declining landings 2017–2020; survey indices variable 2017–2020, declining to low values in 2020 | 2020 | DFO 2019f |
| Rock Crab | *Cancer irroratus* | SS | low or declining landings 2017–2020 | 2020 | - |
| Toad Crab | *Hyas* spp. | sGSL | low and/or declining landings 2017–2020; survey indices variable from 2017–2020, declining to low values in 2020 | 2020 | - |
| Toad Crab | *Hyas* spp. | nGSL | 2017–2019 high landings; strong decline 2020 | 2020 | Lambert et al. 2020 |
| Red Deepsea Crab/Red crab | *Chaceon quinquedens* | SS | 2017–2020 high landings; sharp decline 2020 | 2020 | - |
| **Molluscs** | | | | | |
| Sea Scallop | *Placopecten magellanicus* | nGSL | landings stable but low 2017–2020; below average since 2005 | 2020 | DFO 2021b |
| Iceland Scallop* | *Chlamys islandica* | nGSL | - | - | *included with nGSL Sea Scallop landings |
| Sea Scallop | *Placopecten magellanicus* | sGSL | landings stable but low 2017–2020; below average since 2005 | 2020 | Niles et al. 2021 |
| Sea Scallop | *Placopecten magellanicus* | SS | Healthy Zone; stable landings | 2020 | DFO 2020c–e, 2021q |
| Arctic Surfclam | *Mactromeris polynyma* | nGSL | landings stable 2017–2020 after 2013–2016 decline | 2020 | DFO 2021b |
| Arctic Surfclam | *Mactromeris polynyma* | SS | landings above average but variable 2017–2020 | 2020 | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Greenland Cockle* | *Serripes groenlandicus* | SS | - | - | *included in SS Arctic Surfclam landings |
| Northern Propeller Clam* | *Cyrtodaria silique* | SS | - | - | *included in SS Arctic Surfclam landings |
| Ocean Quahog* | *Arctica islandica* | SS | - | - | *included in SS Arctic Surfclam landings |
| Common Softshell Clam | *Mya arenaria* | nGSL | landings very low 2017–2020 after 2000–2010 decline | 2020 | - |
| Atlantic Surfclam | *Spisula solidissima* | nGSL | landings above average to 2019 then near average in 2020 | 2020 | DFO 2019d |
| Atlantic Jackknife Clam/Razor Clam | *Ensis leei* | nGSL | landings variable; increased 2015–2017 then decline 2018–2020 | 2020 | - |
| Whelk | *Buccinum undatum* | nGSL | landings declined 2017–2020; below average 2018–2020 | 2020 | DFO 2018b |
| Northern Shortfin Squid | *Illex illecebrosus* | nGSL | survey index increasing since 2017 | 2020 | - |
| **Echinoderms** | | | | | |
| Green Sea Urchin | *Strongylocentrotus droebachiensis* | nGSL | landings declined but above average 2017–2020 | 2020 | DFO 2016a |
| Green Sea Urchin | *Strongylocentrotus droebachiensis* | sGSL | overall decline in survey index anomalies 1990–2020; large negative survey index anomaly 2017–2020 | 2020 | DFO 2016a |
| Orange-footed Sea Cucumber | *Cucumaria frondosa* | nGSL | landings near average 2015–2020 | 2020 | DFO 2021c |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| | | | Chapter 7. Marine and Diadromous Fish | | |
| **Marine Fish** | | | | | |
| *Pelagic Fish* | | | | | |
| Atlantic Herring | *Clupea harengus* | nGSL | spring spawners: 4R increasing in 2017 and 2019 from series low in 2015; 4Sw increased 2019–2020<br>fall spawners: 4R/4Sw slight increase | 2020 | DFO 2021a, b |
| Atlantic Herring | *Clupea harengus* | sGSL | spring spawners: very low biomass<br>fall spawners: low biomass 2016–2020; declining biomass to levels seen in 1970s–1980s | 2021 | DFO 2022a |
| Atlantic Herring | *Clupea harengus* | SS | historically low abundance (4V, 4W); low from 2016–2021 and continues to decline (4X) | 2021 | |
| Atlantic Mackerel | *Scomber scombrus* | nGSL | 2020 lowest landings ever observed; near or below Limit Reference Point for last decade | 2020 | DFO 2021c |
| Atlantic Mackerel | *Scomber scombrus* | sGSL | high survey biomass in 2021 despite low spawning stock biomass | 2021 | DFO 2023 |
| Atlantic Mackerel | *Scomber scombrus* | SS | very low levels in 4V, 4W, and 4X since 2010 | 2021 | |
| Capelin | *Mallotus villosus* | nGSL | landings near average since 2018 (4RST); fishery performance index above average | 2020 | DFO 2021d |
| Capelin | *Mallotus villosus* | sGSL | increased in 2020–2021 from 2018–2019 but still lower than 2017 | 2020 | DFO 2021d |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Capelin | *Mallotus villosus* | NLS | biomass index near 20-year average but much lower than historic levels | 2019 | DFO 2021e |
| Gaspereau | Alewife (*Alosa pseudoharengus*)/ Blueback herring (*Alosa aestivalis*) | sGSL | biomass declined since 1980s and remains low | 2021 | - |
| Rainbow Smelt | *Osmerus mordax* | - | - | - | - |
| Arctic Cod | *Boreogadus saida* | - | - | - | - |
| Sand Lance | *Ammodytes dubius* | - | - | - | - |
| Atlantic Bluefin Tuna | *Thunnus thynnus* | ATL | Endangered | - | COSEWIC 2011a |
| Swordfish | *Xiphias gladius* | ATL | - | - | - |
| Albacore | *Thunnus alalunga* | ATL | - | - | - |
| Yellowfin Tuna | *Thunnus albacares* | ATL | - | - | - |
| Bigeye Tuna | *Thunnus obesus* | ATL | - | - | - |
| *Pelagic sharks – year-round residents* | | | | | |
| Blue Shark | *Prionace glauca* | ATL | Not at Risk | 2016 | COSEWIC 2016 |
| Greenland Shark | *Somniosus microcephalus* | ATL | - | - | - |
| Porbeagle Shark | *Lamna nasus* | ATL | Signs of increase; Endangered | 2013 | Campana et al. 2013; COSEWIC 2014 |
| White Shark | *Carcharodon carcharias* | ATL | Signs of increase; Endangered | 2021 | COSEWIC 2021; Listed on Schedule 1 of the *Species at Risk Act* (DFO 2017b) |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Basking Shark | *Cetorhinus maximus* | ATL | Special Concern | 2009 | COSEWIC 2009a |
| Common Thresher Shark | *Alopias vulpinus* | ATL | - | - | - |
| Shortfin Mako Shark | *Isurus oxyrinchus* | ATL | Endangered | 2019 | COSEWIC 2019 |
| Sand Tiger Shark | *Carcharias taurus* | ATL | - | - | - |
| *Pelagic sharks - occasionally encountered* | | | | | |
| Atlantic Sharpnose Shark | *Rhizoprionodon terraenova* | ATL | - | - | - |
| Deepsea Cat Shark | *Apristurus profundorum* | ATL | - | - | - |
| Dusky Shark | *Carcharinus obscurus* | ATL | - | - | - |
| Smooth Hammerhead | *Sphyrna zygaena* | ATL | - | - | - |
| Oceanic Whitetip Shark | *Carcharhinus longimanus* | ATL | - | - | - |
| Portuguese Shark | *Centroscymnus coelolepis* | ATL | - | - | - |
| Rough Sagre | *Etmopterus princeps* | ATL | - | - | - |
| Tiger Shark | *Galeocerdo cuvier* | ATL | - | - | - |
| ***Demersal Fish*** | | | | | |
| Atlantic Cod | *Gadus morhua* | nGSL | biomass increasing 2020–2021; Endangered (3Ps, 3Pn4RS) | 2021 | DFO 2017c, 2018b; COSEWIC 2010c |
| Atlantic Cod | *Gadus morhua* | sGSL | little recovery; Endangered (4TVnVsW) | 2021 | COSEWIC 2010c |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Atlantic Cod | *Gadus morhua* | SS | low (4VW) or very low (4X) abundance; Endangered (4TVnVsW, 4X5Y5Zjm) | 2020 | COSEWIC 2010c |
| Atlantic Cod | *Gadus morhua* | NLS | stable since 2010 (2J3K); increased since 2017 (3LNO); low but stable since 2014 (3Ps); Endangered (2GHJ3KLNO and 3Ps, 3Pn4RS) | 2020 | COSEWIC 2010c |
| Atlantic Halibut | *Hippoglossus hippoglossus* | nGSL | landings high in 2019; survey biomass increasing | 2021 | DFO 2018a, 2021f |
| Atlantic Halibut | *Hippoglossus hippoglossus* | sGSL | low abundance | 2021 | - |
| Atlantic Halibut | *Hippoglossus hippoglosus* | SS | higher than average; may be declining (4VW) | 2020 | DFO 2020 |
| Atlantic Halibut | *Hippoglossus hippoglossus* | NLS | increasing but low biomass | 2020 | DFO 2020 |
| Deepwater Redfish /Acadian Redfish | *Sebastes mentella/ Sebastes fasciatus* | nGSL | increasing overall;<br>*S. mentella*: Endangered (3P4RST)<br>*S. fasciatus*: Cautious Zone; Special Concern (Bonne Bay); Threatened (Atlantic) | 2020 | Senay et al. 2021; DFO 2020b; COSEWIC 2010d |
| Deepwater Redfish/Acadian Redfish | *Sebastes mentella/ Sebastes fasciatus* | sGSL | increasing biomass;<br>*S. mentella*: Endangered (3P4RST)<br>*S. fasciatus*: Threatened (Atlantic) | 2021 | COSEWIC 2010d |
| Deepwater Redfish/Acadian Redfish/Golden Redfish | *Sebastes mentella/ Sebastes fasciatus /Sebastes marinus* | SS | relatively stable since 2012 (4VW);<br>lower abundance since 2016 (4X)<br>*S. mentella*: Endangered (3P4RST)<br>*S. fasciatus*: Threatened (Atlantic) | 2020 | COSEWIC 2010d |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Deepwater Redfish /Acadian Redfish | *Sebastes mentella/ Sebastes fasciatus* | NLS | 2J3KL and 3Ps high biomass decreased sharply in 3LNO;<br>*S. mentella*: Endangered (3P4RST, northern)<br>*S. fasciatus*: Threatened (Atlantic) | 2020 | COSEWIC 2010d |
| Greenland Halibut | *Reinhardtius hippoglossoides* | nGSL | slight increase and stabilized after earlier declines | 2021 | Bourdages et al. 2021; DFO 2021h |
| Greenland Halibut | *Reinhardtius hippoglossoides* | sGSL | low abundance | 2021 | - |
| Greenland Halibut | *Reinhardtius hippoglossoides* | NLS | stable at higher than average biomass since 2017 (2J3K) | 2020 | - |
| American Plaice | *Hippoglossoides platessoides* | sGSL | little recovery; Threatened (4RSTVWX) | 2021 | COSEWIC 2009b |
| American Plaice | *Hippoglossoides platessoides* | NLS | High proportion of biomass in 2J3KL; Threatened (2GHJEKLNOPs) | 2020 | COSEWIC 2009b |
| White Hake | *Urophycis tenuis* | sGSL | little recovery; Threatened (4TVn) | 2021 | COSEWIC 2013 |
| Haddock | *Melanogrammus aeglefinus* | SS | low abundance (4VW, 4X) | 2020 | - |
| Silver Hake | *Merluccius bilinearis* | SS | low abundance (4VW, 4X) | 2020 | - |
| Silver Hake | *Merluccius bilinearis* | NLS | more prominent | 2020 | - |
| Witch Flounder | *Glyptocephalus cynoglossus* | NLS | overall low biomass but increasing since 2010 (2J3K) | 2020 | - |
| Yellowtail Flounder | *Limanda ferruginea* | NLS | high proportion of biomass in 3LNO | 2020 | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| ***Demersal Sharks and Skates*** | | | | | |
| Thorny Skate | *Amblyraja radiata* | ATL | Special Concern | 2012 | COSEWIC 2012a |
| Thorny Skate | *Amblyraja radiata* | nGSL | increased slightly in 2020 and decreased in 2021 | 2021 | Bourdages et al. 2021 |
| Thorny Skate | *Amblyraja radiata* | sGSL | historic low abundance | 2021 | - |
| Thorny Skate | *Amblyraja radiata* | SS | low abundance | 2020 | - |
| Thorny Skate | *Amblyraja radiata* | NLS | stable at low biomass (3LNO); peaked in 2018 (2J3KL) | 2020 | - |
| Winter Skate | *Leucoraja ocellata* | sGSL | low abundance; Endangered (4T) | 2021 | COSEWIC 2015 |
| Winter Skate | *Leucoraja ocellata* | SS | low abundance (4VW), high abundance (4X); Endangered (4VW) | 2020 | COSEWIC 2015 |
| Winter Skate | *Leucoraja ocellata* | NLS | declining (3LNO); Endangered | 2020 | COSEWIC 2015 |
| Smooth Skate | *Malacoraja senta* | ATL | Special Concern | - | COSEWIC 2012b |
| Smooth Skate | *Malacoraja senta* | nGSL | remaining at very low abundance; Special Concern (3NOPRST4VWX5Y) | 2021 | Bourdages et al. 2021;<br>COSEWIC 2012b |
| Smooth Skate | *Malacoraja senta* | sGSL | low abundance<br>Special Concern (3NOPRST4VWX5Y) | 2021 | COSEWIC 2012b |
| Smooth Skate | *Malacoraja senta* | SS | Low abundance (4X)<br>Special Concern (3NOPRST4VWX5Y) | 2020 | COSEWIC 2012b |
| Smooth Skate | *Malacoraja senta* | NLS | declining but variable (3LNO);<br>Special Concern (3NOPRST4VWX5Y);<br>Endangered, higher than average (2J3KL) | 2020 | COSEWIC 2012b |
| Barndoor Skate | *Dipturus laevis* | SS | higher abundance (4X) | 2020 | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Little Skate | *Leucoraja erinacea* | SS | higher abundance (4X) | 2020 | - |
| Spinytail Skate | *Bathyraja spinicauda* | NLS | increasing but variable (3LNO) | 2020 | - |
| Jensen's Skate | *Amblyraja jenseni* | NLS | declined since 2014 (2J3K)<br>low abundance (3LNO) | 2020 | - |
| Round Skate | *Rajella fyllae* | NLS | variable but low biomass (3LNO) | 2020 | - |
| Bigelow's Skate | *Rajella bigelowi* | - | - | - | - |
| Arctic Skate | *Amblyraja hyperborea* | NLS | very low biomass (2J3K) | 2020 | - |
| Spiny Dogfish | *Squalus acanthias* | ATL | Special Concern | 2010 | COSEWIC 2010a |
| Spiny Dogfish | *Squalus acanthias* | sGSL | virtually absent | 2021 | - |
| Spiny Dogfish | *Squalus acanthias* | SS | low abundance (4VW)<br>average abundance (4X) | 2020 | - |
| Spiny Dogfish | *Squalus acanthias* | NLS | peaked in late 2010s then declined (2J3KL/3NO) | 2019 | - |
| Black Dogfish | *Centroscyllium fabricii* | nGSL | record high in 2021 | 2021 | - |
| Black Dogfish | *Centroscyllium fabricii* | sGSL | virtually absent | 2021 | - |
| Smooth Dogfish | *Mustelus canis* | ATL | - | - | - |
| **Diadromous Fish** | | | | | |
| *Anadromous* | | | | | |
| Striped Bass | *Morone saxatilis* | sGSL | decline from peak biomass in 2017; remains above recovery target | 2019 | DFO 2021i; COSEWIC 2012c |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Striped Bass | *Morone saxatilis* | SS | Endangered (Bay of Fundy) | - | COSEWIC 2012c |
| Atlantic Salmon | *Salmo salar* | nGSL | Special Concern (Eastern and Western North Shore); Endangered (Anticosti Island) | - | COSEWIC 2010b |
| Atlantic Salmon | *Salmo salar* | sGSL | declined by 27% 2007–2019 (large salmon); declined by 63% 2007–2019 (small salmon); Special Concern (Inner St. Lawrence, Gaspé–sGSL) | 2019 | DFO 2020f; COSEWIC 2010b |
| Atlantic Salmon | *Salmo salar* | SS | egg deposition stable in 3 rivers, marked declines in non-indexed rivers (Eastern Cape Breton DU); egg deposition and return rates lowest on record (Southern Upland DU); egg deposition and return rates at historically low levels (Outer Bay of Fundy DU); egg deposition and return rates at low levels (Inner Bay of Fundy DU); Endangered | 2019/ 2020 | DFO 2020g, 2021j; COSEWIC 2010b |
| Atlantic Salmon | *Salmo salar* | NLS | abundance of large salmon below average on 61% of monitored rivers; total returns lower in 14, higher in 3, and similar in 1 river; Threatened (South Newfoundland) | 2019 | DFO 2020e; COSEWIC 2010b |
| Brook Trout (anadromous form) | *Salvelinus fontinalis* | - | - | - | - |
| American Shad | *Alosa sapidissima* | - | - | - | - |
| Sea Lamprey | *Petromyzon marinus* | - | - | - | - |
| Atlantic Sturgeon | *Acipenser oxyrhynchus* | sGSL/SS | Threatened | - | COSEWIC 2011b |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Atlantic Tomcod | *Microgadus tomcod* | - | - | - | - |
| *Catadromous* | | | | | |
| American eel | *Anguilla rostrata* | - | - | - | - |
| Chapter 8. Marine Mammals | | | | | |
| **Pinnipeds – year-round residents** | | | | | |
| Atlantic Walrus | *Odobenus rosmarus* | - | Extinct (Nova Scotia–Newfoundland–GSL) | - | COSEWIC 2017 |
| Bearded Seal | *Erignathus barbatus* | GSL/NLS | - | - | - |
| Grey Seal | *Halichoerus grypus* | ATL | increasing trend | - | DFO 2022 |
| Harbour Seal | *Phoca vitulina* | ATL | abundance est. | - | Hammill and Stenson 2000 |
| Harp Seal | *Pagophilus groenlandicus* | GSL/NLS | increasing trend | 2017 | Stenson et al. 2020b; Hammill et al. 2021 |
| Hooded Seal | *Cystophora cristata* | GSL/NLS | increasing/unknown | 2005 | Hammill and Stenson 2006 |
| Ringed Seal | *Pusa hispida* | - | Special Concern | - | Kingsley 1998; COSEWIC 2019a |
| **Cetaceans – seasonal migrants** | | | | | |
| Blue Whale* | *Balaenoptera musculus* | ATL | abundance est./stable or decreasing trend; Endangered (Atlantic) | 2009 | Beauchamp et al. 2009; *some wintering individuals; COSEWIC 2012 |
| Common Bottlenose Dolphin | *Tursiops truncatus* | ATL | - | - | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Fin Whale* | *Balaenoptera physalus* | ATL | abundance est.; Special Concern (Atlantic) | 2007 | Heide-Jørgensen et al. 2010; NAMMCO 2016; Lawson and Gosselin 2009; *some wintering individuals; COSEWIC 2019b |
| Humpback Whale | *Megaptera novaeangliae* | ATL | abundance est./increasing trend | 2007 | Heide-Jørgensen and Laidre 2015; NAMMCO 2016; Lawson and Gosselin 2009; *some wintering individuals |
| Minke Whale | *Balaenoptera acutorostrata* | ATL | abundance est. | 2007 | Lawson and Gosselin 2009; Heide-Jørgensen et al. 2010; NAMMCO 2016 |
| North Atlantic Right Whale | *Eubalaena glacialis* | ATL | abundance est./decreasing trend; Endangered | 2019 | DFO 2020; Pettis et al. 2021; COSEWIC 2013 |
| Sei Whale* | *Balaenoptera borealis* | ATL | Endangered | - | *some wintering individuals; COSEWIC 2019c |
| **Cetaceans – year-round residents** | | | | | |
| Atlantic White-sided Dolphin | *Lagenorhynchus acutus* | ATL | abundance est. | 2007 | Lawson and Gosselin 2009 |
| Beluga Whale* | *Delphinapterus leucas* | GSL | abundance est./decreasing trend; Endangered (SLE) | 2015 | Marcoux et al. 2016; Mosnier et al. 2015; NAMMCO 2016; COSEWIC 2004a |
| Bowhead Whale | *Balaena mysticetus* | - | abundance est./increasing trend | 2013 | Doniol-Valcroze et al. 2015a |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| Short-beaked Common Dolphin | *Delphinus delphis* | ATL | abundance est. | 2007 | Lawson and Gosselin 2009 |
| Cuvier's Beaked Whale | *Ziphius cavirostris* | ATL | - | - | - |
| Harbour Porpoise* | *Phocoena phocoena* | ATL | abundance est.; Special Concern (NWA) | 2007 | NAMMCO 2016; Lawson and Gosselin 2009; COSEWIC 2022 |
| Killer Whale | *Orcinus orca* | ATL | abundance est.; Special Concern | - | J.W. Lawson, DFO, unpublished data; COSEWIC 2008 |
| Long-finned Pilot Whale | *Globicephala melas* | ATL | abundance est. | 2007 | NAMMCO 2016; Lawson and Gosselin 2009 |
| Narwhal | *Monodon monoceros* | - | abundance est.; Special Concern (Arctic) | 2013 | Doniol-Valcroze et al. 2015; NAMMCO 2016; COSEWIC 2004b |
| Northern Bottlenose Whale | *Hyperoodon ampullatus* | SS | stable; Endangered (Scotian Shelf) | 2019 | COSEWIC 2011 |
| Northern Bottlenose Whale | *Hyperoodon ampullatus* | NLS | Davis Strait/Baffin Island/Labrador Sea: unknown/unknown | 2019 | COSEWIC 2011 |
| Risso's Dolphin | *Grampus griseus* | - | - | - | - |
| Sowerby's Beaked Whale | *Mesoplodon bidens* | - | Special Concern (Atlantic) | 2019 | COSEWIC 2019d |
| Sperm Whale | *Physeter macrocephalus* | - | - | - | - |
| Striped Dolphin | *Stenella coeruleoalba* | - | - | - | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| True’s Beaked Whale | *Mesoplodon mirus* | - | - | - | - |
| White-beaked Dolphin | *Lagenorhynchus albirostris* | - | - | - | - |
| Chapter 9. Sea Turtles | | | | | |
| **Dermochelyid sea turtles** | | | | | |
| Leatherback Sea Turtle | *Dermochelys coriacea* | ATL | NWA subpopulation in decline (60% decline in nest abundance); Endangered | 2020 | NAWLG 2018; NMFS and USFWS 2020; COSEWIC 2012 |
| **Cheloniid sea turtles** | | | | | |
| Loggerhead Sea Turtle | *Caretta caretta* | ATL | NWA subpopulation increasing; Least Concern (NWA)<br>Endangered (Canada) | 2017 | Ceriani and Meylan 2017; COSEWIC 2010 |
| Green Sea Turtle | *Chelonia mydas* | ATL | Endangered (global) | - | Seminoff et al. 2004 |
| Kemp’s Ridley Sea Turtle | *Lepidochelys kempii* | ATL | Critically Endangered (global) | - | Wibbels and Bevan 2019 |
| Chapter 10. Seabirds | | | | | |
| **Alcidae (Alcids/Auks)** | | | | | |
| Razorbill | *Alca torda* | ATL | large increase since 1970 | 2020 | - |
| Atlantic Puffin | *Fratercula arctica* | ATL | large increase since 1970 | 2020 | - |
| Common Murre | *Uria aalge* | ATL | moderate increase since 1970 | 2020 | - |
| Black Guillemot | *Cepphus grylle* | ATL | moderate increase since 1970 | 2020 | - |
| Thick-Billed Murre | *Uria lomvia* | ATL | moderate decrease since 1970 | 2020 | - |

| Environmental Variable/Common Name | Scientific Name | Bioregion | Status/Trend Information | Most Recent Data | References/Notes |
|---|---|---|---|---|---|
| **Hydrobatidae (Northern Storm Petrels)** | | | | | |
| Leach's Storm-Petrel | *Oceanodroma leucorhoa* | ATL | moderate decrease since 1970; Threatened | 2020 | COSEWIC 2020 |
| **Laridae (Gulls, Terns, and Kittiwakes)** | | | | | |
| Common Tern | *Sterna hirundo* | ATL | moderate increase since 1970 | 2020 | - |
| Great Black-backed Gull | *Larus marinus* | ATL | large decrease since 1970 | 2020 | - |
| Herring Gull | *Larus argentatus* | ATL | large decrease since 1970 | 2020 | - |
| Arctic Tern | *Sterna paradisaea* | ATL | large decrease since 1970 | 2020 | - |
| Roseate Tern | *Sterna dougallii* | ATL | small increase since 1970 | 2020 | - |
| Black-legged Kittiwake | *Rissa tridactyla* | ATL | small decrease since 1970 | 2020 | - |
| **Phalacrocoracidae (Cormorants)** | | | | | |
| Double-crested Cormorant | *Phalacrocorax auritus* | ATL | large increase since 1970 | 2020 | |
| Great Cormorant | *Phalacrocorax carbo* | ATL | small increase since 1970 | 2020 | |
| **Procellariidae (Fulmars)** | | | | | |
| Northern Fulmar | *Fulmarus glacialis* | ATL | large decrease since 1970 | 2020 | |
| **Sulidae (Gannets)** | | | | | |
| Northern Gannet | *Morus bassanus* | ATL | large increase since 1970 | 2020 | |

# APPENDIX 2. PROCEEDINGS OF THE STATE OF THE OCEANS–2022 ATLANTIC SYNTHESIS WORKSHOP

## Agenda

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| Location | Virtual meeting on Microsoft Teams (Eastern Standard Time) |
| Date | February 1–2, 2022 |
| Co-chairs | Katherine Middleton and Keith Clarke, DFO Science |

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| *Workshop Objectives* | To describe the status and trends in the Atlantic Ocean<br>To identify key messages about the state of the Atlantic Ocean<br>To inform the public report |

### Day 1

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|---|---|
| 0830–0840 | Opening Remarks<br>Catherine Ste-Marie, Director, Environment and Biodiversity Science |
| 0840–0855 | Introduction<br>Katherine Middleton and Keith Clarke, DFO Science |
| 0855–1220 | Theme Group Summary Presentations |
| *0855–0920* | *Ocean Environment* |
| *0920–0930* | *Chemical Oceanography (pH and Oxygen)* |
| *0930–0955* | *Lower Trophic Levels* |
| *0955–1020* | *Marine Plants and Macroalgae* |
| *1035–1100* | *Invertebrates* |
| *1100–1125* | *Fish* |
| *1125–1150* | *Marine Mammals* |
| *1150–1205* | *Sea Turtles* |
| *1205–1220* | *Seabirds* |
| 1220–1300 | Wrap-up and preview of Day 2 |

### Day 2

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|---|---|
| 0830–0845 | Review of Day 1 |
| 0845–1000 | Discussion: Theme group key messages<br>• *Bioregional reporting*<br>• *Review of 2022 key messages from Day 1*<br>• *Agree on key messages for 2022 report* |
| 1015–1130 | Discussion: Atlantic Ecosystems Overview<br>• *Overarching Atlantic key messages*<br>• *Ecosystem connections*<br>• *Development of ecosystem case studies* |
| 1130–1200 | Discussion: Gaps, uncertainties, and future considerations |
| 1200–1220 | Technical and Public Reports: format, timelines, and ongoing expectations |
| 1220–1300 | Wrap-up and closing comments |

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## Workshop Discussion

### *Reporting (Day 1)*

- Invited speaker, Catherine Ste-Marie, Director of Environment and Biodiversity Science of the National Capital Region (NCR), welcomed all workshop participants and gave opening remarks.
- Recognition was given to different Indigenous traditional territories by acknowledging several First Nation lands on which DFO employees of the Quebec, Gulf, Newfoundland and Labrador, Maritimes, and National Capital Regions gather for their work.
- Brief introduction was given on DFO's State of the Oceans Reporting Initiative, its priority within the department, and the annual reporting cycle of its four reports (Atlantic, Arctic, National, Pacific). Since the implementation of this initiative in 2016, DFO has published State of the Oceans reports for the Atlantic (2018), Arctic (2019), National (2020), and Pacific (2021).
- Feedback was provided on communication tools to promote DFO's State of the Oceans Reporting: the official video trailer for the National State of the Oceans' public report (Canada's Oceans Now, 2020–Trailer) was one of the most watched DFO videos ever produced. Consequently, efforts will be taken to develop trailer videos for upcoming Pacific and Atlantic public reports.
- DFO's State of the Oceans Reporting has attracted the interest of other reporting initiatives (for which advice and input has been sought), such as the State of the Forest, State of Fish and Fish Habitat, and State of the Mackenzie as well as by ECCC, Agriculture and Agri-Food Canada, and MPA reporting within DFO.

### *Reporting (Day 2)*

- The co-chairs 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.
- The Ocean Environment and the Lower Trophic Levels theme group have a very integrated Atlantic Zone approach to data monitoring reporting, as subject matter experts report annually via AZMP and AZOMP, but this was not the case for other theme groups, except for the Marine Mammal working group who report on migratory species within the Northwestern Atlantic Ocean.
- Keeping an overall geographic overview in the introductory section of the Atlantic synthesis technical report was favoured as the three main biogeographic units would be used to report status and trends for several theme working groups throughout the report.
- A portion of Day 2 of this workshop was dedicated specifically to the inclusion of Ecosystem Connections. Comments and suggestions were discussed.
- There was concern over the lack of material related to ecosystem integration during the 2022 Atlantic SOTO process leading up to this workshop. This may have been an artifact of theme groups working independently and ecosystem linkages may become more apparent once Atlantic SOTO coordinators combine and start editing working group summaries.

- The desired level of ecosystem integration in the Atlantic SOTO reporting depends on the overall structure of the reports and the involvement of scientists during the SOTO process (DFO scientists, working actively on ecosystem based science, could provide insight as opposed to scientists mainly working on species stock assessments reporting on status and trends).
- A number of Science funding (e.g. SPERA, CSRF) proposals on coordinated ecosystem reporting approaches were submitted, with DFO SOTO being identified as a specific client. However, this approach does not seem to be considered as a DFO Science priority since these requests were not successfully funded.
- Ecosystem approach could still be included by structuring the report to focus on ecosystem links as opposed to presenting species status and trends. Participants proposed aiming for an ecosystem-level risk assessment based on available DFO evidence, similar to the ICES Ecosystem Overviews. Participants recognized that this higher level of ecosystem integration cannot realistically be reached in less than 6 months and suggested the need for an ongoing, coordinated approach similar to the AZMP. Some of the elements that have supported AZMP were incorporated into this document (https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40567461.pdf) making recommendations for a coastal zone monitoring program. Would a central theme similar to this one for AZMP be prescribed by the SOTO group or is there a way to draw ideas for this from Atlantic scientists? Would there be enough support available to warrant annual meetings and the generation of publications?
- Several gaps/uncertainties were identified:
    - unevenness of data for certain species or trophic levels due to nature of DFO's mandate (e.g. DFO focuses more on the commercial species or species that require direct management (invasive species, species at risk) as opposed to the more ecologically sensitive species)
    - integration of ecosystem links
    - incorporation of Indigenous knowledge
    - spatial data gaps for many habitats within and among bioregions
- Format, timelines, roles and responsibilities of scientists and Atlantic SOTO coordinators with regards to the technical and public reports were discussed. It was confirmed that scientists will have the opportunity to review content of both the technical and public reports before they are published.
- With regards to changing the structure of SOTO reporting to become more of an Ecosystem Overview, the co-chairs reminded all participants that DFO's National SOTO process is tied to the 2016 Science Renewal Initiative and that we need to adhere to some common structure for SOTO reporting, but there is room for improvements and/or change. There was support from participants to do SOTO reporting every year (like AZMP) rather than every 4 years (current Atlantic reporting cycle) to facilitate the integration of ecosystem links. However, there is also a balance of what SOTO coordinators can request of the scientists on a yearly basis as opposed to a 4-year cycle. The SOTO reports were originally structured in such a way that future reports would only require updates to the previous reports to reduce the time and effort that scientists would have to put into gathering the data from the previous 4 years to include in the reports.

## ***Post workshop***

- The DFO National Ecosystem Reporting Steering Committee will organize a Lessons Learned Workshop to share the feedback from regional coordinators and subject matter experts involved in the State of the Atlantic Ocean Reporting. Discussions on this topic will occur after the workshop and will serve as guide for future State of the Oceans reporting.

## ***Theme Group summary presentations***

### *Ocean Environment – Physical and Chemical*

- Information on Physical Oceanography, based on AZMP and AZOMP data from the published CSAS SARs, was presented over the last few years with anomaly score cards for each biogeographic region.
- Ocean acidification (carbonate chemistry and pH) and dissolved oxygen monitoring results were presented for the Atlantic (via AZMP monitoring data and various research projects).
- Precision was needed on the reasons for higher acidification rates in the Labrador Sea compared to elsewhere in the Atlantic zone. It was suggested that due to a strong solubility pump, atmospheric anthropogenic $CO_2$ is sequestrated to the deep ocean by chemical and physical processes (as per Ringuette et al. 2022; https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41058264.pdf). Higher acidification values seen in the Labrador Sea are the result of water pH being controlled mainly by atmospheric increases in $CO_2$ whereas the coastal acidification values are driven by changes in nutrient supplies and primary production.

### *Nutrients and Lower Trophic Levels*

- Data from this section was sourced from AZMP *in situ* observations with seasonal time series and satellite data of spring blooms. Anomaly indices are derived from this varying time series data.
- Larger *Calanus finmarchicus* copepods were stated as a very important indicator for State of the Atlantic Ocean as it is a key source of food for pelagic fish, invertebrates, whales, and some seabirds. *Pseudocalanus* copepods are also a primary food source and contributes to overall biomass of zooplankton. Relative proportion of both copepods are thus important indicators.
- With regards to the monitoring of size-fractionated phytoplankton (chlorophyll *a*) by AZMP: What size fractions are being measured? Have measurements of pigments through HPLC-system been tried as this would give a good idea of the main taxonomic groups present?
- Initial explorations with HPLC for chlorophyll filtrations were confirmed (using 0.2 μm and 3.0 μm polycarbonate track-etched filters).
- A suggestion was made for the figures within the LTL to include a small regional sub-index panel when they differ between NLS, GSL, and SS (for deep nitrates). This might show whether the deep nitrates are related to CIL forcing on NLS versus the deeper Gulf Stream influence on SS, and perhaps a combination thereof in GSL. The more detailed

text that accompany the figures in the LTL section was confirmed to break out regional patterns.

### Marine Plants and Macroalgae

- General comment: There seems to be a 3-tiered habitat issue when talking about gadids and eelgrass and kelp areas. Patterns of recruitment dynamics of fish are subtle when it comes to kelp. As fish grow/mature, they move from eelgrass to kelp around age 3, from nearshore to offshore environments; thus, these issues are tied together as biogenic habitat structure.

There were no questions on this theme group.

### Invertebrates

There were no questions on this theme group.

### Fish

- A clarification was made as to why there were no plots of survey indices for sharks and rays from regions outside the GSL. Pelagic sharks are not generally caught by the pelagic fish survey in Maritimes Region (catch 1 every 5 years or so). Figures within the demersal Chondrichthyan section of the Fish summary included dogfish and skate data from GSL (north and south) specifically. However, data for spiny dogfish and/or skates were provided and highlighted in the research vessel survey figures for demersal fish for GSL (north and south), and areas within the Maritimes and NL Regions instead of separately within the Chondrichthyan section.
- Workshop participants discussed the possibility of a collaborative approach to optimize eDNA shark detection as species-specific primers have already been developed.
- Was there any information provided for migrating species such as tunas? The Fish working group did not address tuna for this iteration of the Atlantic SOTO, perhaps this gap (large pelagics i.e. tuna and swordfish) could be addressed for the next Atlantic SOTO report.
- What is the reason for the resurgence of Striped Bass in the southern GSL? Due to conservation concerns for striped bass in the Miramichi River (the only known Striped Bass spawning area in the southern GSL) in the 1990s, the Striped Bass commercial fishery has been closed since 1996. Striped Bass have recovered partly because of this fishery closure, in addition to locally improved environmental conditions in the Miramichi watershed.
- Are they looking into re-opening a fishery for Striped Bass because of the increased abundance? There are currently exploratory fisheries by Indigenous groups and recreational fisheries for Striped Bass in the sGSL.

### Seabirds

There was no presentation provided by the Seabirds theme working group. No questions ensued.

### *Sea Turtles*

There were no questions on this theme group.

### *Marine Mammals*

There were no questions on this theme group.

## ***Key Messages***

Presentation including all key messages from the 2018 Atlantic SOTO technical report was shared on screen with participants at the present virtual synthesis workshop meeting. Input was sought on editing of past key messages and/or drafting of new key messages for each of the themed working groups.

### *Physical Oceanography*

- 2018 key messages regarding warming ocean, CIL influence, and changing currents are still accurate.
- The discussion began with consideration of a high-level statement emphasizing that the change being observed (i.e. warming ocean and changing currents in Atlantic Ocean) is happening faster in a shorter time period than ever before. Even if the water temperature variability continues, global warming, in addition to this variability is promoting a peak. Should important caveats (such as changes happening on shorter versus longer time scale) be mentioned in this report? Using a 100-year time scale was suggested as a good idea to highlight these changes as being immediate problems, which may not happen as intensely again.
- Working group members suggested shortening the text of first bullet on ocean warming and perhaps removing place names within the bullets to strengthen key points.

### *Chemical Oceanography*

- There was some discussion about whether to mention the now surpassed 15% oxygen saturation threshold directly in the key message bullet (as it wasn't reached in the 2018 report) and if this should be tied to limiting biological consequences. Participants agreed on using 'severe' hypoxia instead of threshold values in bullets. Link to biological consequences will not be expanded upon in bullets.
- It was felt that the statement <hypoxia is generally higher in the Gulf than other parts of the world> needed to be validated or clarified. This statement was sourced from DFO research scientists reviewing GSL hypoxia information and it will be clarified for 2022 key message bullet on pH decrease in Atlantic Canadian waters. Might be better to make comparison to global averages (from IPCC).

### *Lower Trophic Levels*

- There was an overall concern that key messages from this group resembled CSAS Research Document bullets instead of key messages with less detail. Members agreed to examine the 2018 bullets of key messages and adjust them to reflect what is happening now within LTL. There could be three bullets encompassing new information:

one bullet detailing nutrients and how they relate to climate and vary bioregionally, one bullet describing dramatic changes for primary productivity and one bullet on shifts of zooplankton community structure and distribution with mention of resulting biological impacts.

- There was a need to point out that we only report on chlorophyll *a* as a metric of phytoplankton biomass and that this is not a measure of phytoplankton productivity. We need to make it clear that we can't make the link to productivity directly because that is not actually measured.

### *Marine Plants and Macroalgae*

- There was concern that some statements could be misinterpreted as there is a lack of long-term monitoring amongst Atlantic bioregions (e.g. more kelp data available from SS bioregion than from NLS and GSL). Consequently, drafting key messages to reflect changes between bioregions is recommended. Key messages for this working group will be revised and condensed post-workshop.
- This lack of kelp information for some Atlantic bioregions led to a broader discussion on the difficulty of reviewing kelp harvesting proposals by DFO scientists as there is increasing interest in kelp harvesting in some bioregions. This caveat reinforces the need to identify the lack of kelp data in several Atlantic bioregions as an important gap or highlight this need for future considerations.

### *Fish*

- Fish working group members felt that proposed 2022 key messages with regards to salmon were too broad and need to include bioregional details to capture the varying trends between bioregions (e.g. perhaps divided into southern versus northern Atlantic).
- A suggestion was made to redefine the first bullet of proposed 2022 Fish key messages for demersal fish; a distinction needs to be made since Atlantic Halibut is now showing a higher than average level, while redfish in the GSL are at a never-seen-before high level.
- A suggestion was made to change the bullet on sharks as the current text does not adequately describe the status or trends for this group. The text will be adjusted and revised at a later meeting of the Fish theme group.
- The Fish group reached a general agreement that a statement should be made identifying data gaps for non-commercial species or fish species for which stocks are poorly understood. This lead to a discussion on the need to report on the status and trends of invertebrates and fish species assemblages and not just commercial species. There was concern over the lack of, and need for, a coordinated ecosystem reporting approach.

### *Invertebrates*

- Proposed 2022 key messages were organized by invertebrate group (Crustaceans, Molluscs, and Echinoderms). However, there remained a lot of detail within the bullets which could be condensed similar to 2018 invertebrate key messages.
- Ecosystem links were not made specifically in the bullets but links between hypoxia and invertebrates were included in the text of the Invertebrates chapter. There are known

species (e.g. cold-water species) affected by warming trends which could be reflected as an important ecosystem story in overarching key messages. For example, turbot is not expected to do well in the continued warming GSL.

### *Marine Mammals*

- A discussion on whether the NARW should be the most emphasized key message resulted from a suggestion regarding the rewording of the NARW bullet (wasn't worded with terms used by marine mammal researchers). However, there was general agreement that 2018 key messages were still accurate for the 2022 report and that shifts in distribution and abundance of prey still need to be reflected as important drivers of NARW shifts in distribution range.
- Marine mammals working group agreed to edit the proposed 2022 Marine Mammals key messages. Suggestions for modifications included generalization of second and third bullets, have a bullet on populations, one on data, and one addressing habitats. Climate change could be inserted into key messages to reflect its direct (i.e. loss of habitat leading to mortality of breeding seals) or indirect (prey availability or prey distribution shifts) negative impacts on marine mammals.

### *Sea Turtles*

- Key messages were presented but not discussed in detail as Sea Turtles theme group members were not present at this meeting.
- Some participants recommended retaining the 2018 key message about critical habitats for the 2022 key messages as this reflects a link to ecosystem impacts.

### *Seabirds*

- Key messages were not presented nor discussed as summary from this theme group is still being drafted.

### *Overarching Atlantic key messages*

- There was concern over the meaning of the word "ecosystems" in the overarching 2018 Atlantic SOTO key messages. It should be made clear to readers what ecosystem scale level key messages are referring to as ecosystems could be interpreted differently at various levels (e.g. bioregions including several changing ecosystems versus ecosystems in different bioregions experiencing change).
- Specific rewording of the overarching key messages was suggested to reflect details such as "biological components or species are being affected by" as opposed to "climate change is affecting A, B or C" to avoid general statements that may seem more textbook in nature or oversimplified to the point of them becoming non-informative or meaningful.
- The need for a coordinated ecosystem approach was once again identified.
- A point was raised as to the purpose of the overarching key messages. Given that there are already theme group messages, could this be an opportunity to use these to summarize what has changed over the last 4 years? Can we talk about ecosystem connections here and come up with general statements? It was suggested that at

minimum, key messages should be adjusted to highlight what is new or to better reflect the specific content of the 2022 report.

## *Case Studies*

### *A climate index for the Newfoundland and Labrador Shelf*

- Several participants were interested in the time reference period for the data included in the development of the NL climate index (1991–2020), and whether the spatial scale used to calculate this index will be expanded to include other Atlantic bioregions by authors in the future (which was not in immediate workplan for these authors). Although the presented climate index was developed for NL specifically, participants felt it should be possible to develop similar metrics for other Atlantic bioregions.
- Is there interest in trying to compare cold and warm contrasting conditions in the Gulf of Maine and other areas in the 1960s? The sub-polar gyre was suggested as a possible reason for these contrasts: the gyre influences how much cold water is reaching the Grand Banks and there was a displacement of cold water cell to the North in those years. This pattern follows the classic NAO relation (as per Petrie 2007; https://doi.org/10.3137/ao.450302), although the relationship seems to be weaker now.
- Have you examined whether this relatively complex index tracks fish and other related metrics better than any one of the components? Yes, although it is work in progress. There a lot of variables to consider. A recent example where all sub-indices were explored was provided: https://academic.oup.com/icesjms/advance-article/doi/10.1093/icesjms/fsab144/6356489.
- Interest was shown on how water displacement patterns are affecting abundances of Atlantic Cod as it seems as though low abundances of cod coincide with the coldest water period in NL (according to this climate index), even though fishing pressure remained the same, followed by a rebound of cod in 2010 (warmer year). This pattern was suggested as worth investigating further in this context. Attention needs to be given in the interpretation of the overall trend as there is a lot of variability. For example, using composite anomalies seem to capture the variability among the different components of reproductive rate in Harp Seals.
- It was noted that increasing mean and/or variance of temperatures can have important consequences/effects on living resources. Most studies show that variance is not increasing in the atmosphere and ocean, and it is not projected to increase. Extremes are driven by a shifting of the mean of the distributions toward higher values.
- Is the information from the NL climate index meant to stand alone and not be linked to overall warming due to climate change? It is difficult to tie the two together (NL climate index and warming climate in the context of climate change) as warming isn’t happening at the same rate in NL as elsewhere. Natural variability of NL climate index is higher (since NL is closer to cold Arctic climate) than other various indices developed in areas with warmer climate. The score cards used for the NL climate index may not be applicable in all Atlantic bioregions (have to be investigated separately). The figure with the four stacked bars that was presented in the physical oceanography presentation could represent what is happening in different bioregions.
- The lag in time of water movement was indicated as an important factor to consider when linking cold/warm water temperatures to broader ecosystem effects since it takes

several years to move the cold water (inertia) from one area. Consequently, a climate index tracks the variability better of these warm/cold water years.

### *Innovating the way we are monitoring zooplankton dynamics in Canadian sensitive coastal areas*

- What about monitoring phytoplankton to understand how shellfish aquaculture and climatic variability might impact the energy flows within the food web? Phytoplankton were said to be very variable, so it is better to monitor zooplankton instead.
- It would be interesting to have a >20µm size class, these are the diatoms/dinoflagellates groups and you might see more drastic changes. There are also the ones that often carry toxins. The Flow cytometry analyses cover the 2–20µm size range and we are hoping to use the micro-FlowCam® to analyze 50–600µm zooplankton (samples were collected using 30µm net). *In situ* probes would be great to monitor the temporal changes, at least to optimize the sample collection.

### *The North Atlantic Right Whale and its food in a changing western North Atlantic*

- A general comment was made as to the Marine Mammals theme group also discussing the shift in distribution range of NARW (*Eubalaena glacialis*) due to prey (zooplankton) distribution shifts.

### *New sponge species described from Atlantic Canada*

There were no questions on this case study.

### *Development of potential ecosystem case studies*

- A suggestion was made to integrate the ecosystem approach by means of case studies that could bring forth important linkages between species and environment and predator–prey interactions. Workshop participants were reminded that peer-reviewed materials should be used to support these ecosystem impacts. Examples of such case studies were provided:
    - Shifting abundance of zooplankton (e.g. *Calanus* distributions) impacting NARW (lots of work to support this connectivity).
    - Sea ice impacts on Capelin and/or Atlantic Cod (multiple publications show connectivity between the biological to environmental components, from lower to upper trophic levels).
    - How Northern Shrimp are impacted by warmer water temperatures and hypoxia in the GSL.
    - American Lobster benefitting from warmer water temperatures.
    - Coastal versus offshore ecosystems? This could capture recent work by Bob Gregory with Eelgrass as nurseries for juvenile cod and how they move from inshore to offshore as they grow and mature.
- Regarding ecosystem linkages, it was mentioned that DFO has scientists doing this work, but the way in which the report is currently structured makes it difficult to highlight their research (e.g. looking at changes in community structure that doesn’t fall along

species lines), and there wasn’t a category originally identified that could include this type of work. It was mentioned that DFO is moving towards a more ecosystem-based approach, so it seemed strange to some scientists that SOTO starts with individual species then tries to do the integrated/linkage approach afterwards. Some of these barriers are reflected in how the department is set up. Working towards an integrative approach will take a long time.

# APPENDIX 3. ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AMOC | Atlantic Meridional Overturning Circulation |
| AMP | Aquaculture Monitoring Program |
| ATL | Atlantic |
| AZMP | Atlantic Zone Monitoring Program |
| AZOMP | Atlantic Zone Off-Shelf Monitoring Program |
| CCGS | Canadian Coast Guard Ship |
| CER | conservation egg requirement |
| CIL | cold intermediate layer |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| CPUE | catch per unit effort |
| CSAS | Canadian Science Advisory Secretariat |
| CSRF | Competitive Science Research Fund |
| CTD | conductivity temperature depth |
| DFO | Fisheries and Oceans Canada |
| DO | dissolved oxygen |
| DPS | Distinct Population Segment |
| DU | designatable unit |
| EBSA | Ecologically or Biologically Significant Area |
| ECCC | Environment and Climate Change Canada |
| eDNA | environmental DNA |
| GoC | Government of Canada |
| GoM | Gulf of Maine |
| GSL | Gulf of St. Lawrence |
| HCR | harvest control rule |
| HPAI | highly pathogenic avian influenza |
| HPLC | high-performance liquid chromatography |
| ICES | International Council for the Exploration of the Sea |
| IIP | International Ice Patrol |
| IPCC | Intergovernmental Panel on Climate Change |
| IUCN | International Union for Conservation of Nature |
| LCI | lower credible interval |
| LFA | Lobster Fishing Area |
| LOWESS | locally estimated scatterplot smoothing |
| LRP | limit reference point |
| LTL | lower trophic levels |
| MERCINA | Marine Ecosystem Responses to Climate in the North Atlantic |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MPO | Pêches et Océans Canada |
| MRNF | Québec Ministère des Ressources naturelles et de la Faune |
| MSW | multi-sea-winter |
| NABCI | North American Bird Conservation Initiative |
| NAFO | Northwest Atlantic Fisheries Organization |
| NALWG | Northwest Atlantic Leatherback Working Group |
| NAMMCO | North Atlantic Marine Mammal Commission |
| NAO | North Atlantic Oscillation |
| NARW | North Atlantic Right Whale |
| NCR | National Capital Region |

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| NEST | Northeast Fisheries Center Ecosystem Survey Trawl |
| nGSL | northern Gulf of St. Lawrence |
| NLCI | Newfoundland and Labrador Climate Index |
| NLS | Newfoundland and Labrador Shelves |
| NMFS | National Marine Fisheries Service |
| NWA | Northwest Atlantic |
| OBIS | Ocean Biodiversity Information System |
| OECM | other effective area-based conservation measures |
| PA | Precautionary Approach |
| RSL | relative sea level |
| SAR | Science Advisory Report |
| SARA | *Species at Risk Act* |
| SFA | Salmon Fishing Area/<br>Shrimp Fishing Area |
| sGSL | southern Gulf of St. Lawrence |
| SLE | St. Lawrence Estuary |
| SPERA | Strategic Program for Ecosystem-based Research and Advice |
| SOTO | State of the Ocean |
| SS | Scotian Shelf |
| SST | sea surface temperature |
| UCI | upper credible interval |
| USFWS | US Fish and Wildlife Service |
| USR | upper stock reference point |
| XHL | eXtended Halifax Line |