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Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf

Rapport sur l'état et les tendances de l'écosystème du golfe du Maine et du plateau néo-écossais

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ABSTRACT

This document was produced as part of the national Ecosystem Status and Trends Report program, as a deliverable under the Biodiversity Outcomes Framework, focusing on the Gulf of Maine and Scotian Shelf ecozone. It is a compilation of available scientific and technical information on the condition, trends, drivers, and stressors of the Gulf of Maine and Scotian Shelf ecozone. The report was reviewed at a national Department of Fisheries and Oceans (DFO) Science Advisory Meeting in December 2009, at which time a corresponding DFO Science Advisory Report was generated. Key findings identified at that meeting were that a major shift in ecosystem structure had occurred on the Eastern Scotian Shelf; there has been a decline in the size and condition of a number of groundfish species throughout the region; after an exponential increase in grey seal abundance for the last 30-40 years, the rate of increase has slowed considerably; and there have been changes in important oceanographic parameters, such as an increase in the average 0 to 50 m stratification index. Emerging issues included ocean acidification, invasive species, and potential impacts of fisheries on trophic level structure. Data gaps included knowledge of the ecology and trends in deep waters beyond the Scotian Shelf, status and trends of coastal ecosystems, status and trends of many non-commercial species, and the ecosystem impacts of climate change.

RÉSUMÉ

Le présent document a été créé dans le cadre du programme national du Rapport sur l'état et les tendances de l'écosystème, à titre de produit livrable du Cadre axé sur les résultats en matière de biodiversité, et met l'accent sur l'écozone du golfe du Maine et du plateau néo-écossais. Il s'agit d'une compilation de renseignements scientifiques et techniques sur l'état, les tendances, les facteurs et les stresseurs du golfe du Maine et du plateau néo-écossais. On a examiné ce rapport lors d'une réunion d'avis scientifique du ministère des Pêches et des Océans, en décembre 2009, et l'on a rédigé un rapport d'avis scientifique du MPO correspondant. Lors de cette réunion, on a noté les principales constatations suivantes : un changement important de la structure de l'écosystème s'est produit sur le plateau néo-écossais, la taille de diverses espèces de poissons de la région a diminué et leur état s'est détérioré, à la suite d'une hausse exponentielle du nombre de phoques gris au cours des 30 à 40 dernières années, le taux de croissance a considérablement diminué, et d'importants paramètres océanographiques ont subi des changements, comme la hausse de l'indice de stratification moyen de 0 à 50 m. L'acidification des océans, les espèces envahissantes et les répercussions potentielles de la pêche sur la structure trophique faisaient partie des nouvelles questions. On constate qu'il manque des données si l'on se fie aux connaissances relatives à l'écologie et aux tendances des eaux profondes au-delà du plateau néo-écossais, à l'état et aux tendances des écosystèmes côtiers, à l'état et aux tendances de nombreuses espèces non commerciales, et aux répercussions des changements climatiques sur l'écosystème.

OVERVIEW OF GULF OF MAINE AND SCOTIAN SHELF ECOZONE – PRE-HISTORY AND HISTORIC CONTEXT

GEOLOGY, TOPOGRAPHY, CLIMATE

The Gulf of Maine and Scotian Shelf ecozone is bounded by the Hague Line to the southwest (defining the international border with the United States) and by the southern edge of the Laurentian Channel to the northeast. It includes coastal portions of Nova Scotia and New Brunswick, and extends beyond the edge of the continental shelf to the 200 nm limit of the Exclusive Economic Zone (Figure 1). There are a number of subareas within the Gulf of Maine and Scotian Shelf ecozone that are referenced in this report. These include the Canadian portions of the Gulf of Maine and Georges Bank, the Bay of Fundy, and the Scotian Shelf, with some differences observed between the Western Scotian Shelf (WSS) and Eastern Scotian Shelf (ESS).

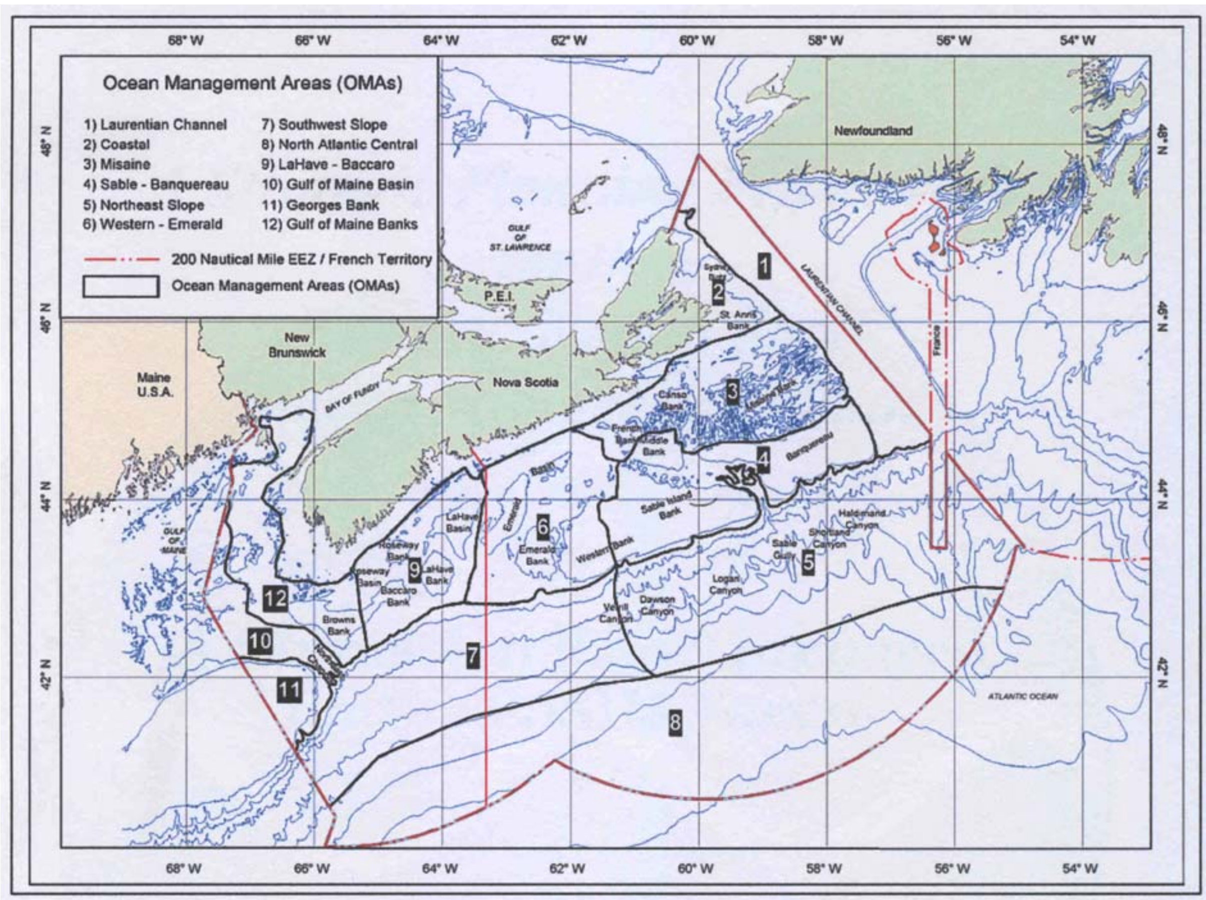

Figure 1. Map of Gulf of Maine and Scotian Shelf ecozone with place names.

The **Scotian Shelf** is part of a continental shelf that averages only 90 m depth and extends some 200 km in length. The shelf can be divided into an inner, middle, and outer shelf, each with its own characteristics (King and MacLean 1976). The inner portion of the shelf, from the Nova Scotia coast to about 25 km offshore is an extension of the coastal bedrock with generally rough topography. This area was scoured by glaciation, and, in southwestern Nova Scotia, there exists a wide flat portion of this inner shelf (Breeze et al. 2002). The middle shelf has broad, deep basins in the central and western portions of the Scotian Shelf, while in the east; the middle shelf is an area of complex topography, with many small to medium-sized banks and small basins ("holes"). The outer shelf, the portion of the Scotian Shelf farthest from the coast, is a series of relatively broad, flat and shallow banks separated by gently sloping lower saddles. Sable Island is an exposed portion of Sable Island Bank and a unique feature of the outer shelf. On the outer shelf, at about 200 m in depth (the "shelf break"), the ocean bottom begins to slope more steeply to a depth of about 2000 m (the continental slope) (Zwanenburg et al. 2006). The series of submarine banks and cross-shelf channels along the outer shelf and basins and troughs along the central shelf serve to limit and guide near-bottom flow (Zwanenburg et al. 2006), resulting in a complex circulation pattern.

The **Bay of Fundy** is a narrow funnel-shaped body of water that lies between Nova Scotia and New Brunswick. It is 270 km long and 60 km wide at its widest point, and encompasses offshore oceanic features with shallow banks and deep channels, as well as diverse coastal marine habitats (Willcocks-Musselman 2003). It is underlain by the Fundian Lowlands formation of Triassic sedimentary rocks (Pritchard 1955). The bottom contours largely follow the coastline and reflect its origin as a former drainage system originating in the Minas Basin-Truro area. It has some of the largest tides in world.

Georges Bank is a broad submarine bank located between the southwestern tip of Nova Scotia and Cape Cod, Massachussetts. The top of the bank above the 100 m isobath has an area of approximately 28,800 km^2, with approximately 7,000 km^2 under Canadian authority. Large portions of Georges Bank lay a mere 40 m below the surface of the Atlantic Ocean, although the bank lies nearly 150 km from the nearest land. On Georges Bank, there is a layer of sedimentary rock between the bottom crystalline bedrock (composed of igneous or metamorphic rock) and upper sediment blanket (Backus and Borne 1987).

The **climate** of this region is varied, including Atlantic, Boreal, and sub-arctic climates, and is strongly influenced by both the warm Gulf Stream and the cold Labrador Current (Lines et al. 2008). The air temperature of the region, as measured on Sable Island, has a weak long-term increasing trend of about 1 degree Celsius per century, amounting to 1 degree Celcius over the length of the record (Figure 2) (DFO 2008a).

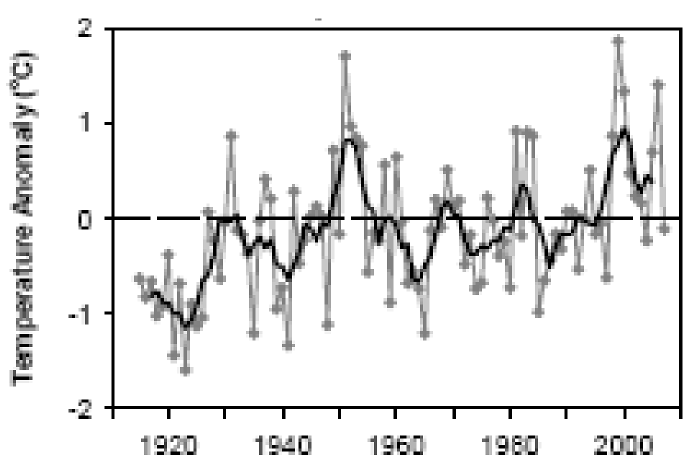

Figure 2. Time series of annual air temperature anomalies (grey line and dots) and 5 year running means (heavy, black line) as measured on Sable Island (DFO 2008a).

HUMAN HISTORY

As with many other marine areas of Canada, the major human uses of the Gulf of Maine and Scotian Shelf ecozone have been fishing, transportation, recreation, and, more recently, offshore oil and gas and aquaculture.

Harvesting the waters of the Gulf of Maine and Scotian Shelf by aboriginal peoples has been underway for thousands of years. Commercial fishing started in the mid-1500s, which included fishing by domestic and foreign fleets. Fisheries removals reached peak levels in the early 1970s, exceeding 750,000 t in 1973. Canada declared a 200-mile Exclusive Economic Zone in 1977, which limited access of foreign fishing vessels to the Canadian portions of the Gulf of Maine and Scotian Shelf. Total landings were relatively stable in the 1980s but were below the previous maximum. In the 1990s, total landings reached historical low levels due to the collapse of the groundfish stocks, with the implementation of a moratorium on groundfish fishing on the Eastern Scotian Shelf (ESS) in 1993. Nova Scotia (NS) was more impacted by this collapse in the groundfish fisheries than was New Brunswick (NB), as the fishery in NB is based more on shellfish and pelagic fisheries (Mandale et al. 2000). Trends in the Nova Scotia commercial fishery in terms of landings and value for 1995-2007 are provided in Figure 3. During this time, landings and value peaked in 2002-2003 and subsequently declined (Gardner Pinford Consulting Economists Ltd. 2009b).

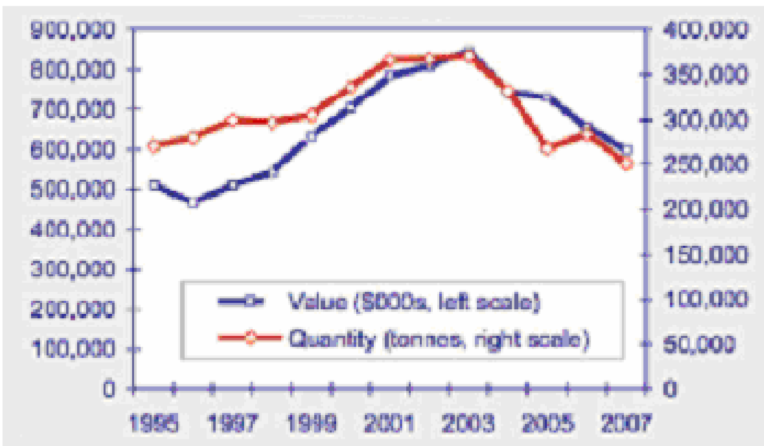

Figure 3. Nova Scotia Fisheries, Quantity and Value of Landings, 1995-2007 (Gardner Pinford Consulting Economists Ltd. 2009b).

The marine **aquaculture** industry within the Gulf of Maine and Scotian Shelf ecozone has grown substantially since around the mid-1980s. To date, finfish (primarily salmon) and shellfish (mussels and oysters) have been the targeted products. In Southwestern New Brunswick, the aquaculture industry brings in more than $200 million per year to the local economy, virtually all from salmon production (Figure 4).

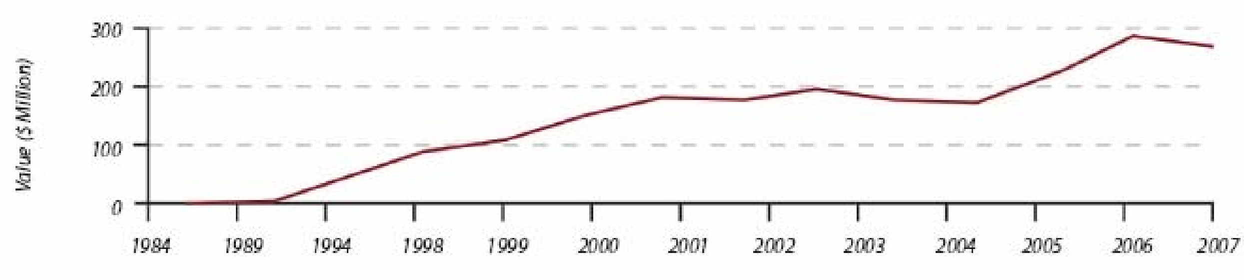

Figure 4. New Brunswick Salmon Production Value ($ Millions), 1984-2007) (Government of New Brunswick 2007).

In Nova Scotia, aquaculture sales topped $53 million in 2007 (Gardner Pinfold Consulting Economists Ltd. 2009b) (Figure 5). All of the aquaculture within the Gulf of Maine Scotian Shelf ecozone has been coastal in nature, generally occurring within a kilometre of land, at sites protected from wind and waves by coves and islands. However, as the number of viable coastal sites becomes limited, efforts have turned to the potential of open ocean aquaculture, at least within the Bay of Fundy. Physical constraints of water temperature and waves, the need for technology advancement, and conflicts with other uses and values such as traditional fishing, shipping, and species at risk are challenges to expanding the aquaculture industry to open ocean areas (Chang et al. 2005).

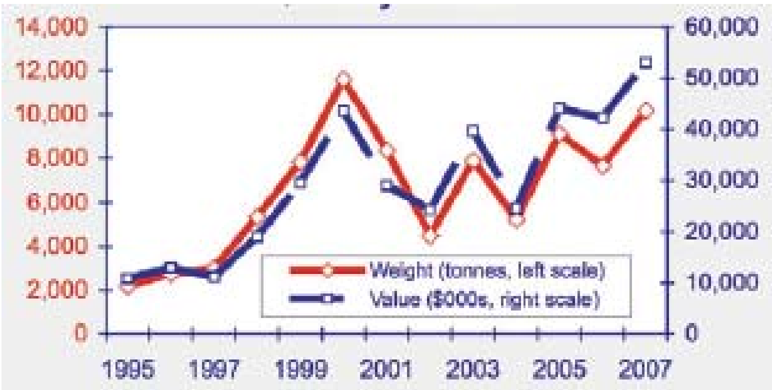

Figure 5. Nova Scotia Aquaculture Sector Production (tonnes) and Value ($000s), 1995-2007 (Gardner Pinfold Consulting Economists Ltd. 2009b).

Oil and gas exploration offshore Nova Scotia began in 1959, and there have been three distinct cycles of activity since that time (Canada Nova-Scotia Offshore Petroleum Board 2009). The first cycle of oil exploration began on Sable Bank, with the first exploration well drilled on Sable Island in 1967. The second phase of exploration from 1979-1989 was initiated by the major gas discovery in 1979 just east of Sable Island. A third cycle included drilling in the relatively shallow waters of the Scotian Shelf, as well as the deep water of the Scotian Slope. Hundreds of thousands of 2D and 3D seismic data has been collected over time. Peaks in area surveyed occurred in the early 1970s, early 1980s, and late 1990s (Figure 6).

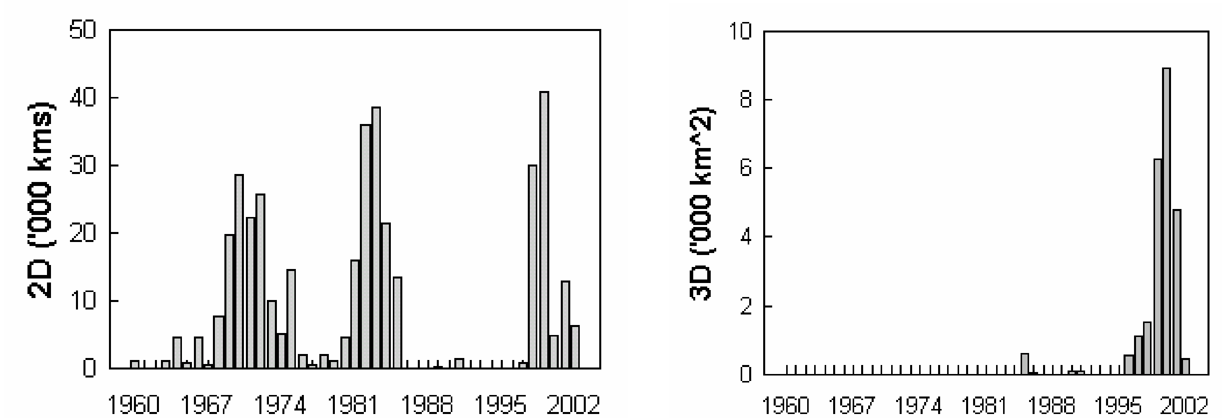

Figure 6. Amount of 2D (km, left panel) and 3D (km^2, right panel) seismic exploration on the Scotian Shelf from 1960 to 2002.

A total of 204 wells have been drilled in the Gulf of Maine and Scotian Shelf ecozone; 127 of these have been exploration wells (Figure 7). Most of these exploration wells exist only for a short period of time (e.g., less than 3 months). Dozens of significant oil and gas discoveries have been made, and the related production wells can last for many years.

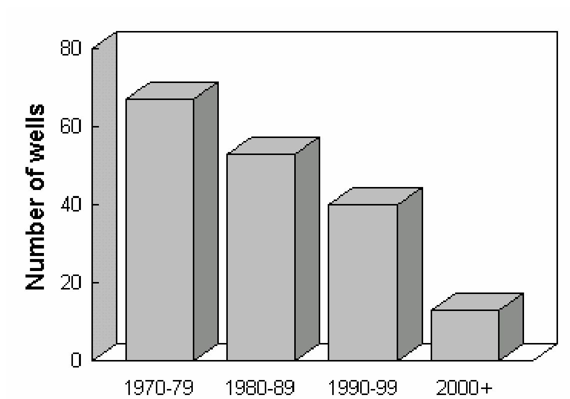

Figure 7. Number of offshore petroleum wells drilled in the Gulf of Maine and Scotian Shelf region since 1970.

In 1988, a moratorium was placed on offshore petroleum activities (i.e., exploration, drilling, and development) on the Canadian portion of Georges Bank. In December 1999, the Georges Bank moratorium was extended until 2012, at which point it will be reviewed.

Marine transportation is an important human use of the Gulf of Maine and Scotian Shelf ecozone. In terms of size, Halifax is the largest port in Nova Scotia, and Saint John is the largest port in New Brunswick. Halifax is the third largest container port in Canada, and it is a major cruise ship destination. It handled 14.1 million tonnes of cargo in 2005 (Gardner Pinfold Consulting Economists Ltd. 2009a). Port Hawkesbury, on the Strait of Canso in Cape Breton, is the largest port by tonnage of cargo handled – 30.7 million tonnes in 2005 – primarily in terms of petroleum transhipment, gypsum, paper products, aggregate, and imports of coal (Gardner Pinfold Consulting Economists Ltd. 2009a). The port of Saint John, NB, handles and average of 27 million tonnes of cargo annually (27.5 million tonnes in 2005; Saint John Port Authority 2005).

Trends in the **recreational use** of the Gulf of Maine and Scotian Shelf ecozone, which would include whale watching, pleasure boating, cruise ships, and recreational fishing, are harder to describe, as there is limited reporting of this type of activity. However, some statistics on cruise ship activity are available for this area (Figure 8).

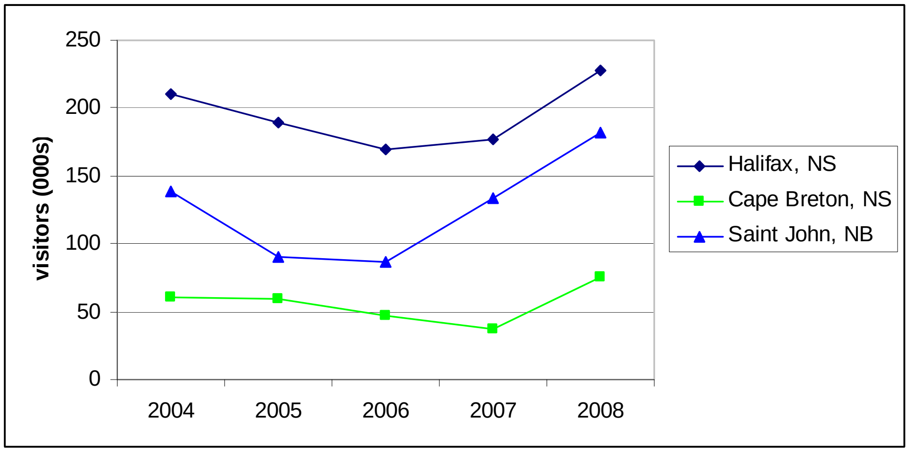

Figure 8. Cruise ship passenger visits to Halifax (NS), Sydney (NS), and Saint John (NB) from 2004 to 2008 (Government of Nova Scotia – Tourism, Culture and Heritage 2009; Tourism Saint John 2009).

DESCRIPTION OF THE CONDITION OF THE ECOZONE

ABIOTIC DRIVERS

The **North Atlantic Oscillation** (NAO) is the dominant atmospheric pattern in the North Atlantic Ocean and a significant large-scale abiotic driver of the Gulf of Maine and Scotian Shelf ecozone. The NAO generally affects water properties and circulation through air-sea heat exchange and wind stress (DFO 2008a), though it affects the water properties of the Scotian Shelf primarily by advection (Petrie and Drinkwater 1993). The NAO is a seesaw pattern between a perennial high-pressure cell over the Azores in the southeast Atlantic and a low-pressure cell around Iceland. The NAO Index measures the difference in sea level pressure between the two locations in winter. A high index brings increased westerly winds, precipitation, and results in warmer water temperatures over the Gulf of Maine and Scotian Shelf ecozone. A negative, or low index brings the opposite to the area, with drier conditions and decreased storminess, along with cooler water temperatures resulting from an increased influence of the Labrador Current southwards along the coast (Figure 9). During the 20-year period of the 1950s to 1970s, the NAO index was low and waters were generally cooler in the Gulf of Maine and Scotian Shelf ecozone.

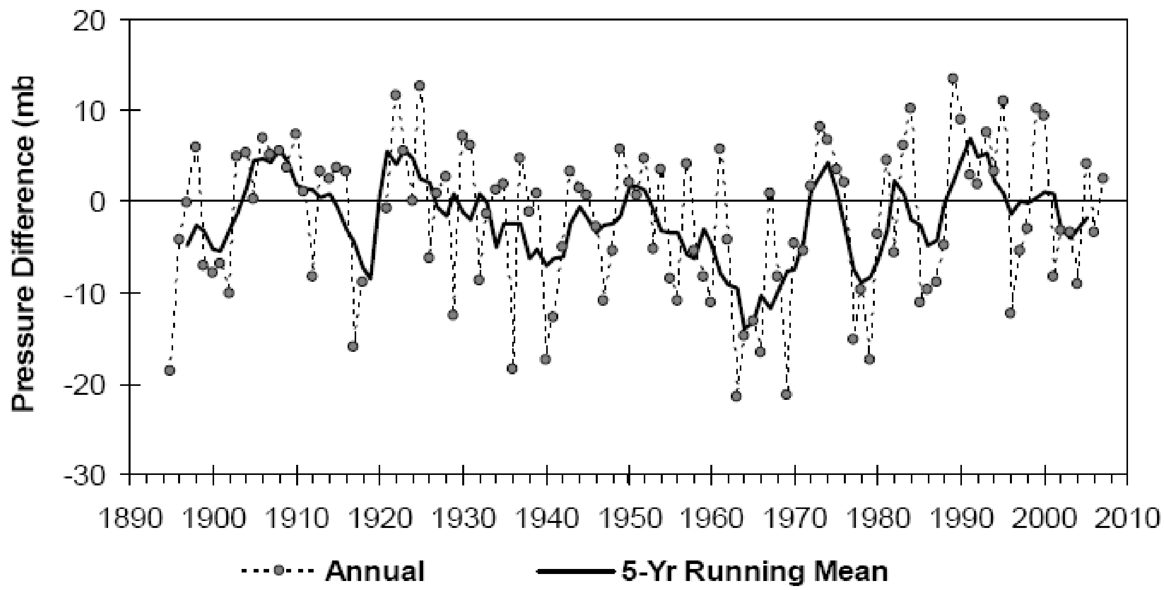

Figure 9. Anomalies of the North Atlantic Oscillation index.

The **circulation** patterns on the Scotian Shelf (Figure 10) are governed largely by its complex topography and the influence of three major currents - the warm, salty Gulf Stream over the continental slope to the south, the downstream influence of the cold Labrador Current from the north, and the cool, fresh Scotian Shelf Current derived from the outflow of the Gulf of St. Lawrence. The dominant oceanographic feature of the ESS is the strong southwesterly flow of the Nova Scotia current, centered between the 100 and 150 m isobaths on the inner shelf. Current speeds are typically 5-30 km per day and vary seasonally, generally stronger in the winter (Zwanenburg et al. 2006). Further to the south, the waters moving southwest along the Scotian Shelf enter the Gulf of Maine, joining a current moving northwest through the deep Northeast Channel between Georges Bank and Browns Bank. This initiates a general counterclockwise circulation pattern in this portion of the ecozone. The exception to this circulation is a clockwise pattern around Georges Bank. Within the ecozone, there is a general transport of water and organisms from the northeast towards the southwest. The distribution of the three primary source waters, with cool fresh water coming from the north and east and warm salty water coming from the south and west, result in not only a predominance of flow from the northeast to southwest, but also a general increase in the temperature and salinity in the same direction (Zwanenburg et al. 2006).

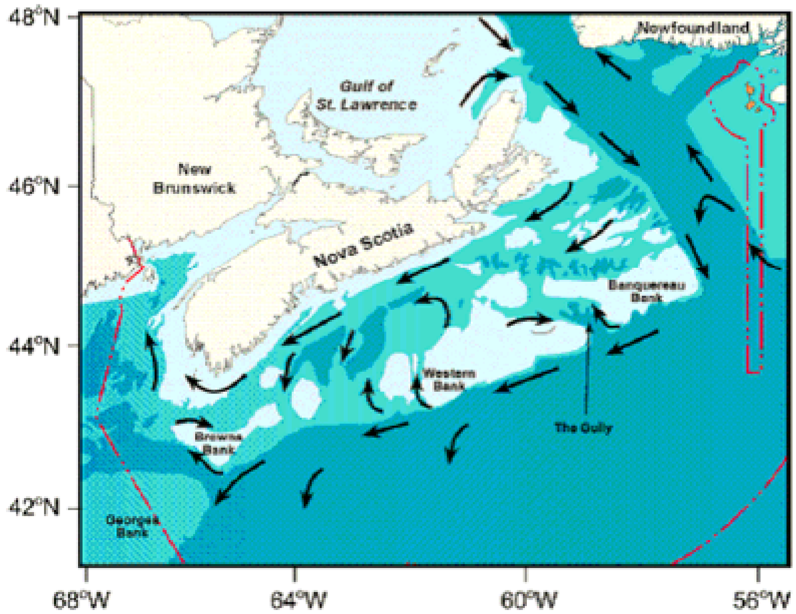

Figure 10: Detailed surface circulation on the Scotian Shelf (Breeze et al. 2002).

Similar to atmospheric fronts, **oceanic fronts** exist where there is a sharp boundary between currents and water masses with different hydrographic properties. The primary front in this ecozone is the Shelf/Slope front that runs along the southwestern edge of the Scotian Shelf (Breeze et al. 2002) (Figure 11). The Gulf Stream does not contact the Scotian Shelf directly. However, as the Gulf Stream approaches the Gulf of Maine and Scotian Shelf ecozone from the south, it flows in such a way that it tends to trap the cooler Labrador and St. Lawrence waters on the shelf near the Nova Scotian land base (Breeze et al. 2002), and mixes with Labrador Current water over the continental slope so that the water along the shelf edge (Slope Water) is cooler and fresher in the northeast and warmer and saltier in the southwest (Zwanenburg et al. 2006). Like atmospheric fronts, the shelf front is dynamic and is known to move by tens of kilometers over a few days and may move upwards of 150 km over several months (Breeze et al. 2002). Fronts are important for organisms such as plankton and jellyfish, which tend to collect at a front, and their congregation attracts predators such as sea turtles, whales, and pelagic seabirds. Euphausiids and silver hake have also been noted to aggregate along the shelf slope (Breeze et al. 2002).

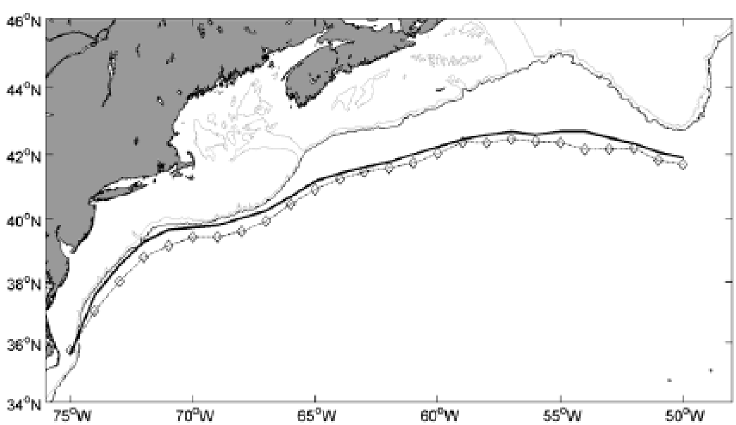

Figure 11. The 2007 (dashed line) and long-term mean (1973-2000; solid line) positions of the shelf/slope front (Petrie et al. 2008b).

Water temperature is well recognized for its effect on the growth and maturation of most fish and invertebrate species. Year to year, water temperatures on the Scotian Shelf and in the Gulf of Maine are among the most variable in the North Atlantic ocean. Temperatures also vary with depth and location. Within the region, some areas may experience above normal, others normal, and still others below normal ocean temperature anomalies in the same year. For example, the WSS remains generally warmer than the ESS, as warmer Gulf Stream water is conducted onto the WSS over the southwest slope between Browns and Western banks; whereas, the ESS is more influenced by the cool, low salinity water from the north coming in over the Misaine Bank near Cape Breton (Breeze et al. 2002).

A summary shown in Figure 12 indicates the year to year and within year variability at a variety of different locations within the Gulf of Maine and Scotian Shelf ecozone. The results are displayed as the number of standard deviations above (red) and below (blue) normal; the deeper the shades of red (blue) the more the temperatures are above (below) normal.

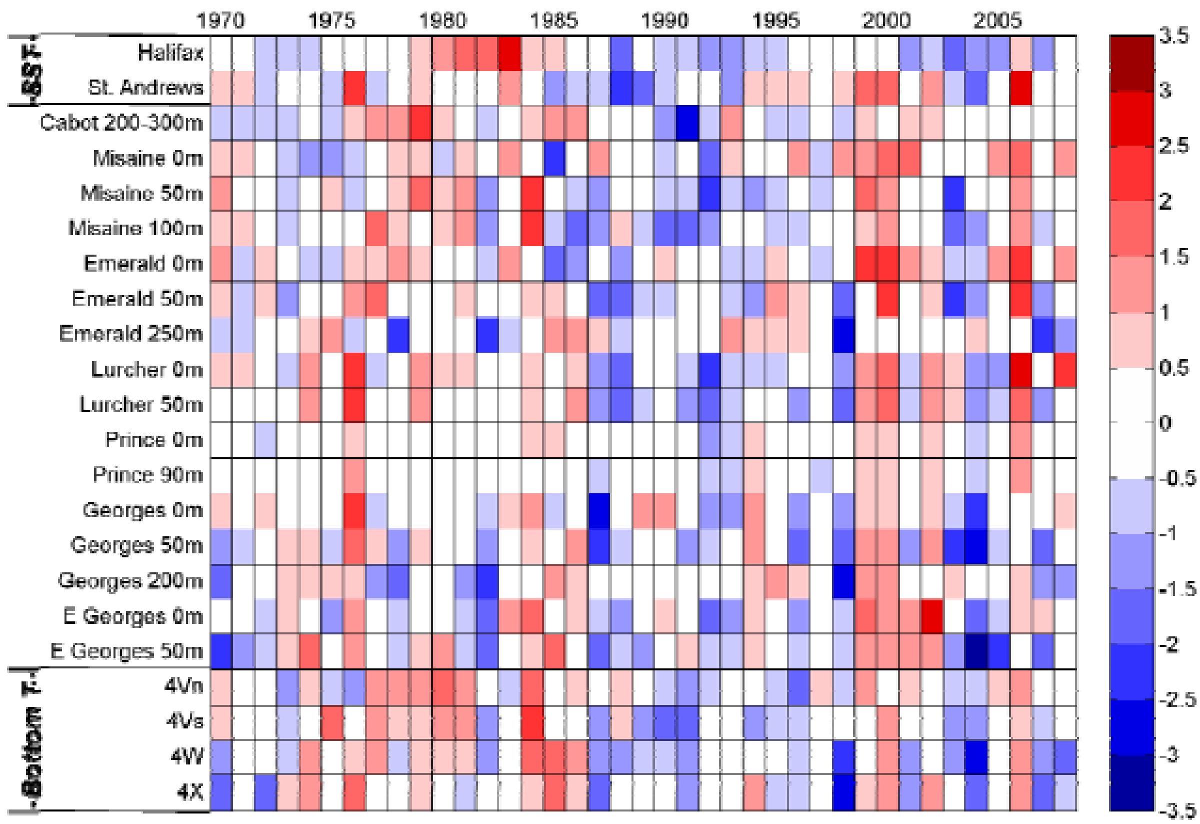

Figure 12. Normalized annual anomalies of temperatures at the bottom and discrete depths for the Scotian Shelf - Gulf of Maine region. The normalized, annual anomalies are based on the 1971-2000 means, divided by the standard deviation. The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal (Petrie et al. 2009).

Despite the variability in water temperature, there are some trends and patterns that can be seen (Figure 13). For example, water temperature during the periods 1987-1993 and 2003-2004 were predominantly colder than normal, while 1999-2000 was warmer than normal. From 1979 to 1986, temperatures tended to be warmer than normal but not as dominantly so as 1999-2000. In 2006, 16 of the 18 variables were above normal and the composite index, the sum of all the normalized anomalies in Figure 12, was the highest of the 38 year time series. In 2007, 9 variables had normalized anomalies lower than normal. Based on the composite index, 2007 ranked as the 7th coldest in 38 years (DFO 2008a). In 2008, 14 of the 22 series shown were within 0.5 standard deviation of their normal values. Of the 8 remaining series, 4 were more than 0.5 standard deviation greater than normal and 4 were more than 0.5 standard deviation below normal. Most of the series associated with the eastern and central Shelf had negative anomalies; most associated with the western Shelf were positive (Petrie et al. 2009). It appears that the variability in water temperature has been increasing in the past decade.

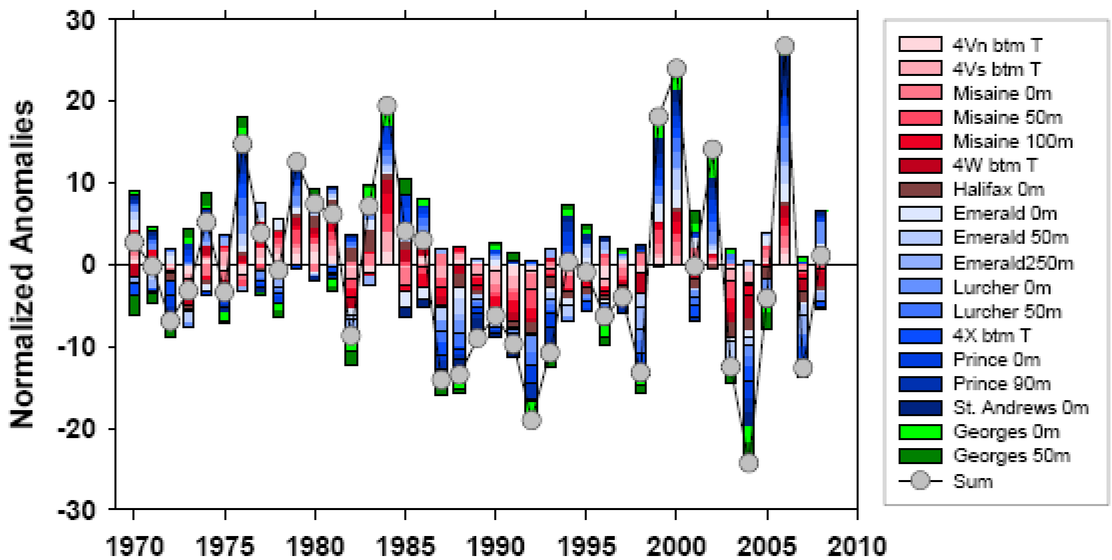

Figure 13. The contribution of each of the normalized anomalies are shown as a bar chart and their summation as a time series (grey circles, black line) (Petrie et al. 2009).

Salinity is an important characteristic of marine waters. The Labrador Current and Gulf Stream are both saltier (34-36 ppt) than the Shelf Current waters (31-33 ppt), and areas near the coastline are generally less saline (30-32 ppt) than the Shelf, although there is considerable variability, particularly in surface waters (Breeze et al. 2002). Salinity measurements have been taken since 1924 at a fixed station near Saint Andrews, NB, adjacent to the entrance of the Bay of Fundy. Results at 0 m are shown in Figure 14. There appears to have been a decrease in salinity from the mid-1970s to the mid-1990s (low in 1996), followed by an increase to 2002. This was followed again by a decline (DFO 2008a). This pattern is consistent with the pattern of salinities measured by the Northeast Fisheries Science Centre on the continental shelf (Gulf of Maine) since the 1970s (Ecosystem Assessment Program 2009).

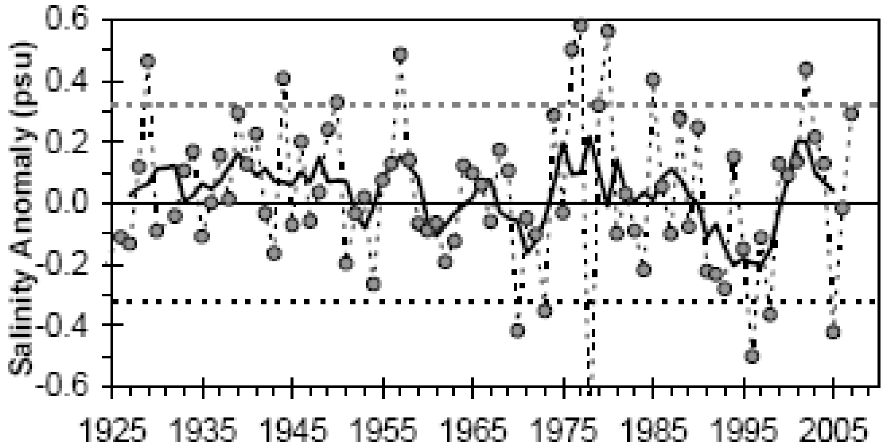

Figure 14. Time series of annual surface salinity anomalies (grey line and dots) and 5 year running means (heavy, black line) (DFO 2008a).

Seawater density depends on temperature, salinity and pressure, and increases with depth in the ocean. The density difference between waters at two depths is referred to as the density **stratification**. The density stratification divided by the depth difference is called the stratification index. Increased stratification inhibits vertical mixing, can decrease nutrient fluxes to the surface waters and thus affect phytoplankton production. Alternatively, increased stratification may reduce turbulence, concentrate phytoplankton and lead to increased production [20086]. On the Scotian Shelf, the average 0 to 50 m stratification index increased significantly in the 1990s. From the mid- to late 1990s, the index was at or near its maximum over the 50-year record (Figure 15). Stratification in 2008 was above normal by 1 standard deviation, the 4th strongest in 49 years (Petrie et al. 2009).

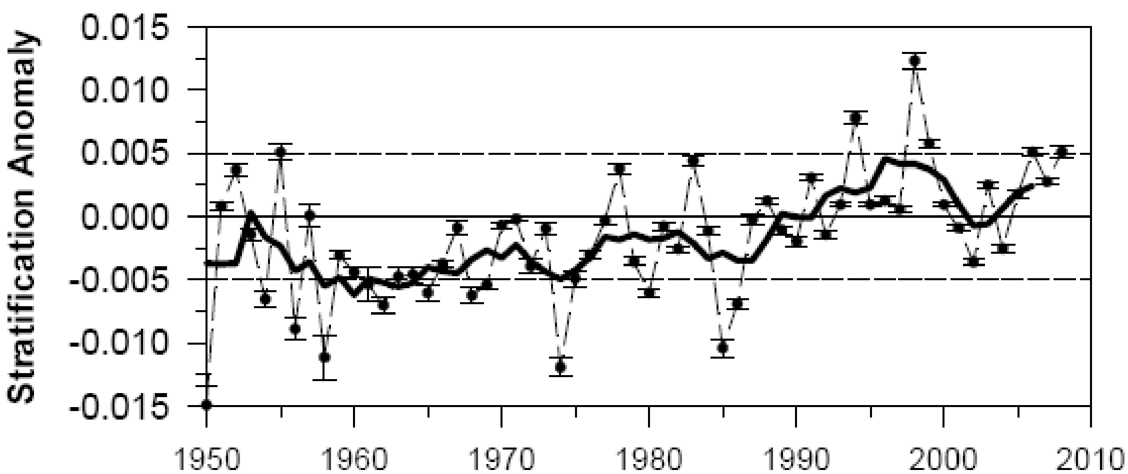

Figure 15. The mean annual (dashed line) and 5-year running mean (solid line) of the stratification index over the Scotian Shelf. Standard error estimates for each annual value are shown (Petrie et al. 2009).

Important changes in stratification have also been noted over time in the eastern Gulf of Maine and Georges Bank with increasing temperature and changes in salinity. Stratification has increased steadily from the mid-1980s on Georges Bank and in the eastern Gulf of Maine (Figure 16). Highly stratified water exists in the deep basins, such as Emerald Basin and Roseway Basin.

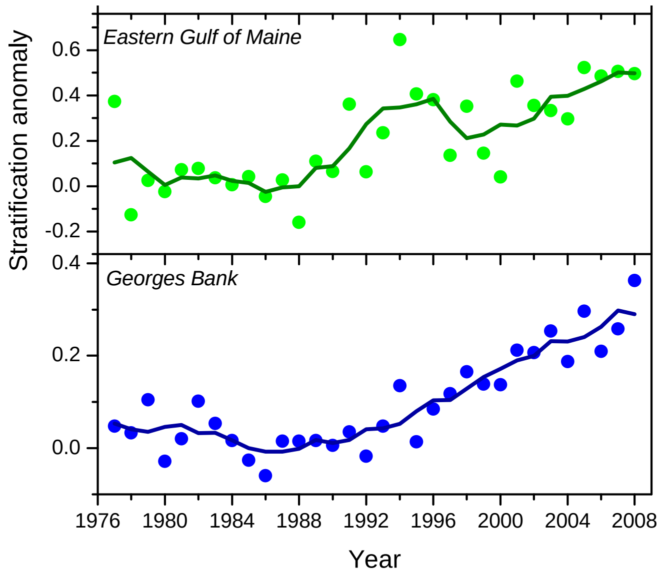

Figure 16. Trends in stratification for the eastern Gulf of Maine and Georges Bank (Maureen Taylor, pers. comm.).

Strong stratification sometimes inhibits vertical mixing enough to cause **dissolved oxygen** levels in deeper layers to become depressed. Although the waters of this ecozone do stratify, low dissolved oxygen is not apparent with the exception of a few coastal locations and potentially some of the deepest basins (Figure 17).

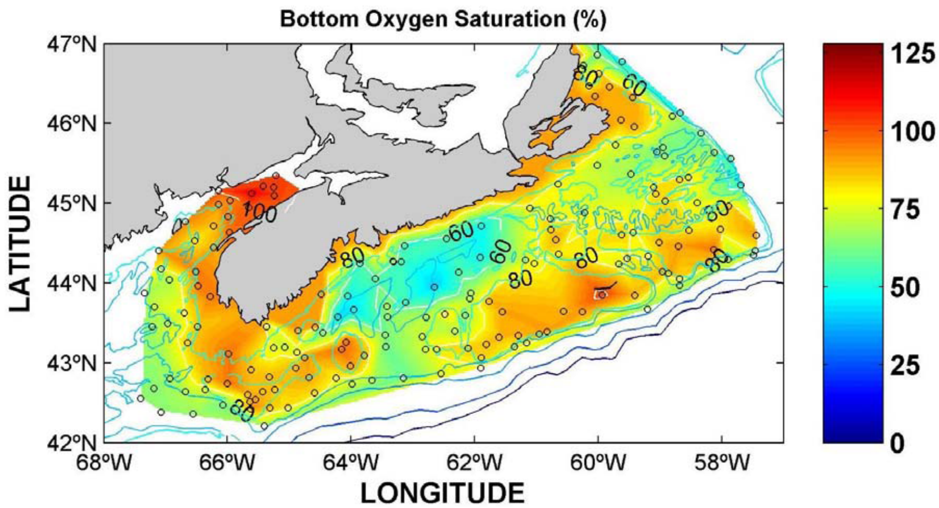

Figure 17. Bottom oxygen saturation oxygen saturation on the Scotian Shelf during the annual July groundfish survey in 2008 (Harrison et al. 2009).

The **sediments** covering the Scotian Shelf seafloor are important structurally and functionally to this marine ecozone. Attributes such as the micro and macro relief, porosity, grain size and shape, all influence the organisms living on or in the sediments (Breeze et al. 2002). The interaction of ocean currents and ocean bottom substrates create a diverse array of habitats. They range from areas that are regularly disturbed by tidal and other currents and where nutrients are relatively abundant to those that are very low energy, stable and where nutrients are scarce. A mix of organisms with unique life-history characteristics inhabits each of these habitat types. The ability of these communities to withstand or to rebound from the impacts of human activities varies (Zwanenburg et al. 2006).

Freshwater inputs from rivers is another important factor that influences the salinity, nutrient levels, and other oceanographic characteristics of coastal waters. For example, the Saint John River constitutes approximately 70% of the freshwater entering the Bay of Fundy. With a mean of 1105 $m^3 s^{-1}$ discharged from this river, this low salinity water flows towards the Gulf of Maine along the northern shore of the Bay during ebbing tides (Hunter and Associates 1982). Freshwater inputs to coastal waters peak during April and May, with spring runoff and rainfall flooding from a number of large rivers. Freshwater inputs are also a source of contaminants to the marine ecozone.

Ice cover is rare in the offshore of the Scotian Shelf, but sea ice is generally transported out of the Gulf of St. Lawrence through Cabot Strait, pushed by northwesterly winds and ocean currents, onto the ESS south of Cape Breton (Breeze et al. 2002). Localized sea ice may also occur along the coastline of Nova Scotia. The monthly average sea ice area seaward of Cabot Strait (off Cape Breton) has been measured since 1970 (Figure 18), as has the duration of ice (Figure 19). Many of the recent years have had lower than average ice cover (Petrie et al. 2008a).

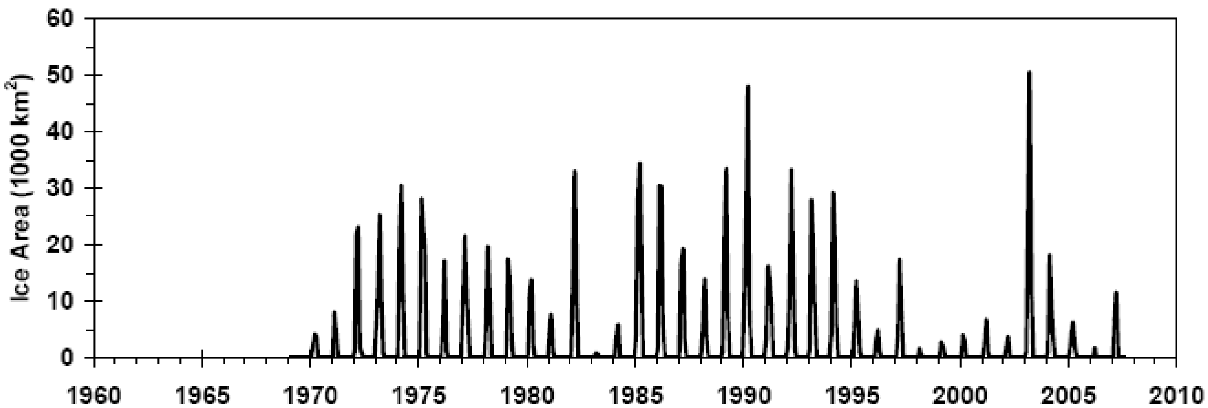

Figure 18. Time series of monthly mean sea ice area seaward of Cabot Strait (Petrie et al. 2008a).

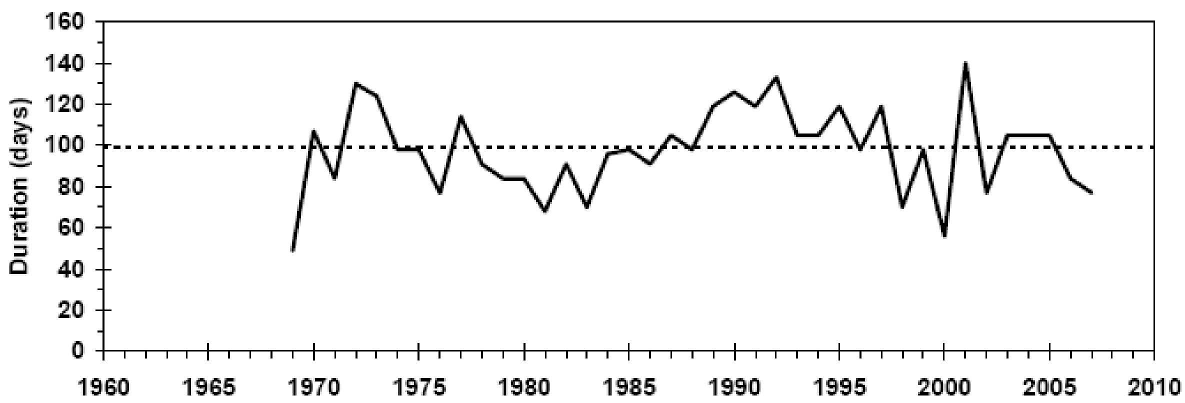

Figure 19. Time series of the duration of ice seaward of Cabot Strait (Petrie et al. 2008a). The horizontal line represents the long-term (1971-2000) mean.

ECOSYSTEM FUNCTIONS AND PROCESSES

<u>Natural Disturbances</u>

<u>Extreme Weather Events</u>

The annual distribution of independent storms for Atlantic Canada in shown in Figure 20 (Ecosystem Assessment Program 2009). The outstanding characteristic of this figure is the large number of storms in 1972 and 1974. A study of **severe storms** in Atlantic Canada based on maximum wind speeds also indicated peaks in severe storms at this time (Lewis and Moran 1984).

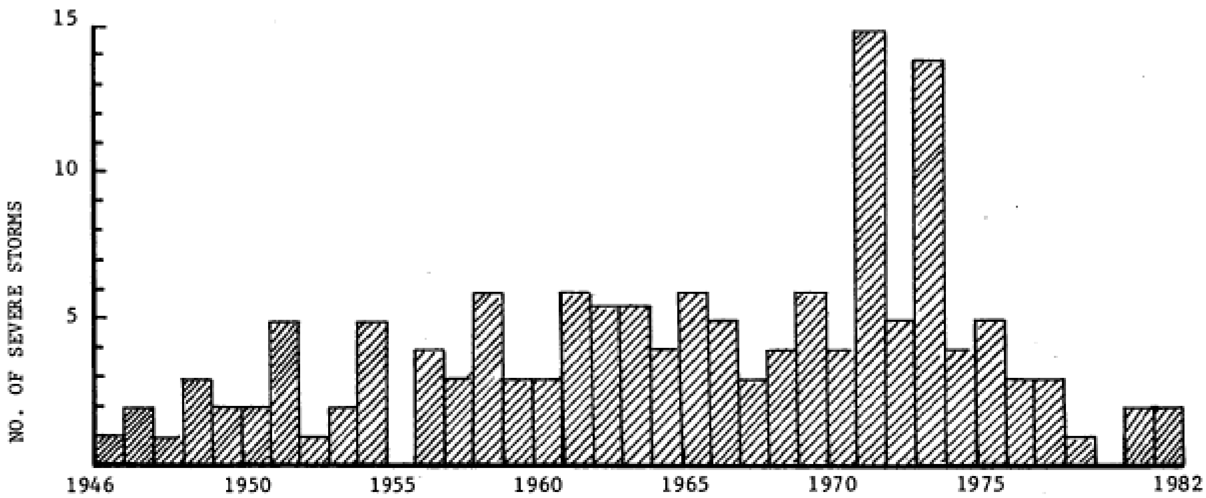

Figure 20. Annual number of severe storms, 1946-1982 (Ecosystem Assessment Program 2009).

However, reduced storminess, as measured by the variability (standard deviation) in the **wind stress** at Sable Island may have contributed to the increasing stratification during the first half of the 1990s through reduced vertical mixing (Figure 21) (DFO 2003).

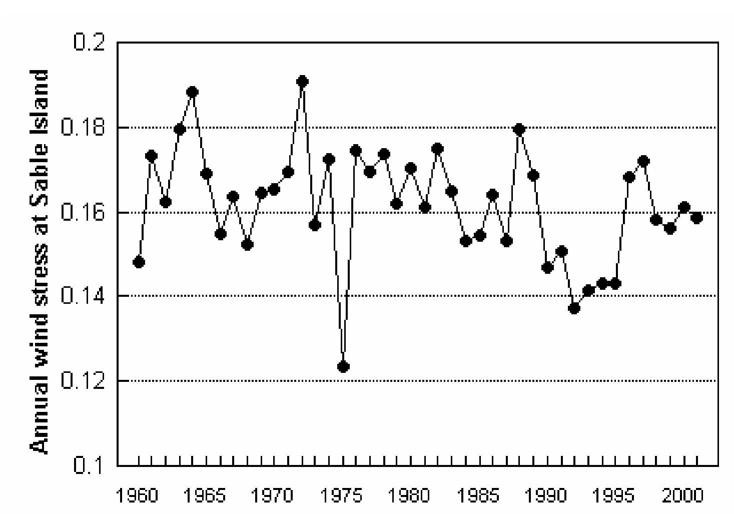

Figure 21. Annual wind stress on Sable Island, 1960-2002 (DFO 2003).

Natural Benthic Disturbance

Natural benthic disturbance occurs as a result of processes such as tidal and circulation currents, storm and internal waves, i.e., is a result of natural, mechanical forces on the substrate. For the Gulf of Maine and Scotian Shelf ecozone, benthic disturbance has been characterized by the frictional velocity on the seabed and critical shear stress for a given particle size (DFA 2005a). A map depicting natural benthic disturbance is provided in Figure 22. This map indicates that the sediments on the tops of banks of the Scotian Shelf, including Sable Bank and Banquereau, are naturally more highly disturbed than the deeper basins.

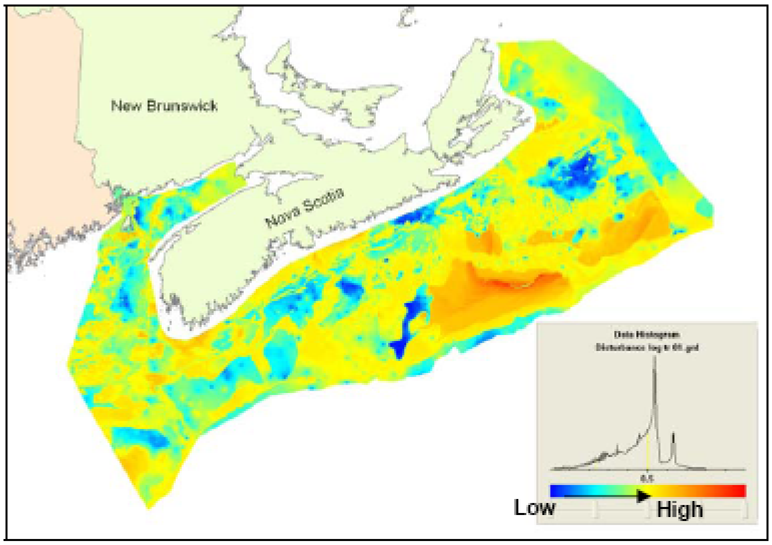

Figure 22. Natural disturbance map for Gulf of Maine and Scotian Shelf benthic habitats. Blue areas are relatively stable, while red areas are relatively disturbed (DFA 2005a).

Community and Population Dynamics

Predator-Prey Cycles

Phytoplankton constitute the base of the marine food web and consequently their production sets an upper limit on the production of all higher trophic levels. The world's great coastal fisheries tend to be located in regions where primary production is highest (e.g., the Grand Banks and Georges Bank in the Northwest Atlantic). High-frequency spatial (kilometers) and temporal (days) variability in phytoplankton biomass is a common feature of the Scotian Shelf (Zwanenburg et al. 2006). Continuous Plankton Recorder observations indicate that, compared with the historical data record starting in 1961, phytoplankton color index and abundance of large diatoms and dinoflagellates on the Scotian Shelf have been notably higher, starting in the early 1990s and continuing into the 2000s, than levels observed in the 1960s/1970s (Figure 23) (Harrison et al. 2007).

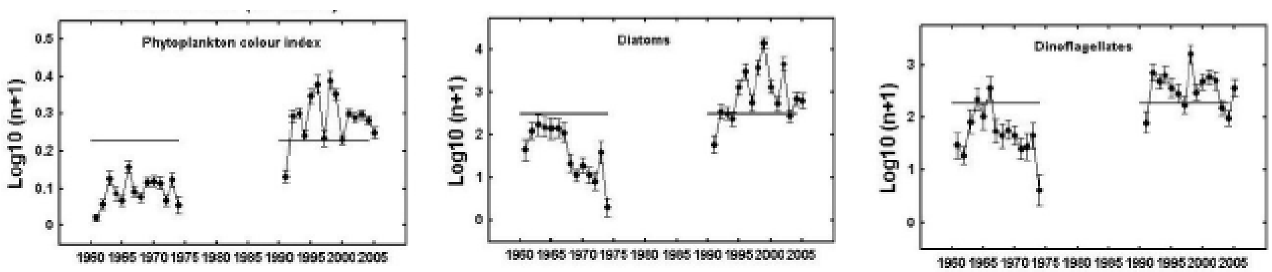

Figure 23. Time-series of phytoplankton biomass (color index), diatom and dinoflagellate relative abundance (annual means) on the Scotian Shelf from Continuous Plankton Recorder surveys, 1961-2005. Vertical bars are standard errors (Harrison et al. 2007).

The dynamics (timing and magnitude) of **zooplankton** determines, in part, how much energy produced from phytoplankton is transferred to the fishes, mammals, and birds of the pelagic food chain, and how much goes directly as detritus to the sea floor. Zooplankton can be divided into three main categories on the basis of size. Mesozooplankton are 0.2-2 mm in length. On the Scotian Shelf, the mesozooplankton communities are consumed directly by larval and juvenile groundfish, juvenile and adult pelagic fish, baleen whales, and seabirds. The shelf community is characterized by relatively high mesozooplankton biomass (1-6 g dry wt. m-2) and relatively low diversity. Copepods, small primitive shrimp-like creatures, generally account for >80% of the biomass and abundance of mesozooplankton in the 0-100 m depth range in spring and >70% in fall (Zwanenburg et al. 2006). Copepods provide the main link between the phytoplankton and higher trophic levels of the ecozone.

Three species of *Calanus* usually make up >70% of the copepod biomass on the Scotian Shelf in spring: *C. finmarchicus*, a North Atlantic species; *C. hyperboreus*, an Arctic deepwater species; and *C. glacialis*, an Arctic shelf species (Zwanenburg et al. 2006). The requirement for deep water for overwintering means that *Calanus* spp. are not found over most of the shelf for part of the year. The exception is overwintering *Calanus* spp. that are present in dense layers near the bottom of the deeper shelf-basins, where they are heavily preyed upon by fish and, in Roseway Basin, by right whales.

C. finmarchicus appears to be a significant link in the food chain because its eggs and early larvae are preferred food items for spring-spawned cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) larvae, two species that contribute greatly to the biomass of the ecozone. As such, disruptions in the normal timing of the phytoplankton bloom and *C. finmarchicus* developmental cycles may have serious consequences for the survival of pre-settled groundfish (Zwanenburg et al. 2006). Overall it has been estimated that >60% of the annual net production of *C. finmarchicus* on the Scotian Shelf is exported to the southwest. A portion is retained along the shelf edge, but most is transported to overwinter in the deep basins of the Gulf of Maine, never to return to the Scotian Shelf. *C. finmarchicus* that mature on the Scotian Shelf resurface to seed populations that grow and develop in the Gulf of Maine and on Georges Bank (Zwanenburg et al. 2006). While phytoplankton were high on the Scotian Shelf in the 1990s/2000s compared with the 1960s/1970s, zooplankton were generally the reverse (i.e., lower in more recent years), particularly during the early to mid-1990s (Figure 24). During the last several years, zooplankton numbers have been recovering from the mid-1990s lows on the Scotian Shelf. Of particular note is the dramatic increase in the younger development stages (CF1-4) of *C. finmarchicus*; levels are now at or above the long-term average (Harrison et al. 2007).

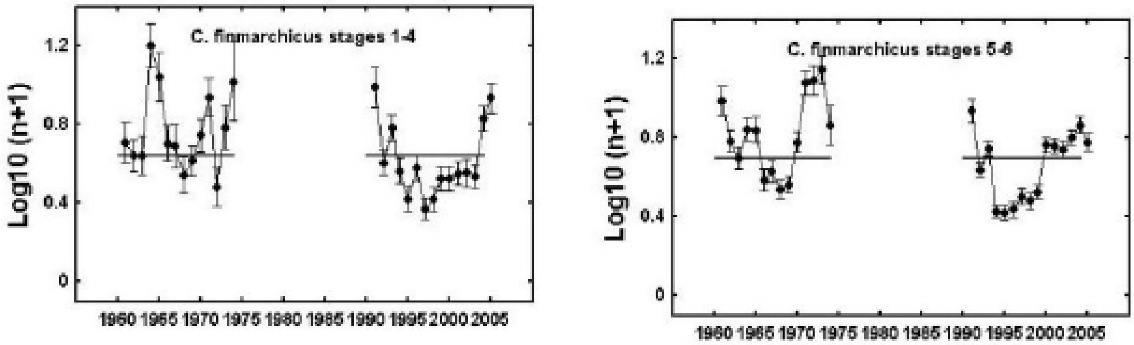

Figure 24. Time-series of relative abundances of C. finmarchicus (annual means) on the Scotian Shelf (57-66º W) from Continuous Plankton Recorder surveys, 1961-2005. Vertical bars are standard errors (Harrison et al. 2007).

Seasonal patterns of *C. finmarchicus* abundance at a fixed sampling station near Halifax, NS, is shown in Figure 25.

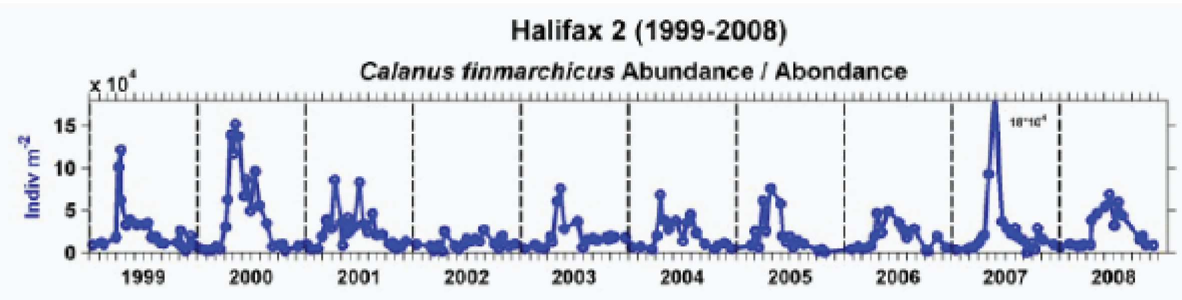

Figure 25. Time series (1999-2008) of Calanus finmarchicus abundance at the Halifax-2 fixed sampling station.

Calanus spp. may dominate the biomass of the mesozooplankton, but the copepod *Oithona* spp. is numerically most abundant. This genus has a ubiquitous distribution and is extremely small -- so small that the early stages pass through sampling nets. Nevertheless, the later stages of this copepod generally account for >40 % of the copepods caught on the ESS (Zwanenburg et al. 2006).

Euphausiids, or krill, have an important role on the Scotian Shelf. They are omnivorous; the youngest stages feeding on phytoplankton and then small zooplankton as they grow. The euphausiids are in turn preyed upon by juvenile groundfish, pelagic fish species, and baleen whales. *Meganyctiphanes norvegica* is the dominant species (Zwanenburg et al. 2006). As with *Calanus* spp., euphausiid abundance as determined from Continuous Plankton Recorder measurements appears to be lower in the 1990s/2000s as compared to the 1960s/1970s (Figure 26).

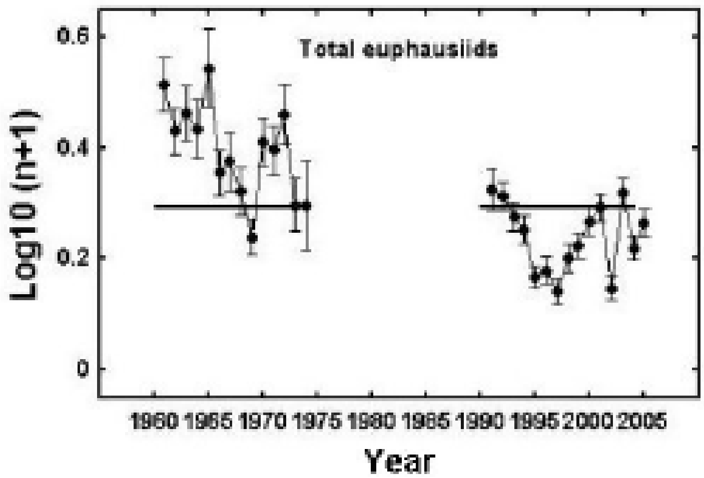

Figure 26. Time-series of relative abundances of euphausiids (annual means) on the Scotian Shelf (57-66º W) from Continuous Plankton Recorder surveys, 1961-2005. Vertical bars are standard errors.

Fish that are consumed by a broad spectrum of predators are called **forage fish**. For the Scotian shelf, the major forage fish species are considered to be capelin (*Mallotus villosus*), herring (*Clupea harengus*), mackerel (*Scomber scombrus*), sand lance (*Ammodytes dubius*), shortfin squid (*Illex illecebrosus*), and witch flounder (*Glyptocehalus cynoglossus*). In conjunction with the decline in groundfish, the abundance of small pelagic forage fish such as mackerel, herring, sand lance and capelin appears to have increased in DFO's multispecies research surveys since the early 1980s (DFO 2003). However, there is some debate on whether bottom trawl surveys accurately reflects the abundance of these small fish and whether their increase may also be related to changes in survey catchability over time. Figure 27 shows the relative abundance of capelin and cod (previously one of its main predators) on the ESS from this survey (Zwanenburg et al. 2006).

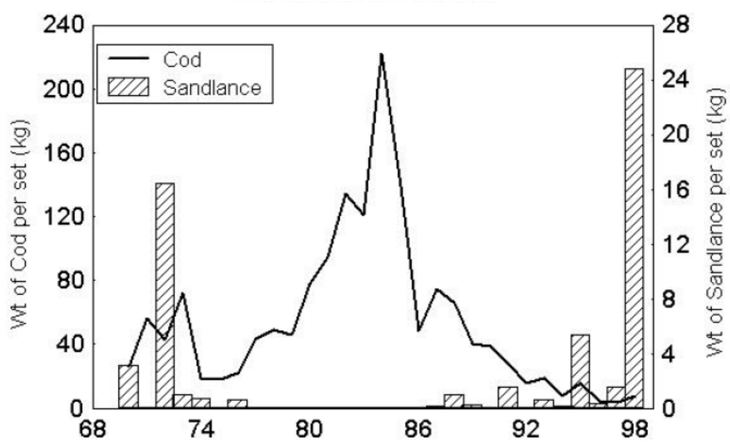

Figure 27. Trends of cod (Gadus morhua) and sand lance (Ammodytes dubius) biomass on the Eastern Scotian Shelf (Zwanenburg et al. 2006).

Atlantic herring has long been a key forage fish, as well as a commercial fish species. In recent years, marine mammals have increased their consumption of herring in the Gulf of Maine to the point where they consume a roughly equal amount as piscivorous (predator) fish do (Figure 28). Consumption of herring by these natural predators is now potentially larger than that of the commercial fishery in some areas of the ecozone. This is a significant change from the early

1990s when fish were the dominant natural predator of herring, accounting for approximately 70% of predation, and nearly three times that eaten by marine mammals (Overholtz and Link 2007).

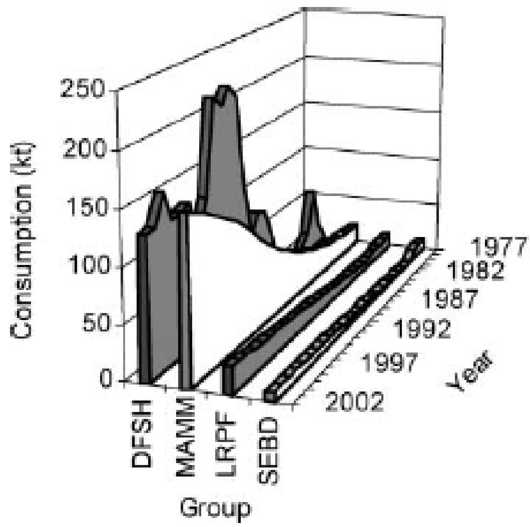

Figure 28. Consumption of Gulf of Maine – Georges Bank herring by the four groups of predators (DFSH, demersal fish; MAMM, marine mammals; LRPF, large pelagic fish; SEBD, seabirds) during the years 1977–2002 (Overholtz and Link 2007).

Piscivores (fish eating organisms) are the major influential predators of the Scotian Shelf. During the early 1980s (and likely up to that point in time), cod was the main fish predator of fish and commercial invertebrates in the ecosystem. Other important predators included bottom dwelling piscivores (large and small) and silver hake. However, in the late 1990s, cod predation became minimal on the ESS with the collapse of that population. Grey seals (*Halichoerus grypus*) and silver hake (*Merluccius bilinearis*) became the main predators of fish and commercial invertebrates on the ESS. The biomass and consumption by grey seals continued to increase, particularly on the ESS, and they have become the main predator of fish. Conversely, though the biomass of and consumption by large silver hake has decreased, it remains an important predator of capelin and small pelagics, as well as pollock (*Pollachius virens*), haddock, small cod, and silver hake (Table 1) (Bundy 2005), at least on the ESS.

Table 1. Comparison of the biomass (t / km²) of functional groups in the early 1980s and late 1990s based on DFO research vessel survey results. Asterisks indicate that the difference between the two periods were significant, according to the Mann-Whitney U test (Bundy 2005).

Ecopath group[a]	Early 1980s	Late 1990s	>20% change[b]	Mann–Whitney U test[c]
6. Large silver hake	0.80	0.33	↓	***
7. Small silver hake	**2.13**	**2.23**		***
15. Redfish	3.40	1.40	↓	***
19. Small demersal piscivores	0.11	0.08	↓	***
20. Large demersal feeders	0.10	0.05	↓	***
21. Small large demersal feeders	0.22	0.12	↓	***
22. Small demersal feeders	**0.26**	**0.78**	↑	***
24. Sand lance	**1.10**	**11.20**	↑	***
25. Transient pelagics	0.05	0.05		
26. Small pelagics	**1.22**	**8.50**	↑	***
27. Small mesopelagics	0.63	0.42	↓	***
28. Squids	0.66	0.53		***
30. Small crabs	**1.69**	**3.78**	↑	***
31. Shrimp	**2.77**	**13.57**	↑	***
36. Large zooplankton	**16.13**	**34.58**	↑	***
37. Small zooplankton	**34.00**	**44.00**	↑	***

The condition index of both large and small cod has declined since the 1970s and remains below average since the early 1990s. Several factors may account for this, but, for small cod, reduced consumption due to competition for prey is likely to be a significant contributing factor (Zwanenburg et al. 2006). The cultivation/depensation theory proposes that top predators such as cod cultivate their young by cropping down forage species that are potential predators and competitors of their young. Given that adult cod were largely removed from the ecosystem, this may result in reduced small cod survival due to predation and competition from the now abundant forage species. It is believed that large cod of the ecozone kept the populations of sand lance and small pelagics (herring) in check through predation. When the numbers of large cod collapsed, this released the predation pressure on sand lance and small pelagics, leading to a large increase in their abundance. These pelagic species now compete with small cod for prey, thereby reducing their survival (Zwanenburg et al. 2006). Further potential food web implications exist through analysis of Scotian Shelf data that indicates that the abundance of the copepod *Calanus* decreased from the 1980s to the late 1990s. If copepods are important in the diet of larval cod, as appears to be the case, this could be another contributing factor to the poor condition of cod and the lack of recovery of the cod stocks (Zwanenburg et al. 2006).

Juvenile cod feed on a wide variety of invertebrates and only later as they grow include fish in their diet (DFO 2006a). Small demersal fish also appear as the main predators of sand lance and small crabs, primarily due to the increase in the biomass of longhorn sculpin (*Myoxocephalus octodecemspinosus*) (Zwanenburg et al. 2006).

Although it is estimated that **seabirds** remove about 60,000 t of biomass annually from the ESS, there is little information on what they are eating (O'Boyle 2000). This consumption rate is about two thirds of that for grey seals in the same area. Birds use a wide variety of marine species as food sources, and their forage techniques range from surface pickers, through plunge divers to pursuit divers, and some feed on benthic prey. Typical prey species selected tend to be small / medium size and highly nutritious, such as oil fish (e.g., herring, capelin, mackerel, myctophids), squid, and plankton such as copepods and krill. Waterfowl include eiders and scoters that prey on shellfish such as mussels, and can be a nuisance at aquaculture sites. Black ducks (*Anas rubripes*) and Canada geese (*Branta canadensis*) feed in shallow water on vegetation such as eelgrass, and also take invertebrates.

Wildlife Diseases and Parasites

Groundfish in the North Atlantic can be heavily infected with larval **sealworm**, a parasitic nematode (*Psdeudoterranova decipiens*). As their name implies, adult sealworm are found in various seal species, particularly grey seal. Larvae of the sealworm are found in the musculature of groundfish and a major cosmetic problem affecting the marketability of infected groundfish (Marcogliesse 1997). Infested fish fillets must be examined individually by “candling” to identify and remove the worms by hand, which adds substantially to the processing cost of the fish, lowers the quality and appearance of the product, and the added time factor may also result in increased microbial growth and enzymatic degradation of the flesh. There is some evidence that the prevalence of sealworm has been increasing in groundfish since the mid-1980s on the Scotian Shelf (McLlelland et al. 1983).

Phenology

Annual growth cycle (timing of the spring bloom and fall bloom) are thought to be important in linking phytoplankton to production at higher trophic levels as the bulk (annual) primary production. For example, recent analysis of the phytoplankton and zooplankton growth cycles on the Scotian Shelf has shown that strong year classes of haddock (1981, 1999) coincided with years when the onset of the spring phytoplankton bloom and reproduction of zooplankton were notably earlier than in years when recruitment was average (Zwanenburg et al. 2006). Therefore, early spring mixing (or stratification) is a critical physical property of the ESS, since it likely determines the timing of the spring bloom (Zwanenburg et al. 2006).

Decadal trends in the magnitude and duration of the **spring bloom** on the Scotian Shelf indicate that blooms start earlier now than they did in the 1960s and 1970s, and that spring blooms are now more intense and last longer (Sameoto 2004). For example, the timing, duration and magnitude of the spring phytoplankton blooms at a fixed sampling station near Halifax (Halifax-2) from 1999 to 2008 is shown in Figure 29. This change has been attributed in part to the decrease in late winter storminess in the North Atlantic Ocean in recent years. Decreased storminess could translate to less intense mixing and earlier stratification, during the spring, when the bloom occurs. Chlorophyll levels outside of the peak March-May spring bloom period have generally been declining since 1999, from approximately 39 mg m-2 in 1999 to approximately 27 mg m-2 in 2006 (Harrison et al. 2009).

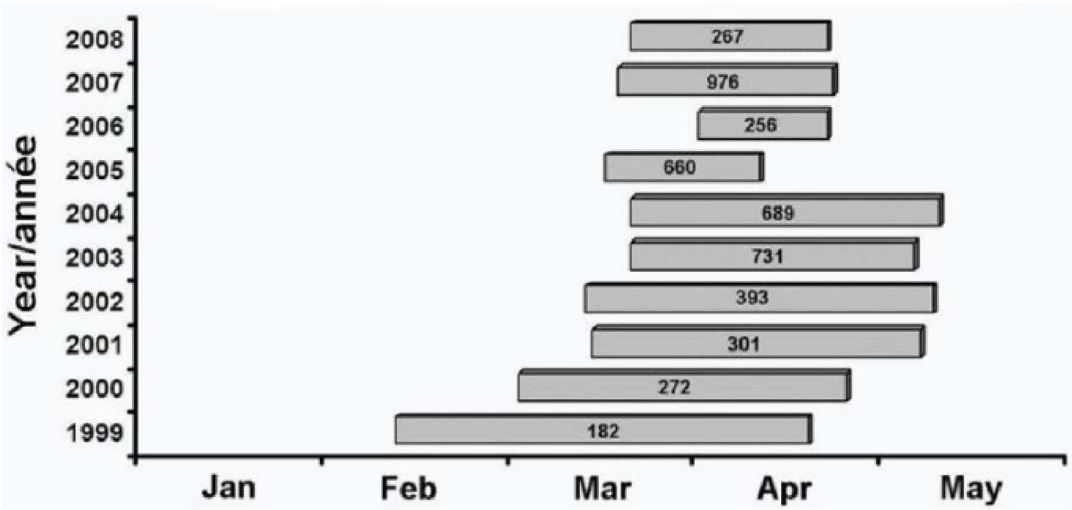

Figure 29. Changes in the duration and timing of the spring bloom at a fixed station near Halifax, 1999-2008 (Harrison et al. 2009).

The timing of the onset of **sea ice**, duration, and last presence of sea ice on the Scotian Shelf have been monitored since the 1960s (Drinkwater et al. 1999). For example, In 2007, ice first appeared seaward of the Strait in early February, which is approximately the normal time for first appearance. In fact, some ice appeared on January 26 but was less than one tenth cover and was restricted to the eastern shore of Cape Breton. The first concentrations of ice greater than one tenth were observed on February 6, when concentrations of three tenths moved from the Gulf to Sydney Bight. By February 10, ice had filled all of Sydney Bight. The maximum extent of ice on the Scotian Shelf occurred between late February and mid-March. Overall the last presence of ice was about normal. The duration of ice cover on the Scotian Shelf was slightly longer than normal (Petrie et al. 2008a).

Nutrient Cycling

The Northwest Atlantic, including the Gulf of Maine and Scotian Shelf ecozone, is considered relatively productive areas within the global oceans (Breeze et al. 2002). The main source of supply of nutrients (nitrogen, phosphorous, and silicon) to inshore waters of the Scotian Shelf is through water exchange with the adjacent coastal waters. This creates highest inshore concentrations in winter, and following a bloom, most harbours have depleted nutrients in the spring through summer period before fall mixing begins replenishment. There is a general spatial coastal pattern of relatively higher nutrients along the Cape Breton coast to lower nutrients at the southwestern end of Nova Scotia. There is also an increase in salinity and a decrease in stratification in the same east to west direction (Bundy et al. 2007) that are indicative of the mixing and upwelling that occurs in the south, and the processes that bring marine nutrients toward the surface where they can be used in primary production.

As in most marine ecosystems, **nitrogen** availability is the limiting factor in primary production in the Gulf of Maine and Scotian Shelf. Although there is significant seasonal variation in nitrate concentrations in surface and deep waters of the Gulf of Maine and Scotian Shelf ecozone, no long-term trends have been observed at coastal and offshore sampling stations over the past 10 years (Figure 30).

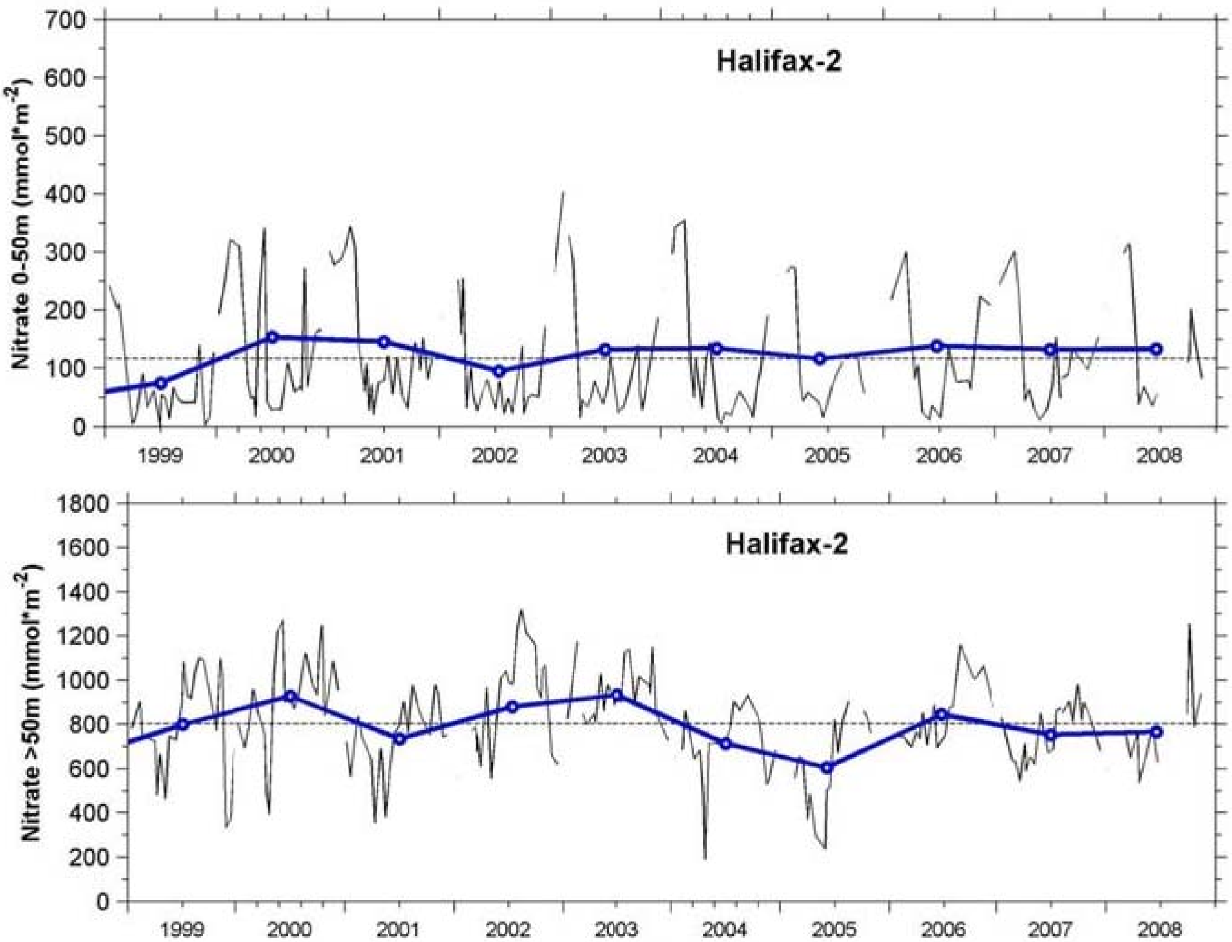

Figure 30. Nitrate inventories at the Halifax fixed station, 1999-2008, from 0-50 m (top panel) and >50 m (bottom panel), including annual averages (solid lines). Dashed lines are overall mean levels (Harrison et al. 2009).

Similar to the inshore, the open water areas of the shelf regularly experience a distinctive two part seasonal cycle of growth; a conspicuous and widespread spring biomass peak (the spring bloom) and a more diffuse fall bloom (Zwanenburg et al. 2006). More local factors will initialize additional smaller blooms. The Gulf of St. Lawrence is the primary source of nitrate for the Scotian Shelf during the winter, as well as being the most significant external source during the spring and summer. However, during the spring and summer, local vertical mixing and upwelling processes on the Shelf are equally important as the horizontal inflow from the Gulf of St. Lawrence in bringing nutrients from depth up into the photic zone where they are available for production (Breeze et al. 2002). Tidally driven upwelling on the western bank, the Gulf of Maine and the Bay of Fundy, and wind induced upwelling as the result of prevailing summer southwesterlies are important processes that enhance vertical mixing and nutrient replenishment to surface waters (Breeze et al. 2002). Additionally, remineralization by bacteria and microplankton, the microbial loop, plays an important role in the recycling of nutrients in the Gulf of Maine and Scotian Shelf ecozone (Ecosystem Assessment Program 2009).

Human Stressors on Ecosystem Functions and Processes

Ocean Acidification

The global increases in atmospheric and oceanic CO_2 are evident in the changes in pH (negative logarithm of the hydrogen ion concentration) on the Scotian Shelf (Figure 31). Figure 31 provides a very simple picture of the decreases in pH with time. A more rigorous multivariate analysis of the data shows that pH varies with time, depth, location on the shelf, and season. The trend with time after accounting for these other dependencies is highly significant and corresponds to a decrease of 0.002 pH units per year. Increases in CO_2 could stimulate more primary productivity, but increases in H^+ (decreases in pH) will negatively affect the ability of carbonate shell forming organism to form and maintain their shells (DFO 2009c).

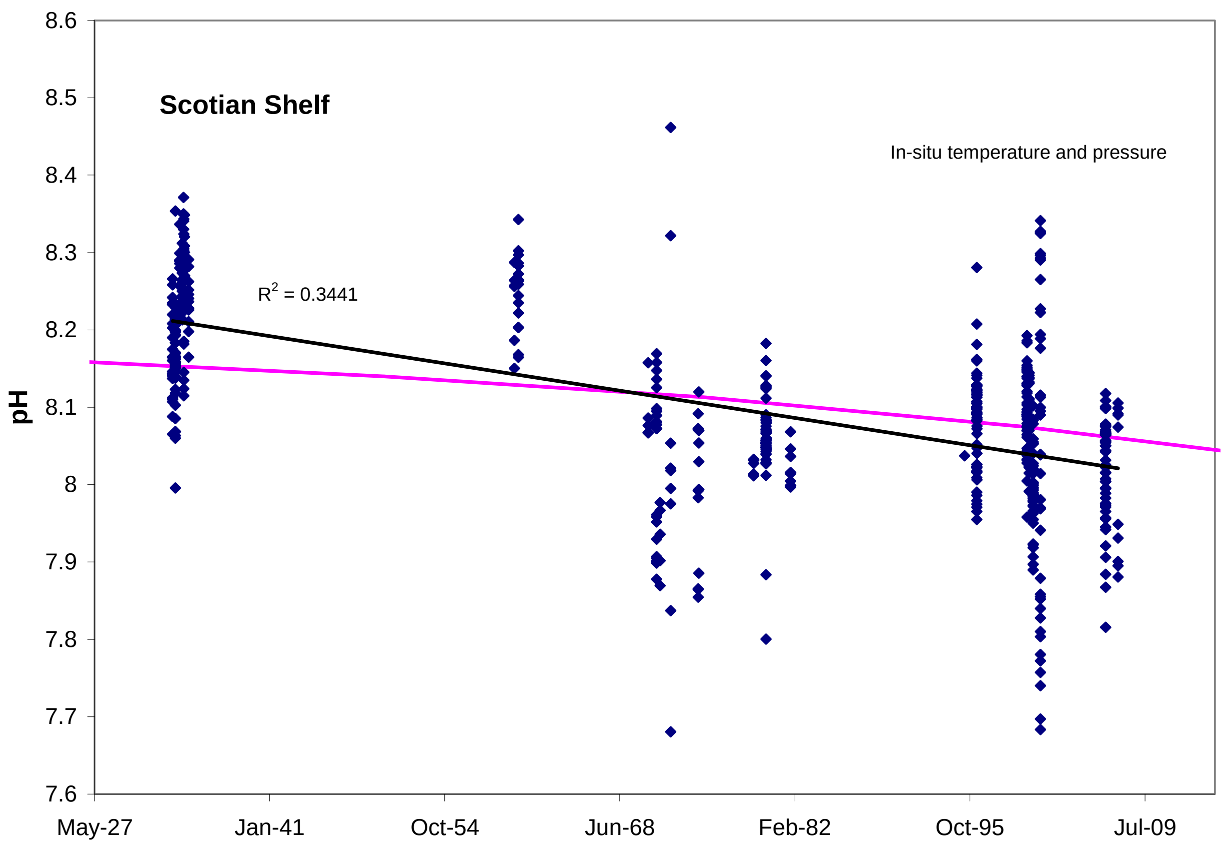

Figure 31. pH trends on the Scotian Shelf. Curved red line shows the global average trend in ocean pH (DFO 2009c).

One species that may be vulnerable to ocean acidification is *Limacina* spp., a pelagic mollusk that is a relatively abundant member of the Scotian Shelf zooplankton community. This species has a thin calcium carbonate shell that is degraded by low pH seawater. In spring, *Limacina* spp. are most abundant on the WSS and in the offshore, ESS, while in the fall they are most abundant in the outflow of the Gulf of St. Lawrence. In general, *Limacina* spp. were most abundant from 1999 to 2001 (Figure 32). In 2008, abundance remained low on the ESS and close to average on the WSS (Harrison et al. 2009).

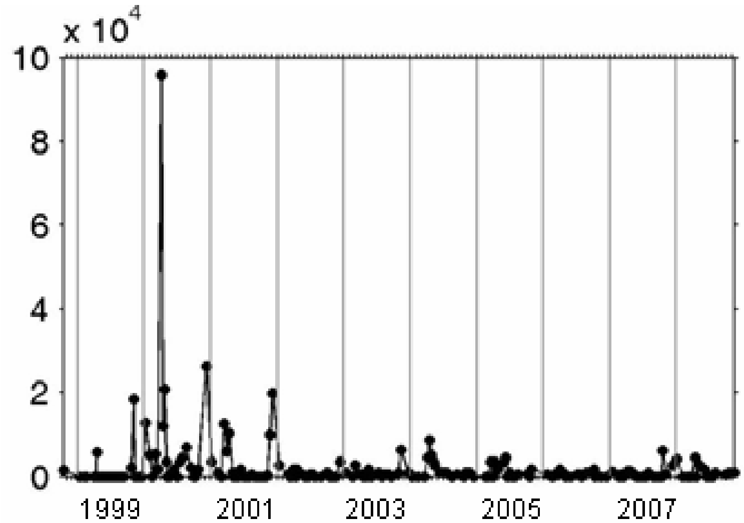

Figure 32. Time series of Limacina spp. from a fixed station near Halifax for 1999-2008.

<u>Eutrophication</u>

Eutrophication, or nutrient enrichment, is a major concern in many coastal areas around the world. Eutrophication has been linked to increased algal biomass, including harmful algae species, hypoxia/anoxia, and increased water turbidity (Ecosystem Assessment Program 2009). A study of coastal eutrophication indices indicated that, of 17 sites tested on the east coast of Nova Scotia (Figure 33), only the LeHave River estuary showed signs of eutrophication using inorganic nutrient concentrations. Two other sites, Barrington Bay (slightly eutrophic) and New Harbour (quite eutrophic, likely related to low flushing rates), showed signs of eutriphication using amalgamated nutrient and cholophyll *a* ratios (Ryan et al. 2008).

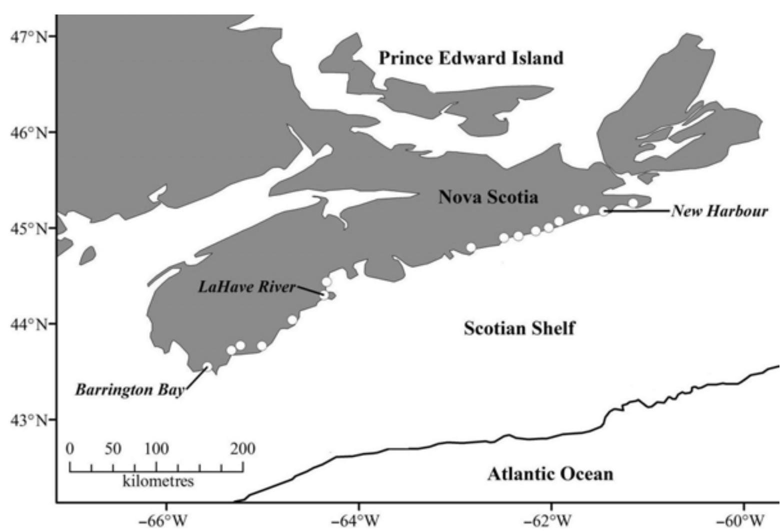

Figure 33. Location of test sites on the east coast of Nova Scotia [adapted from Ryan et al. 2008].

ECOSYSTEM STRUCTURE

Changes in Extent and Quality of Important Biomes

Coastal

Within coastal waters, intertidal and subtidal beds of seagrass are acknowledged to be highly productive areas that provide structural habitat for juvenile fish and invertebrates, a host for epiphytic algae, and spawning habitat for species like herring.

Zostera marina, also known as **eelgrass**, is the dominant seagrass found in coastal and estuarine areas of the western North Atlantic. It can form extensive beds from low intertidal to subtidal (down to 12 m depth) habitat and from sheltered areas to exposed coasts. Eelgrass occurs predominantly as a monoculture but can overlap with widgeon grass (*Ruppia maritima*) in the upper low salinity portions of estuaries in Atlantic Canada (DFO 2009a). Eelgrass is important to the diet of several migratory aquatic birds. It is particularly important to Atlantic Brant (*Branta bernicla hrota*) in eastern North America, which is known to feed, where possible, almost exclusively on eelgrass. The wintering and staging areas reflect the distribution of eelgrass which contributes largely to over-winter survival and serves as fuel for their long migrations. The importance of eelgrass to other waterfowl including Canada goose (*Branta canadensis*), American black duck (*Anas rubripes*), common goldeneye (*Bucephala clangula*) and Barrow's goldeneye (*Bucephala islandica*) has long been recognized (DFO 2009a).

A massive natural eelgrass die off (wasting disease) occurred in the 1930s, with limited recovery until the 1960s. The Maritime Wetland Inventory (Canadian Wildlife Service, Environment Canada) provides an estimate of the areal extent of salt marshes and wetlands in the Maritime Provinces. The information is based on interpretation of colour air photos acquired in 1974-1978 for Nova Scotia and 1980-1985 for New Brunswick. In this ecozone, the distribution is along the eastern coastline of Nova Scotia and the outer portion of the Bay of Fundy. It was estimated that there were about 20,000 ha of eelgrass in Nova Scotia at the time of photo acquisition (DFO 2009a).

Eelgrass declines in the recent decade have been reported on the Atlantic coast of Nova Scotia. There is limited information on coastwide trends, but, in some locations, inter-annual (2-20+ years) declines of 30% to 95% have been reported. Possible reasons for these declines include eutrophication, disturbance by invasive green crab (*Carcinus maenas*), human activities, and environmental changes (DFO 2009a).

Marine

Marine biomes include coral and other reefs, estuaries and the open ocean. While it may be difficult to quantify the change or loss of the ocean biome within the Gulf of Maine and Scotian Shelf ecozone, it is possible to monitor trends in reefs and estuaries.

The Gulf of Maine and Scotian Shelf ecozone includes numerous coral species but only one known **coral reef**. The northeast corner of the Scotian Shelf, often referred to as the "Stone Fence", is home to the reef building coral *Lophelia pertusa*. This species is a long-lived, cold water species that forms reef complexes that can support a wide variety of species. The reef is made up of both living and dead coral. DFO researchers aboard the CCGS *Hudson* discovered the reef in September 2003. It is about one kilometre long and up to several hundred metres wide. It appears as though there has been some damage to this reef from fishing activity, though additional work is required to monitor the health of this reef.

Another type of reef that is found in the Gulf of Maine and Scotian Shelf ecozone is the **horse mussel reef**. Horse mussel (*Modiolus modiolus*) reefs have been identified throughout the Bay of Fundy (Wildish and Fader 1998). Little is know about their status at this time.

Little study of **sponges** has been conducted within the ecozone. However, it is known that long-lived slow growing glass sponges, as well as other species of sponge, exist in an area near the Emerald Basin. This bouldery rough location at about 170 m depth, known as “The Patch”, is one of only a few locations in the Northwest Atlantic that glass sponge has been found (Singh and Buzeta 2007).

Estuaries occur at the mouths of rivers where seawater is diluted by fresh water input from the land. Estuaries are extremely productive ecosystems, in part because they tend to be shallow, receive a continuous supply of nutrients from the river, and are mixed by the tides. The portions of Nova Scotia and New Brunswick that bound the Gulf of Maine and Scotian Shelf ecozone have many estuaries and they vary regionally. One estuary of particular interest in the region is the Musquash Estuary in new Brunswick. This area was declared a Marine Protected Area in 2007.

Species Assemblages

Numerous attempts to describe the **finfish assemblages** of the Scotian Shelf have been made. Some assessed the area through principal components of temperature and depth, others through creating fish groupings and defining areas where these groups could be found, and yet others through substrate and benthic habitat classification. However, each attempt has found over time that a moderate degree of variation in either the spatial use by an assemblage or variation in the assemblage associated with the defining criteria (Breeze et al. 2002).

In general, the Gulf of Maine – Georges Bank area of the ecozone supports a temperate cold water fish community, yet there are recognizably different fish communities on the Scotian Shelf, Gulf of Maine, and Georges Bank. However, studies of fish assemblages on the Scotian Shelf have typically not considered pelagic fish, as many species are highly migratory. Unlike the demersal fish that live near the sea floor on the shelf, pelagic species may not have strong associations with other fishes. Although many species can be organized as distinct, identifiable assemblages that persist over time, they are not always associated with accepted biogeographic boundaries but shift in location through time (O’Boyle 2000).

The fish community has changed structurally over the past 30 years with declines in groundfish and increases in small pelagic fish and commercially fished invertebrates. Changes in the physical environment over this time (e.g., temperature) were associated with expansion of range by some species and the occurrence of new species to the area. Average body size of the declining groundfish stocks also declined, and currently there are few large fish. This situation has not previously been witnessed in the Scotian Shelf waters. Despite expectations to the contrary, groundfish growth and condition has remained low during the past decade despite reduction in fishing effort (DFO 2003).

Attempts to define **benthic invertebrate assemblages** have been conducted based on combinations of water depth and/or substrate. Given the reduced mobility of most invertebrates compared to fish, and their strong affiliation with the parameters of substrate composition and depth, assemblages have been relatively well defined for a number of larger and smaller scale areas of the Shelf (Breeze et al. 2002); however, data tends to be both spatially and temporally limited.

Major Human Stressors on Ecosystem Structure

Invasive Species

Invasive tunicates can pose a threat to the aquatic environment and the economy by displacing native species and fouling aquaculture equipment, the hulls of vessels, and harbour infrastructure. A number of invasive tunicate species (*Ciona intestinalis*, *Botryllus schlosseri*, and *Botrylloides violaceus*) are known to be present in the Gulf of Maine and Scotian Shelf ecozone. Both *C. intestinalis* and *B. schlosseri* have been present in the region since the 1990s but have more recently taken on characteristics of invasive species.

The European **green crab** is another invasive species in the Gulf of Maine and Scotian Shelf ecozone. Green crab are predators and scavengers, consuming a wide array of marine animals and plants. Potential impacts include displacement of native species through competition and predation, as well as alterations of the structure of rocky shore communities.

Codium fragile ssp. tomentosoides (known locally as "**Dead Man`s Fingers**") is a green alga believed to have originated in Japan. Mahone Bay was the first reported location of *Codium* in Nova Scotia. Since 1991, *Codium* has spread throughout Mahone Bay into adjacent St. Margaret`s Bay and beyond. Field observations have shown that areas covered by *Codium* have reduced abundance of some species compared to similai areas covered by kelp (Theriault 2009).

COMPOSITION

Species Diversity

A number of **marine mammal** species inhabit the Scotian Shelf and southern Gulf of St. Lawrence seasonally or throughout the year, including 23 species of cetaceans and 4 species of seals. For cetaceans, the number of species is likely underestimated (Zwanenburg et al. 2006). Of the 4 seal species, only grey and harbour seals (*Phoca vitulina*) are common (DFO 2003).

Other top predators include the **sharks**. Sharks are represented by 19 shark species in the Canadian Atlantic waters, 5 of which can be considered to be common residents of the Eastern Scotian Shelf: the blue shark (*Prionace glauca*), porbeagle (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*), basking shark (*Cetorhinus maximus*) and the spiny dogfish (*Squalus acanthias*) (Zwanenburg et al. 2006).

There are 538 species of **finfish** known to occur in the Canadian Atlantic. Less is known about the fish of the deep waters of the slope on the outer shelf, and less is known of those that are not fished commercially (Breeze et al. 2002). DFO has conducted summer research bottom trawl surveys of the Scotian Shelf and Bay of Fundy annually since 1970. However, sampling effort has been low relative to the size of the Scotian Shelf (only about 0.12% of the Scotian Shelf). The first research vessel survey in 1970 yielded 50 species. By the year 2000, the total number of species observed had increased by almost 3-fold to 140 species. Twenty-four per cent of the newly observed species since 1971 were only found once. Additional species continue to be observed almost every year (Figure 34). The Bray–Curtis Index of Similarity based on presence/absence was constant over the time series, which means that the species composition in 1974 has not changed significantly over time. In contrast, the Bray–Curtis Index of Similarity based on species abundance declined (Figure 35) reflecting a change in the dominance structure among species (Bundy 2005). This is consistent with other observations related to changes in relative species abundance described in this report.

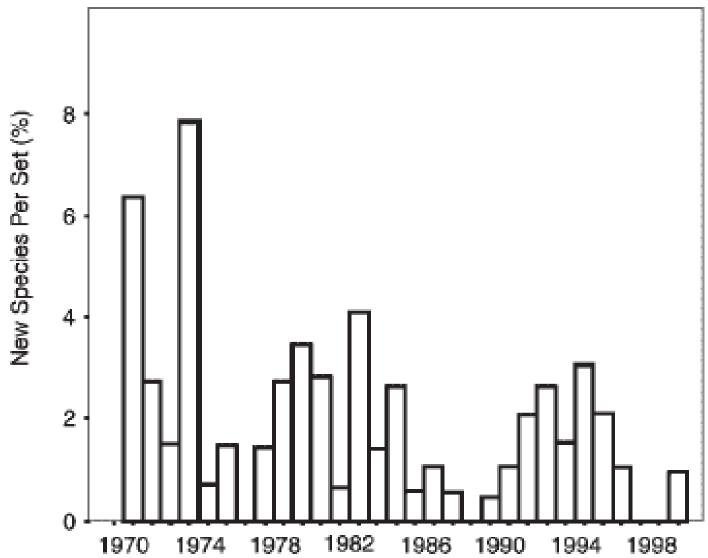

Figure 34. Number of newly discovered species per set in each survey year.

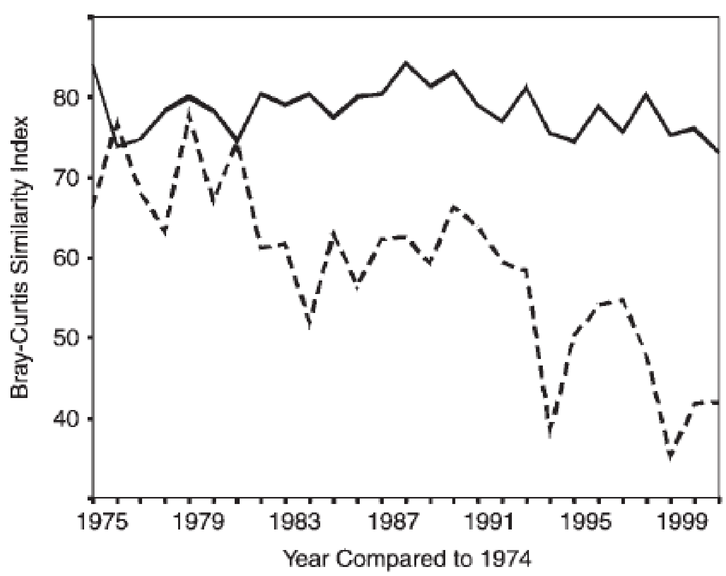

Figure 35. Bray–Curtis Index of similarity of species composition between year 1974 and all successive years until 2000. Solid line is Bray–Curtis Index based on incidence data; Dashed line is Bray–Curtis index based on abundance data.

A map of species richness from this study indicates the variation in finfish diversity across the region, as well as the geographic extent of the sampling (Figure 36).

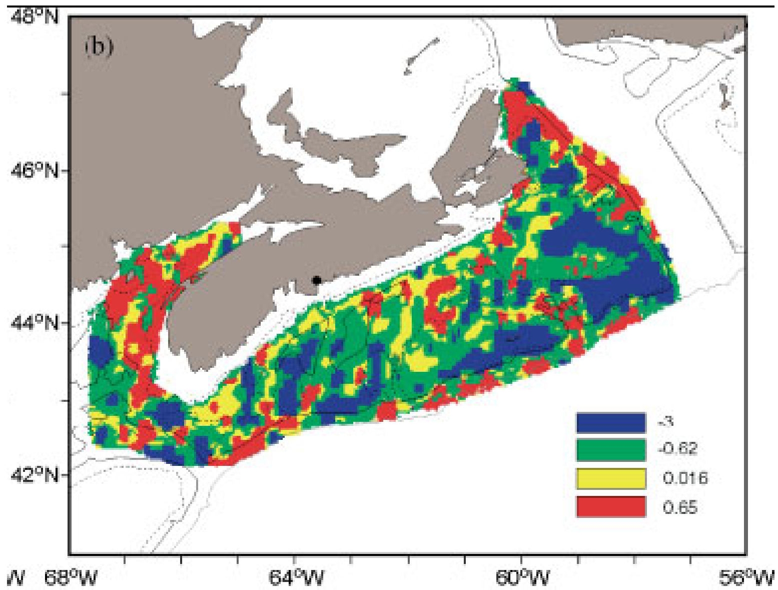

Figure 36. Finfish species richness on the Scotian Shelf and Bay of Fundy after removing the sample effect (residuals of species richness regressed on swept area).

Several species of sub-arctic origin were first recorded during the cooling of the mid-1980s and 1990s, and conversely, several warm temperate/sub-tropical species were captured during warm water conditions that began in the late 1970s. Overall 30 new species to the area have been observed since 1991 (DFO 2003).

The reasons for ongoing observations of new species in the research survey include: species that have immigrated into the region, possibly due to environmental change, increased probability of capture due to increases in sampling effort, an increase in abundance or sampling of additional habitats, or identification skills have improved and interest in noncommercial species has increased. It is expected that a few new species may have colonized the Scotian Shelf over the last 40 years; however, the majority of newly observed species likely have resident but low population sizes (Frank and Shackell 2003).

An intensive study of **mesopelagic** fish on a relatively small area on the continental slope of Canada was conducted in the mid-1990s. In this study, 39.6% of the species collected had never been recorded in Atlantic Canada. Thus, there is undoubtedly a higher level of diversity than has been currently measured, particularly in slope waters (Frank and Shackell 2003; Themelis 1996).

In this ecozone, **seabird** populations are dominated by terns and large gulls, with only small numbers of auks. The most important site for seabird monitoring is Machias Sea Island, where Atlantic Cooperative Wildlife Ecology Research Network has been conducting studies of terns and auks annually since 1995 (Clarke et al. 2008).

Conditions for seabird reproduction at Machias Seal Island were good in the 1990s, but they deteriorated sharply after 2003, with few chicks reared thereafter and no breeding attempts by terns at all in 2007 and 2008. These events seem to be associated with a change in nestling diets from herrings to other fish or crustacea (Figure 32). A similar change in diet was observed for razorbills (*Alca torda*) and Atlantic puffins (*Fratercula arctica*), although they maintained reproduction over the same period (Clarke et al. 2008, Diamond and Devlin 2003).

Large gulls, such as herring (*Larus argentatus*) and great black-backed (*Larus marinus*) gulls, have shown parallel population changes in this ecozone and in the Gulf of St. Lawrence (Chapdelaine and Rail 1997). Numbers of both species generally increased until the 1980s and have declined since (Boyne and Beukens 2004, Boyne and McKight 2005). Tern numbers in Nova Scotia, Prince Edward Island, and New Brunswick declined fairly steadily from the 1970s onwards, perhaps affected by increasing disturbance of the coastal zone, and, in the period up to the mid-1980s, the increasing numbers of large gulls (Boyne et al. 2001, Boyne and Hudson 2002). Terns switch unpredictably among potential breeding sites, making counting them a challenge. It is hard to know how much their population fluctuations are affected by the marine environment, although the recent desertion of Machias Seal Island probably has to do with negative changes to marine food webs (Figure 37).

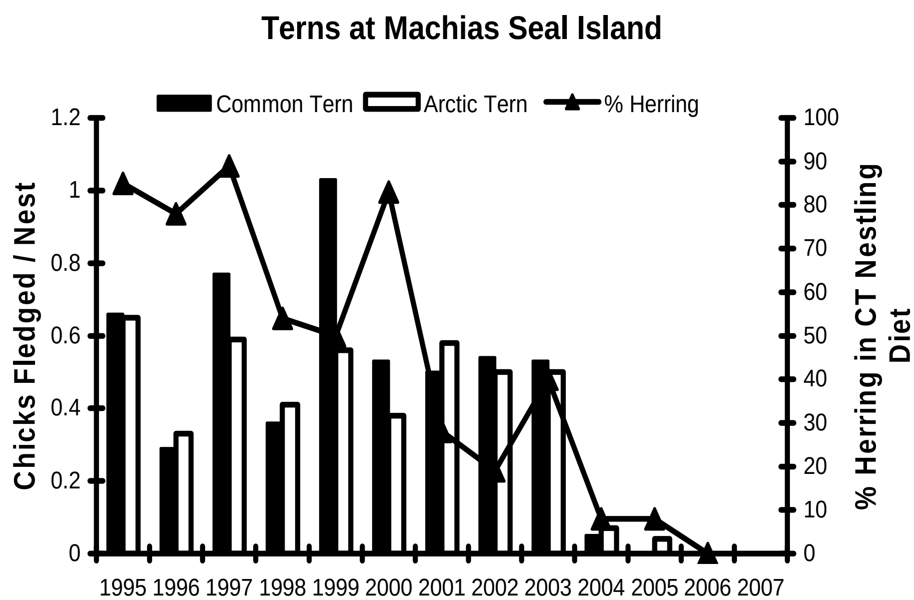

Figure 37. Changes in reproductive success of common (Sterna hirundo) and Arctic (Sterna paradisaea) terns at Machias Seal Island during 1994-2007 and proportion of common tern nestling diets made up by herring (Clarke et al. 2008).

There are approximately 28 species of **invertebrates** ranging from squid to periwinkle to sea cucumber to lobster (*Homarus americanus*) that are commercially fished on the Scotian Shelf (Breeze et al. 2002), and there have been about 25 to 30 species of corals identified off the Atlantic coast of Nova Scotia and New Brunswick. About 8 are stony corals and another 19 are soft corals, leather corals, and sea fans (DFO 2006b). At least 2 to 3 species of coral occur off the southwest coast of New Brunswick in the Bay of Fundy. However, these are soft corals species that are considered less sensitive than other corals. Stony corals are primarily located in the deep Basins of the Gulf of Maine and the edge of the Scotian Shelf (DFO 2006b). However, little is truly known of the distribution or any trends in the coral community of this ecozone.

There were over 300 taxa of **plankton** (phytoplankton and zooplankton) documented through the Continuous Plankton Recorder between 1959 and 1992 on the Scotian Shelf (Breeze et al. 2002). Phytoplankton community structure on the Scotian Shelf is not well known in detail, although general features common to all north temperate coastal waters, are understood.

Photosynthetic forms range in size from one micron (e.g., cyanobacteria, ultra phytoplankton) to hundreds of microns (diatoms, dinoflagellates). The latter forms dominate phytoplankton biomass. Spring and fall blooms on the shelf are comprised principally of diatoms that decrease in importance in summer and fall when flagellates dominate. Because of the complex mixture of water masses on the Scotian Shelf, arctic, temperate and subtropical forms occur on the shelf at various times (Zwanenburg et al. 2006).

Trends in Species of Conservation Concern

There are currently 39 species (some with several distinct populations) identified as Endangered, Threatened, or Special Concern by the Committee on the Status of Endangered Wildlife Species in Canada (COSEWIC) of relevance to the Gulf of Maine and Scotian Shelf marine ecozone (at the time of the writing of this report). These are listed in Table 2. The North Atlantic right whale (important feeding habitat found within this ecozone), the Scotian Shelf population of northern bottlenose whale (found primarily within this ecozone), inner Bay of Fundy salmon (contained within this ecozone), Atlantic whitefish (an andromous fish species endemic to this ecozone), and the “Ipswich” Savannah sparrow (endemic to Sable Island) will be described in more detail in this section.

Table 2. Species listed as Endangered, Threatened, or Special Concern by COSEWIC of interest for the Gulf of Maine and Scotian Shelf ecozone.

Common Name	Latin Name	COSEWIC Status
Mammals		
North Atlantic right whale	*Eubalaena glacialis*	Endangered
Northern bottlenose whale (Scotian Shelf population)	*Hyperoodon ampullatus*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Harbour porpoise (Northwest Atlantic population)	*Phocoena phocoena*	Special Concern
Fin whale (Atlantic population)	*Balaenoptera physalus*	Special Concern
Sowerby’s beaked whale	*Mesoplodo bidens*	Special Concern
Killer Whale (Northwest Atlantic populations)	*Orcinus orca*	Special Concern
Birds		
Piping Plover	*Charadrius melodus melodus*	Endangered
Roseate Tern	*Sterna dougallii*	Endangered
Eskimo curlew	*Numenius borealis*	Endangered
Red Knot *rufa* subspecies	*Calidris canutus rufa*	Endangered
“Ipswich” Savannah Sparrow	*Passerculus sandwichensis prenceps*	Special Concern
Harlequin Duck (Eastern population)	*Histrionicus histrionicus*	Special Concern
Barrow’s Goldeneye (Eastern population)	*Bucephala islandica*	Special Concern
Peregrine Falcon *anatum/tundrius*,	*Falco peregrinus anatum/tundrius*	Special Concern

Common Name	Latin Name	COSEWIC Status
Reptiles		
Leatherback turtle	*Dermochelys coriacea*	Endangered
Loggerhead turtle	*Caretta caretta*	Endangered
Fish		
Atlantic salmon (inner Bay of Fundy populations)	*Salmo salar*	Endangered
Atlantic whitefish	*Coregonus hunstmani*	Endangered
Atlantic cod (Laurentian South and Southern populations)	*Gadus morhua*	Endangered
Roundnose grenadier	*Coryphaenoides rupestris*	Endangered
Porbeagle shark	*Lamna nasus*	Endangered
White shark (Atlantic population)	*Carcharodon carcharias*	Endangered
Deepwater redfish (Gulf of St. Lawrence - Laurentian Channel population)	*Sebastes mentella*	Endangered
Striped bass (Bay of Fundy population)	*Morone saxatilis*	Threatened
Shortfin mako shark (Atlantic population)	*Isurus oxyrinchus*	Threatened
Cusk	*Brosme brosme*	Threatened
American plaice (Maritime population)	*Hippoglossoides platessoides*	Threatened
Winter skate (ESS population)	*Leucoraja ocellata*	Threatened
Northern wolffish	*Anarhichas denticulatus*	Threatened
Spotted wolffish	*Anarhichas minor*	Threatened
Acadian redfish (Atlantic population)	*Sebastes fasciatus*	Threatened
American eel	*Anguilla rostrata*	Special Concern
Roughhead grenadier	*Macrourus berglax*	Special Concern
Spiny dogfish (Atlantic population)	*Squalus acanthias*	Special Concern
Blue shark (Atlantic population)	*Prionace glauca*	Special Concern
Basking shark (Atlantic population)	*Cetorhinus maximus*	Special Concern
Winter skate (Georges Bank-WSS-Bay of Fundy population)	*Leucoraja ocellata*	Special Concern
Atlantic wolffish	*Anarhichas lupus*	Special Concern
Molluscs		
Atlantic mud piddock	*Barnea truncata*	Threatened

The abundance of **North Atlantic right whale** is critically low, numbering approximately 325-350 individuals through 2003. The best available population model indicates a declining trend in abundance over the period of 1980-1995. In Canadian waters, right whales are thought to feed primarily on the copepod, *Calanus finmarchicus*, which has been described in earlier sections. Declining survival coupled with high variability in reproduction has limited population growth over the last 25 years. Increasing mortality of breeding females is of particular concern, and may have driven the decline in population growth rate to levels below replacement. Key areas for right whale in this ecozone include Grand Manan Basin and Roseway Basin (DFO 2007b).

Northern bottlenose whale is a beaked whale that ranges in size from about 7 to 9 m at maturity. They are found only in the northern North Atlantic, occurring in cool and sub-arctic waters. In Canada, they are distributed from Nova Scotia to the Davis Strait. The whales on the Scotian Shelf are considered a distinct population and are highly aggregated. They have been sighted most often in the deep waters of three underwater canyons (the Gully, Shortland Canyon, and Haldimand Canyon) along the shelf edge. The average population estimate for the 1988 to 2003 period is 163 individuals. Population models indicate no statistically significant trend in abundance during this time (DFO 2007c).

Atlantic whitefish, an anadromous species endemic to Nova Scotia, is a member of the family Salmonidae and belongs to the subfamily Coregoninae. Recent genetic analyses supports the distinctiveness of Atlantic whitefish from other coregonid species including lake whitefish (C. *clupeaformis*) and Lake Ontario cisco (C. *artedii*). The absolute abundance of wild Atlantic whitefish is unknown but is considered to be low. They are currently thought to be restricted to the Petite Rivière watershed, with reproduction occurring primarily within the approximately 16 km^2 combined area of Minamkeak, Milipsigate, and Hebb lakes (DFO 2009d).

Inner Bay of Fundy Atlantic salmon include populations found in Bay of Fundy Rivers from Pereaux River, NS, to the Mispec River, NB. Atlantic salmon were found in 32 to 42 rivers in this area but likely used most accessible habitat in this area, at least intermittently in the past. Inner Bay of Fundy salmon are genetically distinct from other Atlantic salmon population groups and have some unique life history traits, including a localized migration strategy while at sea and an incidence of maturity after one winter at sea, which is higher than other populations in the Maritimes. An exception to this pattern is the Gaspereau River population, which has a higher proportion of two-sea-winter salmon than other populations around the inner Bay. Abundance of salmon in the inner Bay of Fundy was estimated to be about 40,000 adults earlier in the 20th century, but abundance was reduced to as few as 250 adults by 1999. Trends in salmon abundance for two index rivers are shown in Figure 38. Inner Bay of Fundy salmon are currently considered to be at risk of extinction (DFO 2008b).

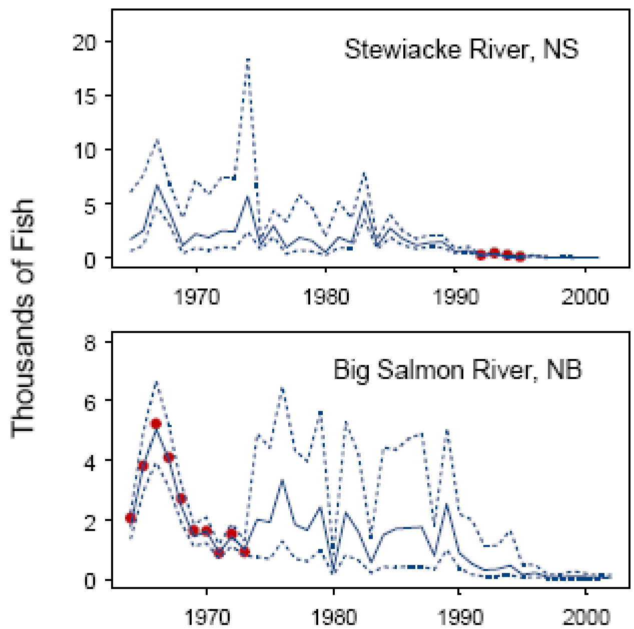

Figure 38. Estimated number of salmon returning to two inner Bay of Fundy rivers from 1965 to 2002. The points are fence counts that are used to "anchor" the model. The dashed lines are 80% Bayesian credible intervals which show the uncertainty associated with these estimates.

The **"Ipswich" Savannah sparrow** nests almost exclusively on Sable Island, 150 km southeast of mainland Nova Scotia, and winters in coastal dunes from Nova Scotia to Florida. Censuses on the breeding grounds since 1967 have estimated an adult population varying between 1250 and 3400 individuals, although different census methods yielded 5962 individuals in 1998. The population is not currently under any known threat, but its restricted distribution would make it vulnerable to localized threats that may arise. In particular, a temporary population crash of about 50% appears to have occurred in the late 1970s, probably because of harsh weather during migration and wintering. Such crashes may introduce new factors as significant threats, including predation, human activity, habitat loss, chance demographic effects, and loss of genetic information (Environment Canada 2006).

<u>Trends in Species of Special Interest</u>

Cod, haddock, and lobster are three species that have been important historically both in terms of biomass and fisheries in the Maritimes Region. While the biomass of cod has declined, it remains a culturally important species. Trends in seal abundance have also been of particularly interest to fishermen in the region.

<u>Cod</u>

Atlantic cod is a bottom dwelling North Atlantic fish. Cod range from Georges Bank to northern Labrador in the Canadian Atlantic. There are several populations of cod within the Gulf of Maine and Scotian Shelf ecozone, including Eastern Georges Bank cod, Western Scotian Shelf / Bay of Fundy cod, and Eastern Scotian Shelf cod. Cod in all three of these management areas have declined significantly since the 1980s.

On Eastern Georges Bank, the adult biomass of cod declined from about 50,000 mt in 1990 to below 10,000 mt in 1995, reaching its lowest level in 2005. From 2005, adult biomass has increased slightly to somewhere in the range of 8,700-12,000 mt in 2009 (Figure 39) (TRAC 2009).

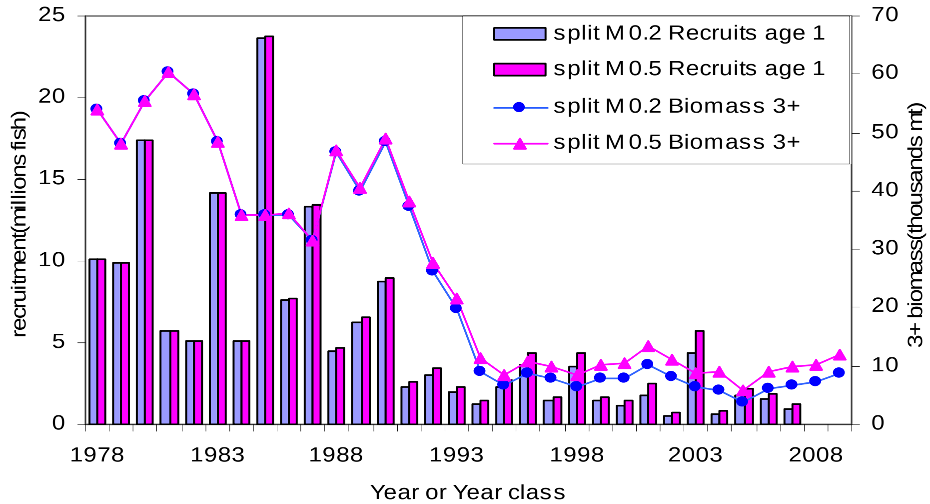

Figure 39. Biomass of age 3+ cod (line) and abundance of age 1 recruits (bars) using two difference modeling approaches (split M0.2 and split M0.5) (TRAC 2009).

The adult biomass of WSS / Bay of Fundy cod has also declined since the 1980s (Figure 40), reaching its lowest level in 2008 of approximately 9,000 mt (DFO 2009b).

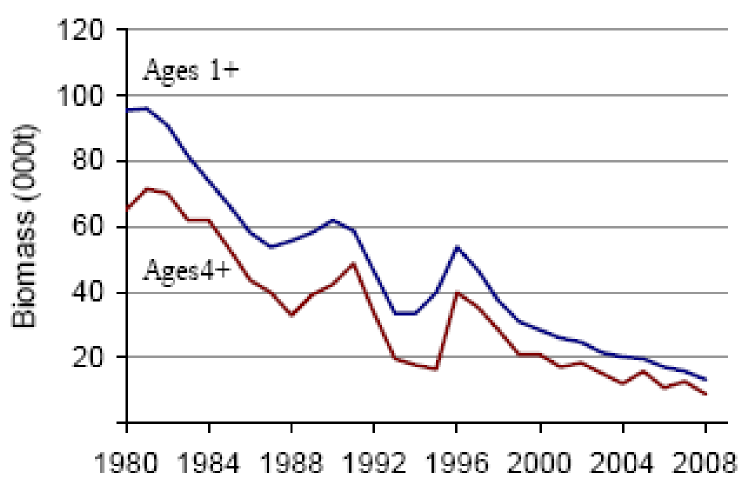

Figure 40. Total and spawning stock biomass estimates derived from population models of Western Scotian Shelf / Bay of Fundy cod (DFO 2009b).

<u>Haddock</u>

Haddock are also found on both sides of the North Atlantic. In the western Atlantic, they occur from Cape Hatteras to southwest Greenland. A major stock exists in the southern Scotian Shelf and Bay of Fundy area. Although seasonal migrations of haddock are evident, there is relatively little exchange between adjacent stocks. Haddock on the southern Scotian Shelf reach 38 cm and 0.5 kg by age 4 on average. Growth slows thereafter and haddock reach only about 48 cm and 1.1 kg by age 10. Haddock in the Bay of Fundy grow more rapidly than those on the southern Scotian Shelf. Approximately 50% of female haddock are mature by age 3; however, the number of eggs produced by a female of this age is low and increases dramatically with age. Major spawning grounds are found on Browns Bank and peak spawning occurs in April/May (DFO 2010).

From 1983-1992, a 10-year period of below average recruitment occurred. However, the 1998, 1999, 2000, 2003, 2005, and 2006 year classes were all above average, and spawning stock biomass has been increasing over the past decade (Figure 41). Mean sizes-at-age for haddock have been decreasing since the mid-1970s, and many ages are at or near the smallest size observed in the time series (DFO 2005b). An index of fish condition shows a decreasing trend from the early 1980s to the early 2000s (DFO 2005b), though condition appears to have improved somewhat over the last 5 years (DFO 2010).

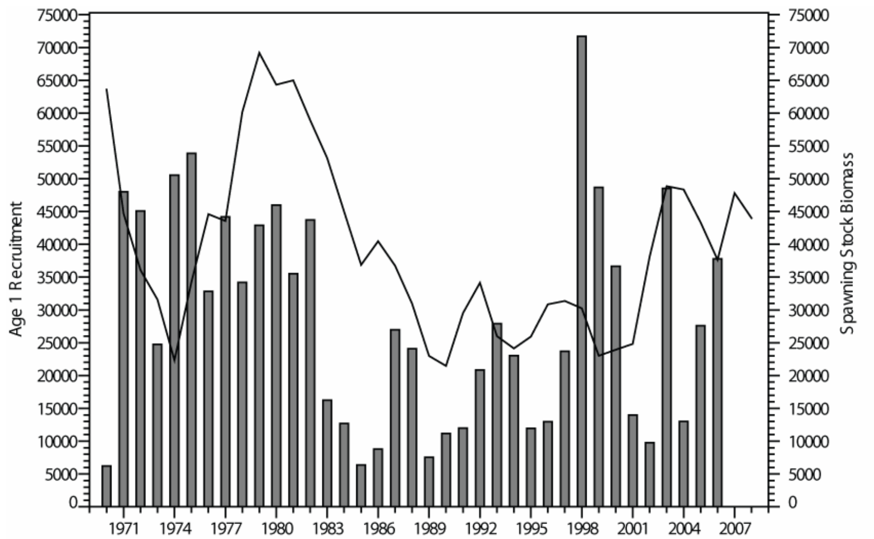

Figure 41. Spawning stock biomass (ages 4+) (line) and age 1 recruitment (10^3) in the subsequent year (bars) for Western Scotian Shelf and Bay of Fundy haddock (DFO 2010).

<u>Lobster</u>

In the Bay of Fundy, commercial lobster fishing began in the mid-1800s and annual lobster landings in the Gulf of Maine were first recorded in 1892. Landings peaked in 1894 at 1,415 mt and were followed by a decline, dropping to 53 mt in the early 1900s. The landings remained low during the 1920s to 1940s. Landings rose following World War II until the mid-1980s. From 1986/87 to 1993/94, landings stabilized at a higher level, averaging 998 mt yearly. From 1994/95 landings, began to increase as part of a western Atlantic wide pattern that saw landings increased over the entire east coast of North America. The underlying cause of this increase is not known, but the large scale nature of the increase suggests environmental condition may have led to improved larval and juvenile survival. During the 2005/06 season, landings peaked at an historical high of 3,997 mt (Figure 42). Landings are a function of abundance, the level of fishing effort and catchability, and they do not necessarily reflect changes in abundance (DFO 2007a).

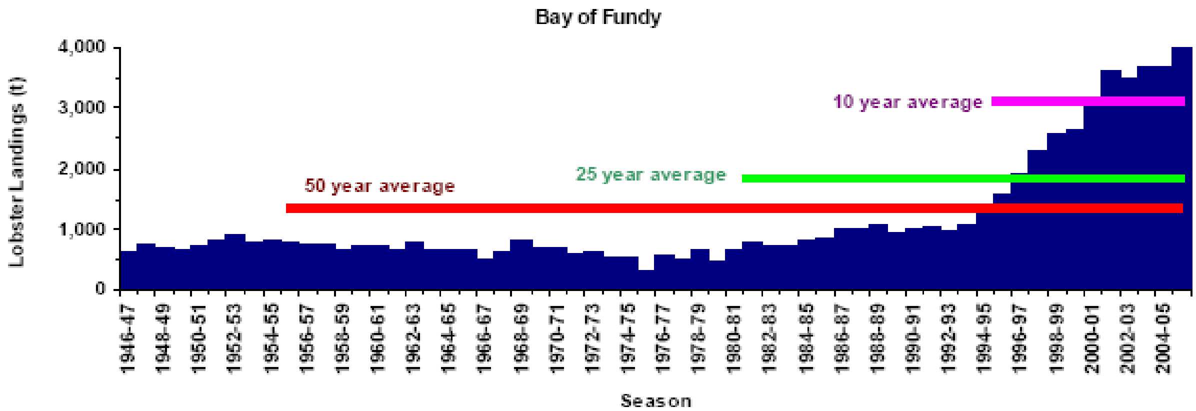

Figure 42. Landings in the Bay of Fundy showing historical means (DFO 2007a).

Lobster Fishing Area 34 off Southwest Nova Scotia encompasses 21,000 km^2 and has the highest landings of any area in Canada, accounting for 40% of Canadian landings and 23% of the world landings of *Homarus* sp. The lobster fishery in this area began in the 1880s and after a period of high landings in the 1890s landings declined from over 12,000 t to under 2,000 t in the mid-1930s. Landings remained between 2,000 t and 4,000 t until the early 1980s when landings increased dramatically. In LFA 34 landings rose steadily and exceeded 19,000 t in the 2001-2002 season (Figure 43) (DFO 2006c).

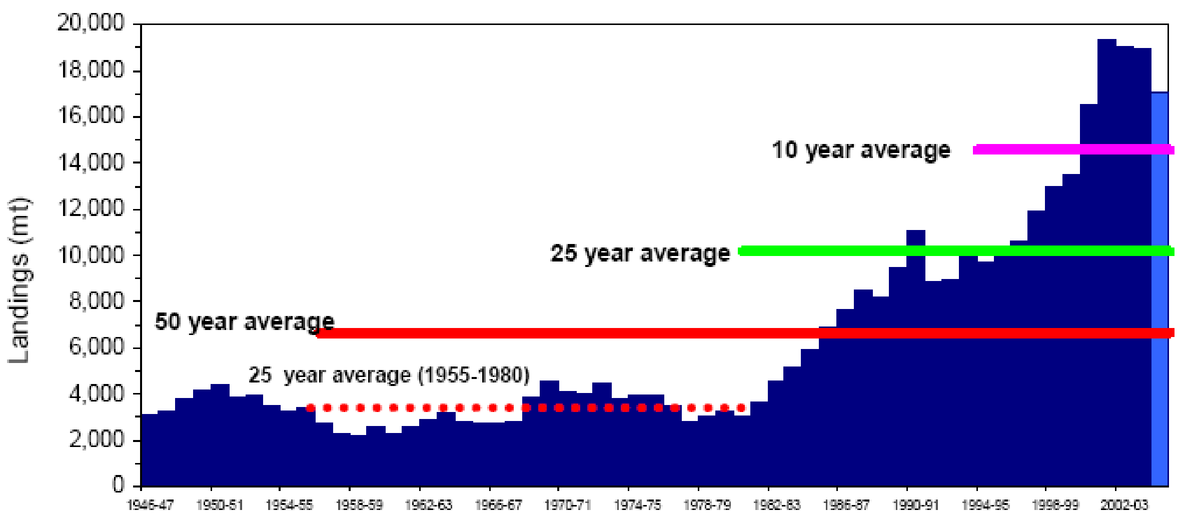

Figure 43. Lobster landings in LFA 34 showing historical means (DFO 2006c).

Seals

Over the past 30 or 40 years, the numbers of **grey seals** on the Scotian Shelf portion of the Gulf of Maine Scotian Shelf ecozone, and within the Gulf of St. Lawrence ecozone, have increased dramatically (Zwanenburg et al. 2006). The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf (Figure 44). Population numbers of the Sable Island colony increased exponentially at an annual rate of 13% per year until the late 1990s (Bowen et al. 2003). Since that time, there has been evidence of a significant slowing in the rate of increase to about 7% per year through 2007

(Bowen et al. 2007). Both a reduction in the rate of increase in pup production coupled with an increase in the age at first birth indicates that the population is approaching resource limitation. Associated with changes in the abundance of grey seals have been changes in the predation mortality exerted by grey seals on commercially harvested and other finfish. The nature of these changes is somewhat uncertain, although most recent sampling methods employed during the 1990s indicate grey seals fed primarily on sand lance and redfish, followed by several species of demersal fishes such as flounders, skates, and gadoids, such as pollock and Atlantic cod. (Zwanenburg et al. 2006).

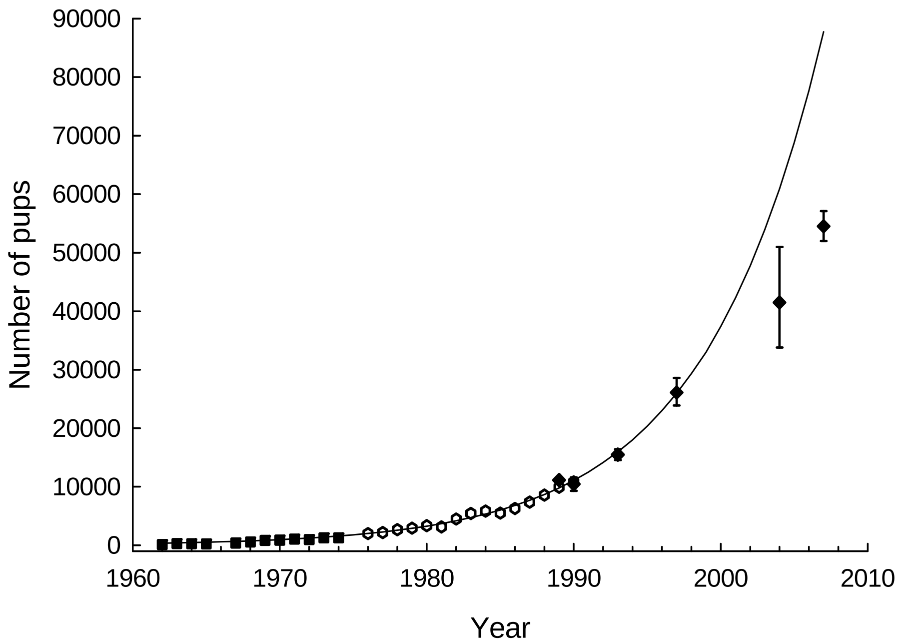

Figure 44. Observed trends (symbols) in the number of pups and exponential model estimates (solid line) of the number of grey seal pups born at the Sable Island colony between 1962 and 2007.

Harbour seal pup production on the ESS also was increasing strongly in the 1970s and 1980s. However, in the 1990s, production fell dramatically as a result of shark predation and competition with the increasing grey seal population. It is expected that Sable Island may soon become a non-breeding site for harbour seals, while the Gulf of Maine and WSS population continues to increase (DFO 2003).

<u>Major Range Shifts in Species Native to Canada</u>

Changes in the oceanic environment, such as the cooling events of the mid-1980s to the mid-1990s, had significant impacts on fish and invertebrate distribution. Because each fish species or stock tends to prefer a specific temperature range, long-term changes in temperature can lead to expansion or contraction of distributional range. These are generally most evident near the northern or southern boundaries of the range with warming (cooling) resulting in a northward (southward) shift (Zwanenburg et al. 2006). Associated with the cooling in the latter half of the 1980s, **capelin**, a cold water species, began to appear in the north-eastern Scotian Shelf annual summer groundfish surveys (Frank et al. 1996). Through the intervening years, the abundance of capelin gradually increased. These capelin are believed to have come from either the Gulf of St. Lawrence or eastern Newfoundland waters. Initially only adults were caught but, over the years, juveniles were found indicating that capelin were successfully spawning on the shelf. The range expansion southward by capelin during cool periods is not unique. The arrival of capelin in the Bay of Fundy was also noted following the cooling in the 1960s, as was their disappearance when temperatures rose in the 1970s. Reported capelin catches in the Bay of Fundy prior to the 1960s all corresponded with periods of colder-than-normal water.

The distribution of **snow crab** (*Chionoecetes opilio*) has also expanded during the recent cold period. Snow crab is a cold water species preferring temperatures of -1° to 3°C. The range extension of this species onto the Scotian Shelf has been attributed to colder temperatures, though reduced predation from groundfish may also have increased the survival and growth of juvenile and adolescent snow crab (Tremblay 1997).

Major Human Stressors on Composition

Pollution

A study of dissolved and dispersed **oil** in water conducted in the 1970s indicated a decreasing trend in the ESS from 1971 to 1976 (Figure 45); however, observations of oiled birds have not shown a decreasing trend (DFO 2009c).

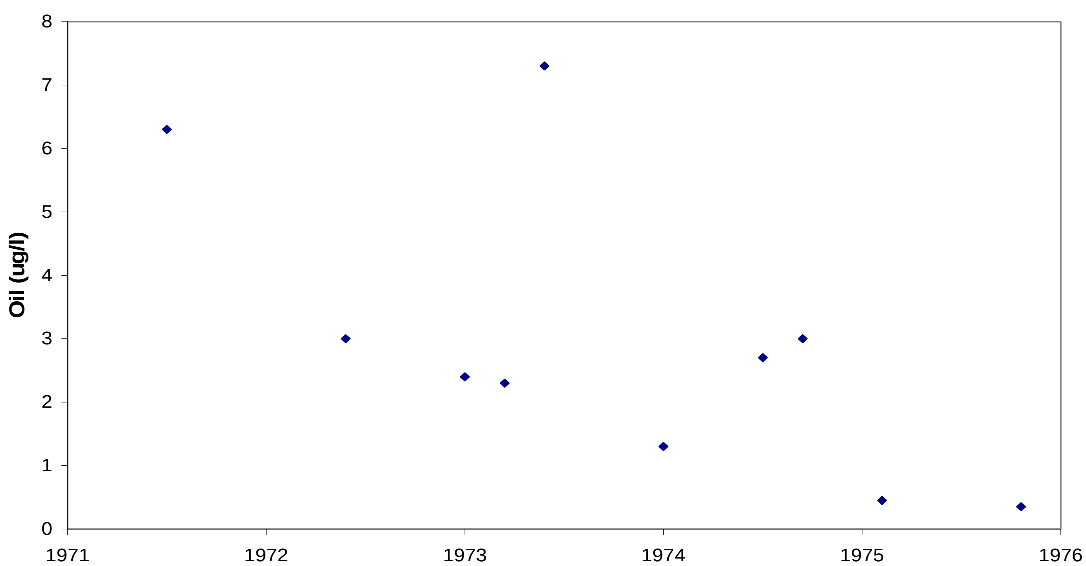

Figure 45. Dissolved and dispersed oil on Eastern Scotian Shelf (DFO 2009c).

A study of **chlorinated organic contaminants** in grey seals from Sable Island, covering the period from 1976 to 1995, indicated decreasing concentrations of DDT and DDE in adult seal blubber throughout the time series, and increasing concentrations from 1974 to 1985 and decreasing concentrations thereafter for PCBs (Figure 46) (Addison and Stobo 2001). Industrial use of these chemicals was curtailed during this time period and these trends reflect the success of regulations. Less dramatic decreases were observed for the pesticides oxychlordane, alpha-hexachlorocyclo-hexane, and trans-nonachlor. Hexachlorocyclobenzene, on the other hand, did not show a significant decrease.

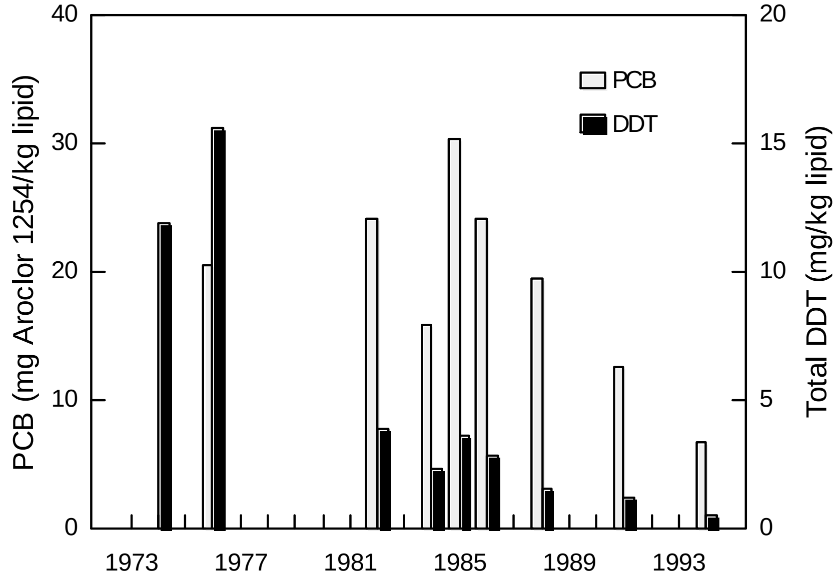

Figure 46. PCB and DDT levels in adult grey seal blubber over time (Addison and Stobo 2001).

Decreases in dissolved **lead** across the ESS are associated with a reduction in anthropogenic releases of lead into the atmosphere, including the elimination of lead from gasoline. Decreases in the industrial discharge of **zinc** into rivers are likely responsible for the decreasing trend in dissolved zinc. No decrease in dissolved **copper** has been observed on the ESS (Figure 47) (DFO 2009c).

Significant decreases in concentrations of large floating debris (mostly plastics) were observed in surveys conducted in the Gully Marine Protected Area in 1990, 1996/97, and 1999, though concentrations of smaller debris collected with plankton nets during these surveys showed insignificant increases (DFO 2009c).

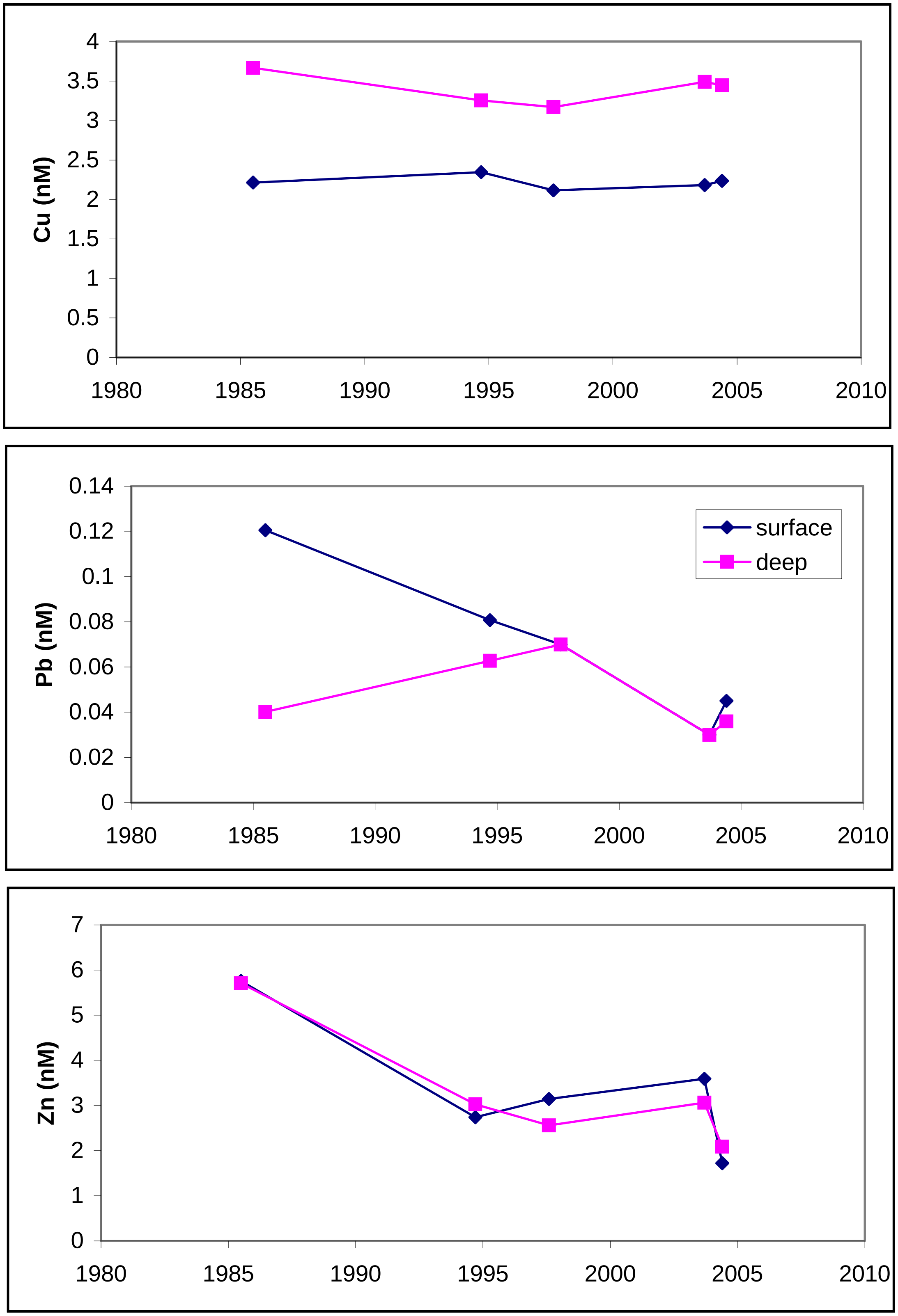

Figure 47. Levels of dissolved copper, lead, and zinc in seawater on the Scotian Shelf over time (DFO 2009c).

ECOSYSTEM GOODS AND SERVICES

Provisioning Services

Harvesting of aquatic resources by aboriginal peoples in the Gulf of Maine and Scotian Shelf started several thousand years ago and commercial fishing started in the mid-1500s. By 1709, Nova Scotia was exporting about 10,000 t of cod and 4,000 t of mackerel and herring. By 1806, this had increased to about 40,000 t, and to over 100,000 t by the 1880s. In 1973, total landings of fish from the Scotian Shelf exceeded 750,000 t (Figure 48) (Zwanenburg et al. 2006). Throughout most of the series, groundfish dominated the landings. However, invertebrate landings have been steadily increasing since the mid-1980s and overtook groundfish as the main contributor in 1996.

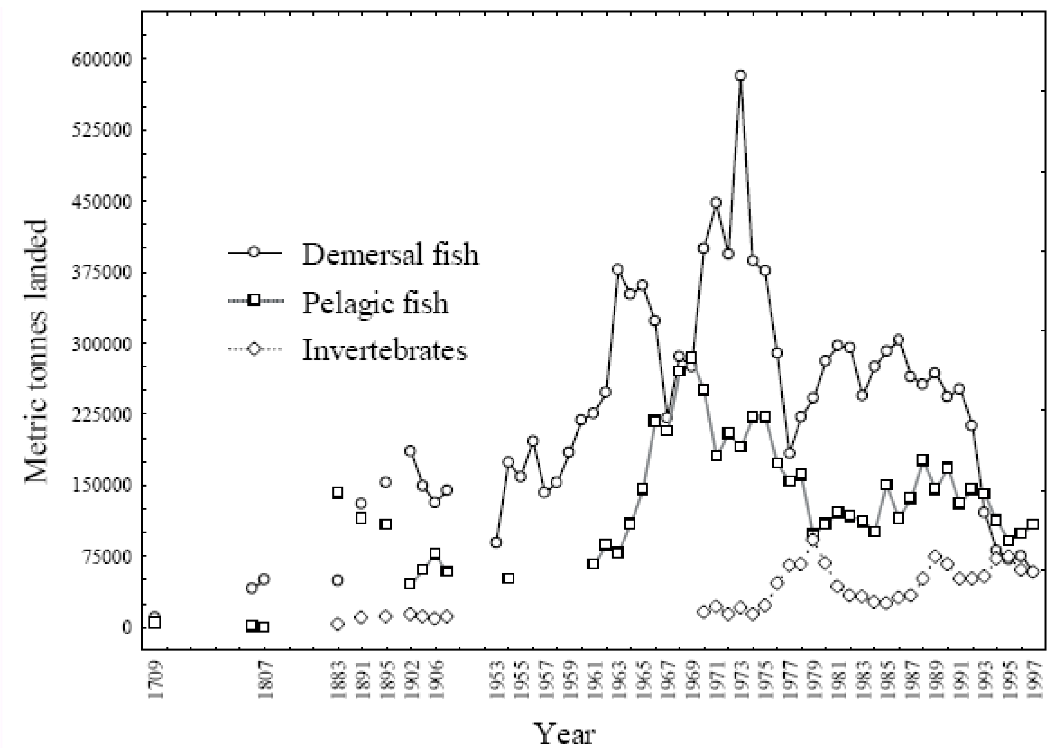

Figure 48. Historical landings of fish and invertebrates from the Scotian Shelf (Zwanenburg et al. 2006).

Total landings of demersal fish (mainly gadoids) on the ESS declined from a maximum of 450,000 t in 1973 to less than 15,000 t in 1997. A moratorium on fishing, especially for cod, was imposed in 1993 and remains in effect. A longline fishery for Atlantic halibut (*Hippoglossus hippoglossus*) is presently the only major demersal fishery operating on the eastern shelf. Landings of pelagic species (mainly Atlantic herring and Atlantic mackerel*)* declined from about 120,000 t in 1970 to about 20,000 t in 1980s. Landings of herring and mackerel were been higher than during the 1990s but with more interannual variation. Landings of invertebrates (mainly northern short-fin squid) increased rapidly to a maximum of about 75,000 t in 1979. Invertebrate landings then declined substantially to less than 4,000 t in 1985 and then increased to 30,000 t in 1997. This increase was mainly due to increased landings of snow crab and northern shrimp (*Pandalus borealis*). It is noteworthy that both of these invertebrate species prefer cold water and their increased landings coincide with the cooling of the ESS, noted previously (Zwanenburg et al. 2006).

Although total landings of fish have dropped, the overall landed value of fish increased dramatically in 1977-1978 with the extension of Canadian jurisdiction to 200 miles, effectively eliminating foreign fishing. In 1980, 1990, and 2000, the percentage contribution of groundfish to the total landed value was 73, 55, and 9%, respectively. In contrast, and demonstrating in part the shift to other species with the collapse of the groundfish, invertebrates rose from 12 to 38 to 85% over the same time period. Pelagic fisheries have not shown any trend and have ranged from 8-15% (DFO 2003).

Although the establishment of the 200-mile limit has greatly reduced foreign fishing within the ecozone, a large-scale foreign fishery for silver hake and squid are allowed within an area restricted to a portion of the Shelf edge, and Japanese pelagic longliners seasonally target tuna immediately adjacent to the shelf (Coffen-Smout et al. 2001).

Aquaculture for salmon and other species (described previously) is another way that food is being produced from the Gulf of Maine and Scotian Shelf ecozone.

HUMAN INFLUENCES

Stressors

The relative effects of changes in the in environmental conditions, compared to impacts of fishing, oil and gas and other human activities on the living resources of the Gulf of Maine and Scotian Shelf ecozone are difficult to quantify and to disentangle. For example, the **decreased size at age** of a species like haddock, cod, pollock, and silver hake (Figure 49) is considered to be correlated with decreased ambient temperature on the ESS. However, in recent decades, a decrease in fish size has been observed both on the ESS, where a downward influence of decreasing water temperature has occurred in the late 1980s through early 1990s, and on the WSS, where temperatures remained relatively stable over this same period (Zwanenburg et al. 2006). A change in the average size of a suite of exploited species is considered to be inversely related to fishing effort.

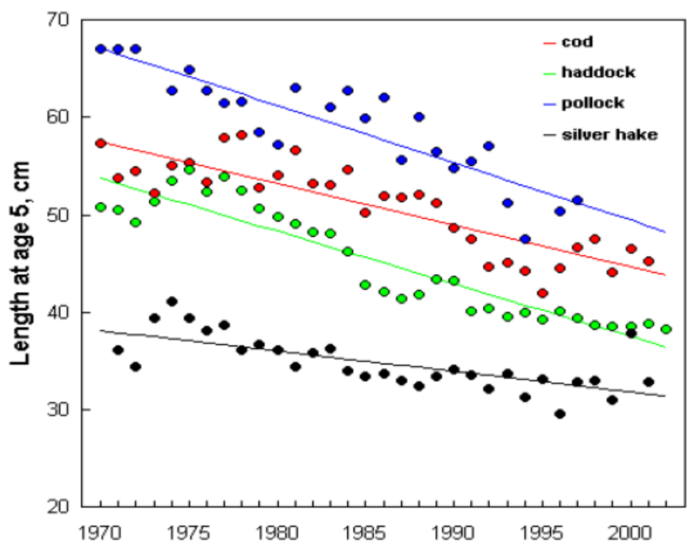

Figure 49. Length of age 5 cod, haddock, pollock, and silver hake. Regression lines are shown (all significant at $p < 0.01$) (Choi et al. 2005).

There has also been an overall decrease in the condition (weight at length) of many groundfish species during this same timeframe (Figure 50), with some stabilization or increases in recent years. Condition is likely related to availability of prey and environmental conditions. Changes in the diet of some species have been noted.

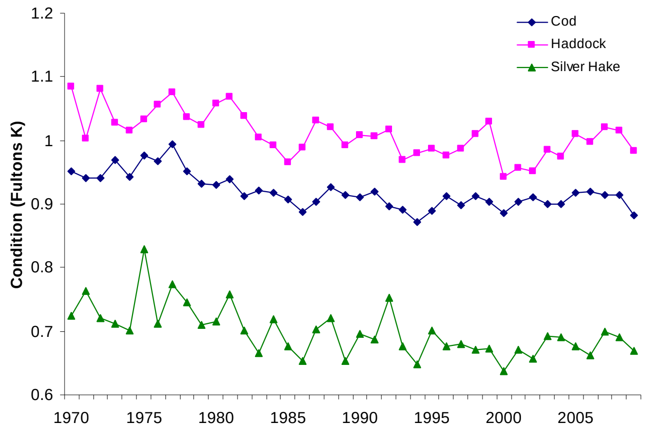

Figure 50. Condition of Atlantic cod, haddock and silver hake on the Eastern Scotian Shelf.

An evaluation of the overall rate of **decline in Integrated Community Size Frequency** (ICSF) (overall fish size) demonstrates a more rapid decline in fish size on the ESS than the WSS, despite much higher levels of fishing effort on the latter (Figure 51). This difference may point to the mitigating impact of the warmer temperatures and higher growth rates of the western shelf compensating for higher fishing effort (Zwanenburg et al. 2006). Regardless, this scenario demonstrates the challenges in trying to manage the relative impacts of exploitation and environmental conditions on the biota of the ecozone.

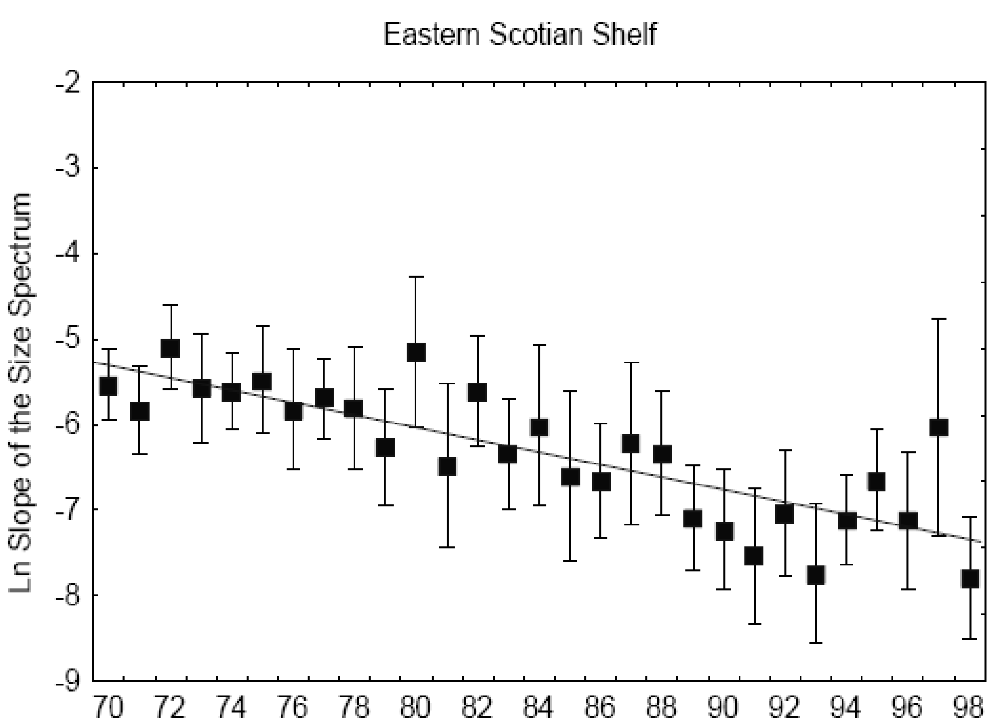

Figure 51. The integrated community size frequency (ICSF) for the eastern and Scotian shelf. Each point represents the average number of demersal fish per hectare caught at length over the 29 survey years (Zwanenburg et al. 2006; Zwanenburg 2000).

Although it is difficult to clearly separate human and environmental impacts on fish stocks, assessment of metrics related to single species (fishable biomass, recruitment, fishing mortality) from 1977 to the present, demonstrate that fishing mortality has been paramount (Zwanenburg et al. 2006). On the ESS, the fishery is increasingly targeting species at lower levels in the food web because of the lack of groundfish available during the past several decades (DFO 2003).

Although its employment impact is relatively small, **oil and gas** activity on the Scotian Shelf is one of the main non-fishing industrial activities taking place on the continental shelf and slope, and the largest direct economic contributor to oceans sector GDP (Gardner et al. 2005). Potential reserves, principally of natural gas, have been identified through exploration activity beginning in the 1960s. Although oil and gas related activities on the Scotian Shelf are relatively modest in scope compared with other areas of the world, exploration and production can still lead to ecosystem impacts and conflicts with the traditional fishing industry (Zwanenburg et al. 2006).

Oil and gas exploration is based on **seismic surveys** that involve the use of air guns discharging sounds over 250 decibels. This activity has the potential to cause physical, physiological and behavioural effects on fish, invertebrates, mammals, and sea turtles (DFO 2004). Seismic surveys continue on the Scotian Shelf. Most of the recent (post 1984) seismic surveys have taken place on the mid- to outer Scotian Shelf and slope, and along the Laurentian Channel. Early surveys (pre-1984) included nearshore areas in the Bay of Fundy, and around Cape Breton. Seismic activity has typically been followed by increased **drilling** activity, primarily of exploratory wells, but also of development wells. A drilling moratorium was instituted on in the southern portion of the ecozone on Georges Bank in 1988, and the moratorium was renewed after an independent review in 2000. The crucial issue was the importance of the scallop stocks on the Bank and the potential of drilling wastes and accidental spills to damage that resource (Zwanenburg et al. 2006).

In 2001, the total area of seabed that had been leased by the Canada-Nova Scotia Offshore Petroleum Board was over 62,000 km^2. This is an area more than 12% larger than the total land area of the Province of Nova Scotia. The median expectation of discovered and undiscovered potential resource was estimated to be 509 billion cubic meters of gas, 366 million barrels of condensate, and 707 million barrels of oil (Coffen-Smout et al. 2001).

As of 2001, the **fishery** was still the largest employer for the Province of Nova Scotia (Gardner et al. 2005). As well, a commercial fishery has existed in the area for some 300 years, compared to about 40 years for oil and gas, and is, therefore, still very much part of the culture and persona of the province. A variety of fishing methods have been used over the centuries, each with their different level of impact to the ocean bottom and the ecosystem as a whole. Dragging, trawling, and dredging (both hydraulic and traditional), which often contact the seabed, have the potential to disrupt sensitive benthic habitats in addition to their impacts on target and non-target populations due to removals. Currently, the overall impact of the trawl fisheries on the Scotian Shelf are not restricted to just the commercially important species of fish but include between 50 and 400 bycatch species. It is estimated that the trawl fisheries exert exploitation rates on individual species range from less than 1% of estimated biomass per year to values in excess of 50% of estimated biomass. Pelagic and bottom longlines have the potential for entanglement with birds, marine mammals, and sea turtles, as well as impacts to other bycatch species. Other methods of fishing in this region include gillnets, seines, traps, pots, harpoons, rakes, and hand collection. The ability of communities to withstand or to rebound from the impacts of human activities is as diverse as the harvest methods used. For example, disruptions to the ocean bottom with fishing gear or other bottom contacting activities (such as exploration drilling), in an area that is regularly turned over by tidal currents will have significantly less long-term impact than that same activity on a deepwater coral reef (Zwanenburg et al. 2006).

Since the collapse of the groundfish fishery, the fishery on the ESS has switched to lower trophic level invertebrates such as lobster and snow crab using traps and pots, and sea scallop and shrimp by trawls and dredges. More recently, fisheries for sea cucumber, whelk and hagfish have also been explored. Some species may have increased in abundance since the collapse of groundfish, likely due to a combination of predator release and cooler water temperatures (Zwanenburg et al. 2006). However, the average trophic level of catch of all species, which was relatively static (3.6) until the late 1980s, had declined to a low of 2.7 by 2000 (DFO 2003).

Other human activities on the shelf with the potential of having ecosystem impacts are commercial shipping, naval operations, government research, ocean disposal, sub marine cables, and pipelines (DFO 2003). The shelf is not immune to the effects of chemical **contaminants** from local activities or those farther afield. Primary distant sources of contaminants include those transported through the atmosphere and by the discharge of the St. Lawrence River through the Gulf of St. Lawrence (DFO 2009c). Nova Scotia and the waters of the Gulf of Maine Scotian Shelf ecozone are also on the Great Circle Route, an international **shipping** route between the eastern seaboard of North America and Europe. Ships traveling to the ports of Saint John, New Brunswick, and Halifax, Port Hawkesbury, and Sydney, Nova Scotia will pass through waters of this ecozone. Shipping poses several potential ecosystem impacts including oil discharges, ballast water borne exotic organisms and pathogens, shipboard wastes including black and grey waters, and noise pollution (Coffen-Smout et al. 2001).

Stewardship, Restoration, and Conservation

The Scotian Shelf area is one of five Large Ocean Management Areas (LOMAs) that has been identified to date by Fisheries and Oceans Canada. While this designation is not associated with any specific management actions or conservation measures, it has helped to focus attention on this area, resulting in increased research, education, and stewardship activities. For example, an Eastern Scotian Shelf Integrated Management (ESSIM) Stakeholder Advisory Council has been created that meets regularly to discuss issues of relevance to the ESSIM area.

Marine fisheries in the Gulf of Maine and Scotian Shelf ecozone have been afforded some broad scale protection by the establishment of Canada’s **200-mile limit**, which protects against foreign over-fishing.

A fishing **moratorium for groundfish** on the ESS has been in place since the groundfish collapse in 1993 (DFO 2003). On the ESS, approximately 13,700 km^2 of the Emerald and Western Banks was closed to year round mobile fisheries, and this was expanded to included groundfish directed fixed gear fisheries in 1993. The closure was aimed at protecting juvenile haddock (DFO 2003). As mentioned previously, there has also been a moratorium on offshore oil and gas exploration on Georges Bank since 1988.

Currently, there are two federally designated **Marine Protected Areas** (MPA) in the Gulf of Maine and Scotian Shelf ecozone. The Gully MPA is an offshore site at the eastern edge of the Scotian Shelf that was designated on 14 May 2004. The Gully is several hundred kilometres off the Nova Scotia coast and encompasses 2,364 km^2 of ocean area. The Gully is approximately 80 km long, 50 km wide, and more than 2,500 m deep at the canyon mouth. The deep canyon area of The Gully had previously been designated as a whale sanctuary in 1994.

More recently, a coastal site was designated around the Musquash estuary of New Brunswick on 7 March 2007. Within the Musquash MPA, performance indicators have been identified for three ecosystem level objectives: biodiversity, productivity, and habitat. These indicators will next be used to determine monitoring needs and programs (Singh and Buzeta 2007).

Cold water corals have been protected by conservation measures in three areas of the ecozone. The first is within the Gully MPA, whereas the **Northeast Channel Coral Conservation Area** (2002) has been established on the western end of the shelf and the **Lophelia Coral Conservation Area** (2004) on the eastern extreme of the shelf at the Laurentian Channel (DFO 2006b).

Sable Island is the only island of the outer continental shelf in this ecozone, and it has been both designated a Migratory Bird Sanctuary and identified as an Important Bird Area. The COSEWIC endangered roseate tern nests on the island within larger colonies of common and Arctic tern. Herring and black-backed gulls, Leach's storm–petrels, waterfowl, and shorebirds also nest on Sable Island. Offshore, birds congregate near the shelf edge, and on waters over Browns Bank, Sable Island Bank, and the Western Gully, where fronts and upwellings concentrate prey (Breeze et al. 2002). Sable Island itself is the most important breeding area for grey seals in eastern Canada and is also a breeding area for harbour seals (Breeze et al. 2002).

The Grand Manan Basin in the Bay of Fundy and the Roseway Basin on the WSS are important feeding and aggregation areas for North Atlantic right whales. These areas were identified as **Right Whale Conservation Areas** in 1993, and they were also identified as critical habitat in the 2009 North Atlantic Right Whale Recovery Strategy (Brown et al. 2009).

Several **Ballast Water Exchange Zones** have been implemented in the Gulf of Maine and Scotian Shelf ecozone to help manage the risk of alien invasive species, which can be introduced and spread via transport in ballast water.

In the Gulf of Maine and Bay of Fundy portion of the ecozone, there are a large number of players involved in the **governance** of the natural resources (ACZISC Secretariat and Dalhousie University, Marine and Environmental Law Institute 2006), as there is across the entire ecozone. Part of this boundary is defined politically, as an international boundary with the United States. As ecological processes and biota function independently of such human boundaries, ecosystem management requires transboundary collaborative arrangements and initiatives. These management arrangements include mechanisms on acid rain, mercury pollution, climate change, fisheries and shellfish sanitation, and shipping, to name a few (ACZISC Secretariat and Dalhousie University, Marine and Environmental Law Institute 2006). Collaborative recovery strategies have been have been initiated between Canada and the United States for the leatherback turtle, North Atlantic right whale, and Atlantic salmon of the inner Bay of Fundy and Gulf of Maine.

INTEGRATED ANALYSIS OF ECOZONE STATUS AND TRENDS

An evaluation of 64 primary and second order indices of species, processes, and conditions on the eastern portion of the Scotian Shelf has demonstrated that nearly all have undergone significant change since the 1970s (Figure 52). The transition period most typically occurred between 1985 and 1990. The magnitude of change has been rapid and, from a species perspective, some groups are flourishing while others are not (DFO 2003), i.e., there has been a dramatic community shift (Choi et al. 2005). Through a technique called principle components analysis, it is apparent that two components appear to account for over 40% of the variance observed. The first principle component accounting for 33% of the variance in the data contrasts the shift from a large bodied groundfish dominated system to a pelagic fish and macro invertebrate dominated system. The second principle component accounting for 9% of the variance reflects a change in ocean climate (e.g., cold intermediate layer, bottom temperature, and Gulf Stream frontal position). The change in environmental conditions preceded the changes in the biotic conditions; this indicates a potential causal effect (Zwanenburg et al. 2006).

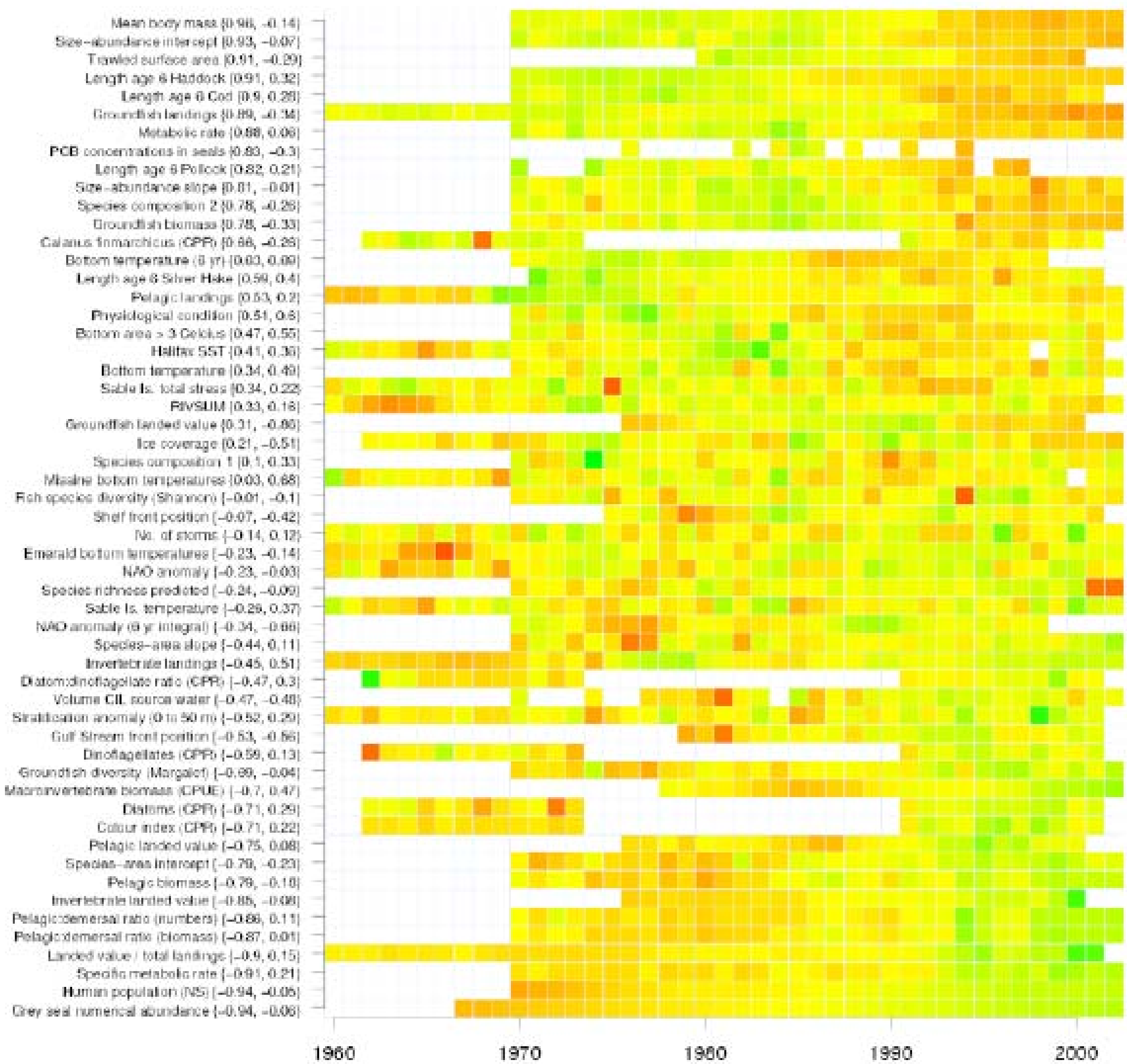

Figure 52. Sorted table of standardised anomalies (standard deviation units) of the indicators of the ESS. The sort sequence is based upon the first axis of variation. In braces { } are provided the factor loadings of the first two axes of variation. Note the coherent transition of a great number of indicators during the early 1990s. Prior to 1990, the ESS was dominated by large body size fish, high biomass, high trawled surface area, greater groundfish landings, greater areal extent of warmer bottom temperatures (>3°C). Subsequently, the system became dominated by small body size fish, low biomass, lower trawled surface area, lower landings, greater dominance of pelagic (fish, seals, dinoflagelates, diatoms) and benthic macro-invertebrate biomass, landings, landed values, and human population size (Choi et al. 2005).

The gradual cooling of the bottom waters of the ESS from the mid-1980s through the 1990s is an example of a decadal length variation that had a measurable impact on the structure and function of ESS ecosystems. This cold period was associated with increased abundance of cold-water fish (e.g., capelin) and invertebrates (e.g., snow crab) that are usually more prevalent in colder Gulf of St. Lawrence and Newfoundland waters to the north of the Gulf of Maine and Scotian Shelf ecozone. Colder temperatures may also have led to reductions in growth rates of demersal fishes and reduced productivity (Zwanenburg et al. 2006). Given that this cooling trend appears to have stopped, with increases in water temperatures in some areas, it will be interesting to track whether range extensions will reverse or whether they will persist as evidence of true ecosystem shift.

Study of salinity and temperature data has found that there is considerable interannual and decadal variability within the ecozone, with the 1960s being a period of cold fresh waters in the Scotian Shelf – Gulf of Maine, followed by a warm more saline period during the 1970s (Breeze et al. 2002). Circulation and the differences in source waters account for the dramatic contrasts in bottom temperature, salinity, and vertical structure between the ESS and WSS. However, there are spatial differences as the gradual cooling of the bottom waters of the ESS from the mid-1980s through the 1990s was not seen in the WSS, and an episodic cooling of the bottom waters in Emerald Basin in 1998 was not observed on the ESS (Zwanenburg et al. 2006). Recent stratifications in the surface layer have been apparent, and are associated with flows from upstream areas (DFO 2003).

As noted, the changes in environmental conditions discussed generally preceded the biological changes that have been observed in the last 30 or so years, and are, therefore, at least a potential causal or contributing effect of environmental conditions on biological changes. For example, a range expansion southward by capelin during the cool periods of the 1960s and 1980s occurred, and reported capelin catches in the Bay of Fundy prior to the 1960s corresponded with periods of colder-than-normal water (Zwanenburg et al. 2006). During periods of cooling, capelin, and snow crab have typically been found on the northeastern portion of the shelf, and are believed to have come from either the cooler waters of the Gulf of St. Lawrence or eastern Newfoundland (Zwanenburg et al. 2006). Conversely, there has been an increase in the number of fish species (diversity) caught on Georges Bank over the last decade, in part reflecting the increase in more southern species found on the Bank.

The period between 1982-1985 was one of high fish diversity in many of the depth strata of the Scotian Shelf and Bay of Fundy (Breeze et al. 2002). Limited Continuous Plankton Recorder data for the 1980s indicates it was a period of high abundance for *Calanus* (a copepod) and euphausiids (krill), arguably among the most important zooplankton categories that feed higher trophic levels within the Gulf of Maine (Zwanenburg et al. 2006). Yet, considering demersal fish data for the past 40 years, biomass by the late 1990s was the lowest observed in 30 years, and ESS commercial species have largely been replaced with other species. The decline on the WSS has been less precipitous, and occurred later (Breeze et al. 2002).

Not only has there been a change in species diversity associated with basic physical oceanographic fluctuations, but there has also been within species changes of size and condition over time. For example, the average size of demersal fish caught generally declined from the late 1970s to the mid-1990s, and has remained stable or increased since then. In fact, the average size (weight) of a demersal fish (top 60 species combined) declined by 66% between 1970 and 1995 (Figure 53). However, unlike the species diversity changes noted previously, the cause for change is less likely to be related to environmental conditions.

The declines in aggregate mean size are, perhaps expectantly, coincident with increasing fishing effort for the period 1977-1995. From 1995-1998 the trend was toward stable or increasing mean weights in the eastern and Western Scotian Shelf. This trend, in increasing mean weights, was coincident with the imposition of a moratorium on fishing for cod on the

ESS, and a significant reduction in total allowable catches on the WSS (Zwanenburg et al. 2006). Overall, the integrated community size frequency (estimated density (numbers per hectare) of all fish by size class (without regard to species), calculated for fish between 35 cm and 85 cm, shows long-term decline. This indicates there have been long-term reductions in the number of larger fish on both the ESS and WSS. Yet, fishing is not the only factor implicated in reduced biomass. The low bottom temperatures during the late 1980s to mid-1990s have been shown to be partly responsible for observed decrease in size-at-age of cod on the ESS (Zwanenburg et al. 2006). Adult cod, haddock, and pollock (along with others) are now much smaller on average than similar aged fish were in the 1970s. The trend of reduced size has occurred despite the current low population levels of groundfish, suggesting that a fundamental population dynamic of these species has been altered on the Shelf (DFO 2003). Such changes do not necessarily translate to an unhealthy ecosystem, but simply one that is functioning in a different manner than it has in the past. However, in an assessment of fish health of 24 common species, sixteen that were in relatively good condition up to 1982 are in below average condition to the present (DFO 2003).

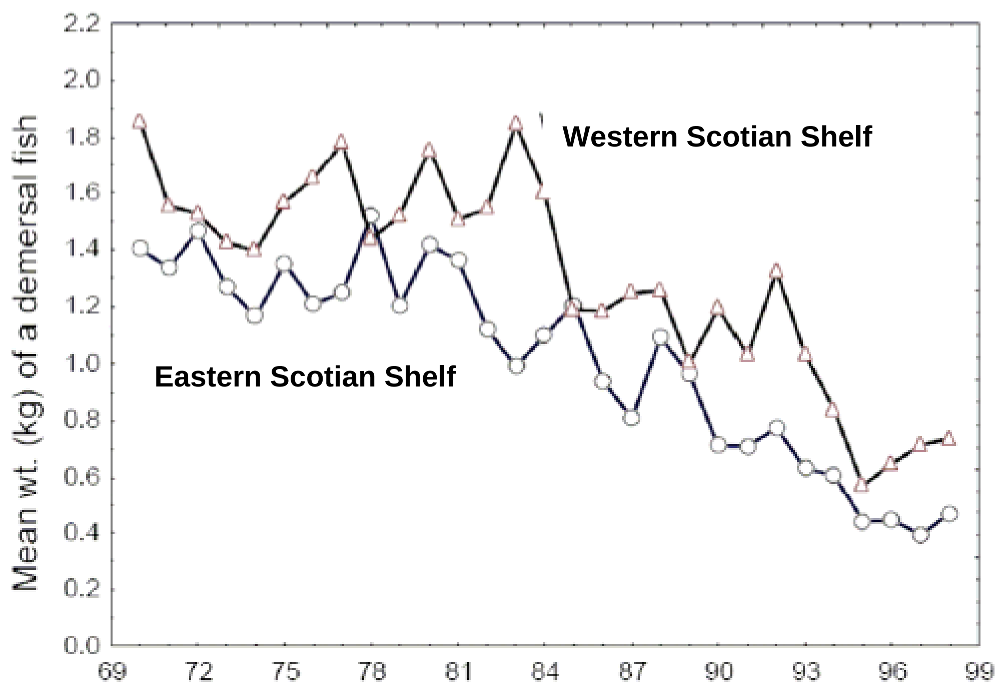

Figure 53. Trends in average weight of demersal fish (all species) since 1970 for the eastern and western portions of the shelf (Zwanenburg et al. 2006).

Undoubtedly one of the biggest changes in the ecology and use of the Gulf of Maine and Scotian Shelf ecozone was brought about by the collapse of the cod stocks in the early 1990s. Exploitation of the fish, primarily cod, on the Scotian Shelf started in about 1560 (Zwanenburg et al. 2006). Since the collapse of the groundfish fishery, the fishery on the ESS has switched to lower trophic level invertebrates such as lobster, sea scallop, snow crab, and shrimp. These species have increased in abundance since the collapse of groundfish, likely due to a combination of predator release and cooler water temperatures, and have resulted in an active fishery (Zwanenburg et al. 2006). In this way, the ESS ecosystem has been profoundly altered and exhibits classic symptoms of what is termed a trophic cascade.

Although total productivity and total biomass of the ecosystem appears to have remained similar between the early 1980s and late 1990s, there appear to have been changes in predator structure, trophic structure, and energy flow. Many of these changes are surrounded by uncertainty. There was a significant decrease in the biomass of demersal groundfish species and a significant increase in biomass of grey seals, possibly small pelagic species, commercial crustaceans, and phytoplankton (Table 3). The greatest change in the ecosystem has been this general switch from a demersal dominated system to a pelagic dominated system, which also indicates a shift in trophic flow from the demersal to the pelagic side of the food web (Zwanenburg et al. 2006).

Table 3. Comparison of the biomass (t / km^2) of functional groups in the early 1980s and late 1990s based on DFO research vessel survey results. Asterisks indicate that the difference between the two periods were significant, according to the Mann-Whitney U test (Zwanenburg et al. 2006).

Functional Group*	early 1980s	late 1990s	% change	Mann-Whitney U test
Cetaceans and birds	0.24	0.27	13	
Grey seals	0.03	0.14	468	***
Demersal fish	13.33	7.72	-42	***
Pelagic fish	3.62	23.28	544	***
Commercial crustaceans	4.60	17.66	284	***
Other invertebrates	138.56	138.43	-0	
Zooplankton	50.13	78.58	57	***
Phytoplankton	34.38	43.56	27	***
Total	244.89	309.65	26	***

*Demersal Fish = Cod (*Gadus morhua*), Silver hake (*Merluccius bilinearis*) Haddock (*Melanogrammus aeglefinus*), American plaice (*Hippoglossoides platessiodes*), Halibut (*Hippoglossus hippoglossus, Reinhartius hippoglossoides*), Flounders (Pleuronectidae), Skates (*Raja sp.*), Dogfish (*Squalus acanthus*), Redfish (*Sebastes sp.*), Pollock (*Pollachius virens*), Demersal Piscivores, Large Demersals, Small Demersals. Pelagic Fish = Transient Mackerel, Capelin (*Mallotus villotus*), Sand lance (*Ammodytes dubius*), Transient Pelagics (*Scomber scombrus*), Small Pelagics (e.g., herring, *Clupea harengus harengus*), Small Mesopelagics. Commercial crustaceans = Shrimp (*Pandalus sp.*), Crabs (e.g., snow crab *Chionoecetes opilio*). Other invertebrates = Squids (*Illex illecebrosus, Loligo pealei*), Echinoderms, Polychaetes, Bivalve Molluscs, Other Benthic Invertebrates.

In short, at least the Eastern Scotian Shelf portion of the ecozone has switched to an alternative state, where it is now dominated by small pelagics, invertebrates and seals. And, although the fishing effort for cod has been largely removed, the current state, whereby the previously abundant cod are kept at low levels of abundance, is maintained through a combination of cultivation-depensation effects (Large adult cod used to consume fish species that would compete with young cod, giving the young cod an advantage. The removal of this advantage because of the harvest of large cod means young cod no longer have a competitive advantage), genetic effects, and a massive reduction in the size structure of what remains of the cod population (Zwanenburg et al. 2006).

Decadal trends of phytoplankton community structure show that during the cold-water periods of the 1960s the relative proportions of the larger forms of diatoms were much greater than dinoflagellates. In contrast, during the warmer water periods of the 1970s and again more recently, diatom dominance has diminished and dinoflagellates have become more important (Zwanenburg et al. 2006). However, although differences have occurred, analysis of phytoplankton taxa abundance has shown little evidence for long-term trends on the Scotian Shelf, although there does appear to be a more recent trend of increased phytoplankton biomass.

Changes have also been observed in zooplankton, with changes occurring at similar time points as the phytoplankton changes. The zooplankton index was low in the 1990s when phytoplankton levels were high, a reversal of the pattern observed in the 1960s and early 1970s.

Long-term changes in the abundance of certain of *Calanus spp.* members of the mesozooplankton community have been observed in samples collected by the Continuous Plankton Recorder program. These species contribute a large portion of the biomass of the Shelf, and are an important food source to many species, including cod and haddock. From the beginning of data collection in 1960, certain of *Calanus spp* have changed, becoming somewhat less abundant on the ESS since 1991 than during the 1960-1975 period (by a factor of about 2). In addition, the seasonal peak in abundance has shifted from June/July to May/June (Sameoto 2004). The interpretation of these changes is not straightforward, with both prey and environmental conditions being suggested as possible driving factors (Zwanenburg et al. 2006).

Within the inshore waters, intertidal, and subtidal beds of sea grass are acknowledged to be highly productive areas that provide structural habitat for juvenile fish and invertebrates, a host for epiphytic algae, and spawning habitat for species like herring. Natural sea grass die off in the ecozone occurred in the 1930s, and commercial harvest and development activities have also had an impact. However, during the 1990s a massive and widespread decline in grass populations occurred in many of the coastal areas of the Gulf of Maine and Scotian Shelf ecozone. One study estimated an average decline of nearly 80% for intertidal *Zostera* marina beds (den Heyer et al. 2006). No consistent pattern of decline was observed, and symptoms of the 1930s wasting disease were not apparent.

As noted earlier, physical oceanographic changes have preceded and likely influenced observed biological changes over the past 3 to 4 decades. And, although this discussion has focused on the lower trophic levels, phytoplankton to piscovores, changes have also affected the top consumers in the ecosystem. Over the past 30 or 40 years, the numbers of grey seals in the Gulf of Maine and Scotian Shelf ecozone have increased dramatically. The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf. Population numbers of the Sable Island colony increased exponentially at an annual rate of 13% per year until the late 1990s, with evidence of slowing to a rate of about 7% per year through 2007. Harbour seal pup production on the ESS also was increasing strongly in the 1970s and 1980s. However, in the 1990s, production fell dramatically as a result of shark predation and competition with the increasing grey seal population. It is expected that Sable Island may soon become a non-breeding site for harbour seals, while the Gulf of Maine and WSS population continues to increase (DFO 2003).

Other top trophic consumers within the Gulf of Maine and Scotian Shelf ecozone include whales and other cetaceans. However, of the 18 species of whale on the ESS, information on temporal change is only available for the Northern bottlenose whale. Between 1962-1967, 87 bottlenose were harvested during a Canadian hunt on the Scotian Shelf, with several coming from what is now the Gully MPA. Much higher numbers were hunted in the waters of Labrador until 1973. The Scotian Shelf population of Northern bottlenose whale was designated as endangered in 2002. There does not appear to have been significant changes in the population numbers for the species between 1988 and 2003, which has averaged 163 whales (DFO 2007c).

The physical changes on the Scotian Shelf affect the biological communities, and the changes in the biological communities impacts on resource use. The relative economic importance of the ocean sector declined slightly during the 1990s associated with the collapse of the groundfish fishery. The sharp rise in direct GDP impact after 1999 is due mainly to revenues from offshore gas production, but also improved fisheries as changes from ground fish to pelagics were implemented. Employment generated by ocean activities increased slightly less than total employment in the province of Nova Scotia in the mid-1990s, and then matched provincial growth after 1999 (Gardner et al. 2005).

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