Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S / **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2010/026 / **Document de recherche 2010/026**

Ecosystem Status and Trends Report for the Newfoundland and Labrador Shelf

Rapport sur l'état de l'écosystème du plateau de Terre-Neuve et du Labrador et les tendances

N. D. Templeman

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des sciences
PO Box 5667, 80 East White Hills Road
St. John's, NL, Canada A1C 5X1

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

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at:

La présente série documente les fondements scientifiques des évaluations des ressources et des écosystèmes aquatiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

TABLE OF CONTENTS

Correct citation for this publication:

Templeman, N.D. 2010. Ecosystem Status and Trends Report for the Newfoundland and Labrador Shelf. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/026 vi + 72 p.

ABSTRACT

In 2006, the Canadian Councils of Resource Ministers (CCRM) identified the completion of the Ecosystem Status and Trends Report (ESTR) as an early deliverable under the Biodiversity Outcomes Framework. ESTR will report on the assessment of 25 Canadian ecozones (15 terrestrial, 1 freshwater, and 9 marine). This science-based technical report corresponds to one such marine ecozone, the Newfoundland and Labrador Shelf, and is a compilation of available scientific and technical information on the condition, trends, drivers, and stressors of the ecozone. Reports on marine and other ecozones will be brought forward to Environment Canada for incorporation into the National 2010 ESTR under the Biodiversity Outcomes Framework, and will also aid in measuring Canada's progress towards the Convention on Biological Diversity's (CBD) 2010 biodiversity targets.

The abiotic characteristics of the Newfoundland and Labrador Shelf Ecozone (NLSE) have changed notably over the past several decades. Since the above average water temperatures of the 1950s and 1960s, and the below average water temperatures of the mid-1980s to mid-1990s, the ocean continues to experience a significant warming trend – with a notable 61-year high in 2006. Sea ice extent and duration has been below average since mid-1990, with 2006 experiencing the lowest sea ice extent since records began in 1963. The biological components of the NLSE have also changed dramatically over the past 40 to 50 years. Phytoplankton biomass has increased over the available time series (since 1961), coinciding with an increase in the numbers of dinoflagellates in the composition of phytoplankton taxa. Many of the larger warmer water offshore demersal species (including the important commercial ones), which were once dominant, have declined to a small percentage of their historic levels and management efforts, mostly through closed fisheries, have not resulted in significantly increased populations, while the remaining individuals are often smaller at maturity. During the same time as the collapse of many larger warmer water offshore demersal species, quite a number of smaller, colder water nearshore species (e.g., alligator fish, shannies etc.) increased in numbers. In the meantime, bottom dwelling crustaceans have increased dramatically, partially due to changing abiotic conditions in the ocean, and partially due to the decline of their predators, demersal fish. Pelagic species have undergone change also – for example, both capelin and herring are increasing in some areas and declining in others, while their size and phenology are also changing. Finally, the use of the oceans is also changing – resulting in economic diversification and competing needs and interests of the marine environment. There has been a shift in commercially fished key species, from groundfish to shellfish. A significant increase has also been observed in offshore oil exploration, development and production, aquaculture development and production, marine commercial transportation, and marine-based tourism.

RÉSUMÉ

En 2006, le Conseil canadien des ministres de l'Environnement (CCME) a indiqué que l'achèvement du Rapport sur l'état des écosystèmes et les tendances (REET) devait être produit à court terme en vertu du Cadre axé sur les résultats en matière de biodiversité. Le REET portera sur l'évaluation de 25 écozones canadiennes (15 écozones terrestres, 1 écozone d'eau douce et 9 écozones marines). Le présent rapport technique fondé sur des données scientifiques traite d'une écozone marine, le plateau de Terre-Neuve et du Labrador, et rassemble l'information scientifique et technique disponible concernant les conditions, les tendances, les éléments catalyseurs et les facteurs de perturbation de l'écozone. Les rapports sur les écozones marines ou autres doivent être présentés à Environnement Canada afin d'être incorporés au Rapport national sur l'état des écosystèmes et les tendances de 2010 en vertu du Cadre axé sur les résultats en matière de biodiversité. Il aidera également à mesurer les progrès accomplis par le Canada quant à l'atteinte de ses objectifs en matière de biodiversité pour 2010 établis en vertu de la Convention sur la diversité biologique.

Les caractéristiques abiotiques de l'écozone du plateau de Terre-Neuve et du Labrador ont varié de façon marquée depuis plusieurs décennies. Après les températures de l'eau supérieures à la moyenne enregistrées dans les années 1950 et 1960 et inférieures à la moyenne entre le milieu des années 1980 et le milieu des années 1990, la tendance au réchauffement s'est poursuivie de façon marquée dans l'océan – avec un sommet de 61 ans en 2006. L'étendue et la durée de la couverture de glace de mer demeurent inférieures à la moyenne depuis le milieu des années 1990, 2006 étant l'année où l'étendue de glace de mer a été la plus faible de la série chronologique qui a débuté en 1963. Les composants biologiques de l'écozone du plateau de Terre-Neuve et du Labrador ont également subi des changements profonds au cours des 40 à 50 dernières années. La biomasse du phytoplancton a augmenté depuis le début de la série chronologique commençant en 1961, ce qui coïncide avec l'augmentation du nombre de dinoflagellés dans le taxon phytoplanctonique. L'abondance de nombre des plus grandes espèces de fond des eaux plus chaudes du large (y compris les espèces importantes sur le plan commercial) qui ont déjà été dominantes a décliné et correspond maintenant à un faible pourcentage des niveaux historiques. En outre, les efforts de gestion, principalement par le biais de fermetures de pêche, n'ont pas entraîné d'augmentations notables des populations, et les individus observés sont souvent plus petits à la maturité. Au même moment que se produisait le déclin de nombre de plus grandes espèces de fond des eaux plus chaudes du large, l'abondance d'un certain nombre de plus petites espèces des eaux côtières plus froides (p. ex. agone atlantique et stichaeidés) a augmenté. Entre-temps, le nombre de crustacés des grandes profondeurs a augmenté de façon spectaculaire, en partie en raison des changements dans les conditions abiotiques de l'océan et du déclin de leurs prédateurs, les poissons de fond. Les espèces pélagiques ont également connu des changements : par exemple, les capelans et les harengs sont en hausse dans certaines zones et en baisse ailleurs, et leur taille ainsi que leur phénologie changent également. Finalement, l'utilisation des océans connaît aussi des changements qui entraînent une diversification sur le plan économique et créent des besoins et des intérêts concurrentiels relativement à l'environnement marin. On a observé un changement dans les espèces visées par la pêche commerciale – autrefois les poissons de fond et aujourd'hui, les mollusques et crustacés. On remarque également un important accroissement de l'exploration et de l'exploitation pétrolière au large, du développement de l'aquaculture, du transport maritime commercial ainsi que du tourisme maritime.

OVERVIEW OF THE NEWFOUNDLAND AND LABRADOR SHELF ECOZONE

The Newfoundland and Labrador Shelf Ecozone (NLSE) encompasses the nearshore, coastal, and offshore areas from the Northern tip of Labrador, at Cape Chidley, to south and west of the island of Newfoundland at Cape Ray, bounded by the line representing Canada's 200-mile Exclusive Economic Zone (EEZ) and its intersection with the western boundary of NAFO regulatory subarea 3 (in red; Fig. 1).

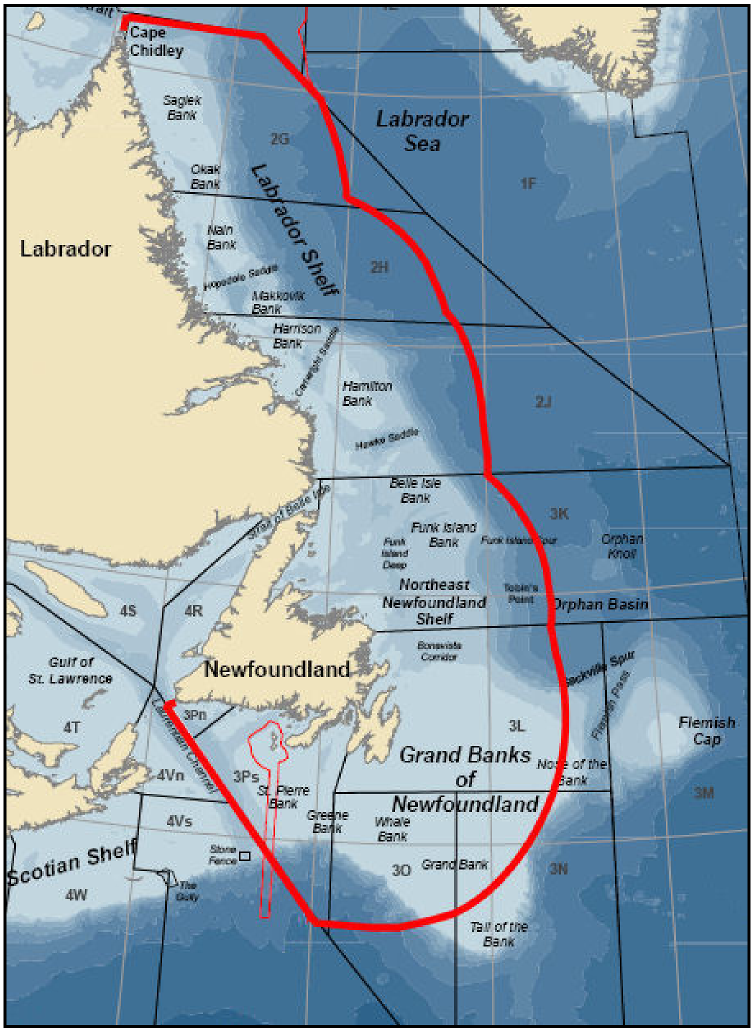


Figure 1. Map of the Newfoundland and Labrador Shelf Ecozone study area (red). Also represented are the NAFO Regulatory areas.

Originally carved by glaciers and continually modified by exposure to wave action, sea ice, and fluctuating sea levels, the coastline of the NLSE is highly irregular, rugged, and barren, and is indented with thousands of inlets, coves, and bays, many of which house small islands. Coastal elevations range from areas of low relief (i.e. sea level) to steep cliffs exceeding 70 m in height.

The seabed topography of the NLSE is dominated by a vast apron of shelf representing one of the largest portions of the Continental Shelf anywhere in the world (Farmer 1981). The continental shelf region is typically divided into three zones: (1) an inner shelf, a narrow zone parallel with the coast up to 20 km wide; (2) an inner-central shelf, consisting of a broad, fairly flat area, averaging 50-150 km in width, and ranging from 50-200m in depth; and (3) an outer shelf. Beyond the continental shelf break of the NLSE lies the continental slope region, rapidly reaching depths over 3,000 m.

The shelves are also divided into two groups (1) a temperate group, south of 48°N, that are dominated by the effects of winds, waves, and currents; (2) a northern group, north of 48°N, that are dominated by the effects of ice rafting and ice scouring (Amos 1990).

While the NLSE study area does include many areas of deep water (> 3000 m) off the shelf and slope regions, the majority of available information for and usage of the ecozone is restricted to the shelf and slope areas.

HISTORY OF USE

The earliest activity dependant on the NLSE was undoubtedly that of a subsistence nature carried out by various native North American peoples. However, this likely occurred exclusively nearshore, and most of the catch was likely Atlantic salmon, Arctic char, Atlantic cod and several types of marine mammals. Commercially, the most historic uses of the NLSE include marine fishing, hunting, and transport. In recent decades, usage of the area has diversified to include activities such as aquaculture, oil and gas exploration and production, and increased recreation and tourism.

Fishing

Areas of the NLSE have entertained commercial fisheries since the 1400s. For most of this history, fishing meant harvesting Atlantic cod (*Gadus morhua*), where records document instability and variation in stock status over the entire course of the resource's use (Rice 2002; Fig. 2). Catches increased rapidly in the last quarter of the 1500s to levels exceeding 100,000 t per annum, and remained at that level until the early 1700s when catches declined for a period of almost two decades in concert with severe cooling of the ocean (Rose 2004). A subsequent increasing trend in landings occurred which generally continued until the mid-1900s (Rose 2004). During this time, catches peaked in the mid-1960s at over 1 million t per year after the 1950s rapid expansion of distant water fleets, declined abruptly in the 1970s, and after a brief respite, declined again in the 1980s and 1990s (Rose 2004). Comparable increases and collapses were observed in other targeted and bycatch species, including haddock, American plaice, redfish and witch flounder, over similar timeframes (Rice 2002). In total, approximately 100 million t of cod have been taken from Newfoundland waters since 1500 - with approximately one-half of the 100 million t being taken between 1500 and 1900, the other half between 1900 and 1993.

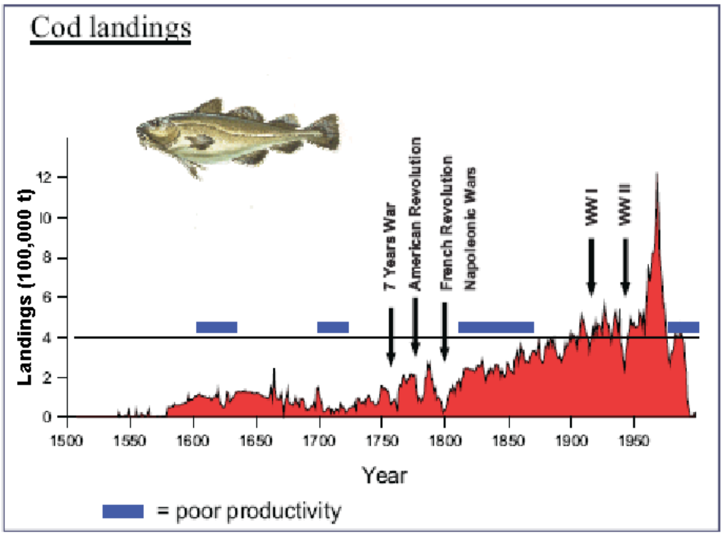


Figure 2. Newfoundland and Labrador cod landings from 1500 to 2000 (equivalent to fresh landed weights) (Taken from Rose 2004).

Hunting (Whaling and Sealing)

From the early 1500s to the early 1600s, Basques ships exploited right and bowhead whale populations of the Labrador coast (Pepper and Pepper 1995). The 1700s saw Americans targeting right whales, and the 1800s saw multiple nationalities target and catch some 225,000 sperm (and some bowhead) whales (Pepper and Pepper 1995). This wave of whaling ceased in the 1880s with the discovery of petroleum resources. Modern era commercial shore-station whaling then began around 1900 in the NLSE and peaked in 1904 at 1275 whales total – but ceased in 1916 due to the instability of local stocks (Pepper and Pepper 1995). Canada banned commercial whaling in 1972 (DFO 2004a).

Seals have been hunted by Inuit and other native peoples in Newfoundland and Labrador for at least 4,000 years. However, settlers began hunting seals commercially in the early 1700s where average reported annual catches were 27,000 for the period 1723-1803 (DFO 2007c). Commercial sealing began in the early 1800s with catches averaging 100,000 seals for the period 1804-1817 (DFO 2007), peaking in the mid-1800s at approximately 600,000 seals (Rose 2003) which accounted for about one-third of Newfoundland's exports at that time (DFO 2007c). After the Second World War, smaller ships and longliners were used in the hunt and landings ranged from 250,000 - 300,000/ year (DFO 2007c). The harvest declined until 1972 when a moratorium was imposed that lasted until the late 1990s.

Aquaculture

The first North American fish hatchery (Fig. 3) was constructed on Dildo Island in Newfoundland in 1889, and was the largest and most advanced in the world ("Aquaculture" 2008). However this operation closed in 1897 and commercial aquaculture as we know it today did not emerge in Canada until the 1970s, and in Newfoundland until the 1980s.

Figure 3. Historic Photo of Dildo Island Fish Hatchery
(http://www.baccalieutourism.com/baccalieu/dildoi.htm).

Marine Transportation

Most early settlements in Newfoundland and Labrador were along the coast and surrounded by rugged terrain. The first network of roads connecting nearby communities with the railway did not appear until the 1890s (http://www.heritage.nf.ca/society/19th_comm.html), and by 1949 there was still only 195 kilometers of paved roads in the Region. Therefore, the ocean served as the country's highway and marine transportation remained the principal means of moving people and goods in Newfoundland and Labrador throughout the 1800s and into the 1900s (http://www.heritage.nf.ca/society/post_1949_comm.html).

Marine transportation has evolved over time such that coastal transportation is now mainly for the purposes of fishing, recreation, tourism, and ferry use between the mainland and nearby small islands. However, an increase in the international transportation of goods through the offshore area and to the major ports of Newfoundland has also increased over time.

Oil and Gas

Offshore petroleum activity in NLSE did not start until 1960s, with the first exploration well being drilled in 1966 (CAPP 2009). However, the last 40 plus years have seen a significant change in activity. Fluctuating levels of exploration, development and production activity have varied in response to levels of success, changing oil prices and government support, and peaks of of seismic and drilling activity occurred during the mid-1970s, mid-1980s and late 1990s (CNLOPB 2009). Newfoundland and Labrador is now ranked the 3rd greatest oil producing province in Canada (CAPP 2009).

DESCRIPTION OF ECOZONE

ABIOTIC DRIVERS

Bathymetry

Seafloor bathymetry, along with the Earth's rotation, winds, and several other factors determine the directions of ocean currents. In turn, currents circulate in complex ways that result in highly productive, as well as unproductive, areas. Marine species in the NLSE rely on these different bathymetric features to provide suitable habitat, since about 98% of the world's marine species live in, on or just above the seafloor (MCBI 2008).

The bathymetry of the NLSE (Fig. 4) is characterized by a wide and relatively shallow continental shelf, varying in width from about 100 km off Labrador to over 600 km off the east coast of the island of Newfoundland, transected in places by deeper troughs or channels. Parts of the Grand Bank portion of the continental shelf are less than 50 m deep, while some are as deep as 400 m. Beyond the shelf edge, the ocean floor descends to depths beyond 4000 m.

Figure 4. Bathymetry of the Newfoundland and Labrador Shelf (taken from NRCAN).

Atmospheric Conditions

Changes in climate can affect the NLSE structure and function in a number of ways. Changes in atmospheric temperatures affect water temperatures; changes in precipitation and runoff from land affect the saltiness (salinity) of the water; and changes in the strength and direction of winds affects ocean currents and also the mixing of the water column. Combined, these factors indirectly affect the basic oceanography of the NLSE area.

North Atlantic Oscillation

The North Atlantic Oscillation (NAO) index is a key indicator of climate conditions in the Northwest Atlantic (Colbourne et *al.* 2009). The NAO itself is a climatic phenomenon that controls the strength of the winter westerly and northwesterly winds over the Northwest Atlantic (Rogers 1984). In most years, a high NAO index corresponds to strong northwest winds, cold air and sea surface temperatures and heavy ice conditions in the NLSE, with the inverse being true for low index years (Colbourne et *al.* 2007). By altering circulation patterns in the northwest Atlantic, the NAO can also affect bottom temperatures throughout the region - during positive NAO conditions, volume transport in the Labrador Current is increased, resulting in colder bottom temperatures and lower salinities in the shelf waters north of the tail of Newfoundland's Grand Banks (Green et *al.* 2009).

The NAO has been a dominant factor in recurrent atmospheric oscillations in the North Atlantic and the NLSE, and exhibits considerable variability at approximately biennial and decadal time scales (Parsons and Lear 2001). For example, during the 1920s and 1930s, there was a dramatic warming of the northern North Atlantic Ocean – warmer-than-normal sea temperatures, and reduced sea ice conditions continued through to the 1950s and 1960s, with the timing of the decline to subsequent cooler water temperatures varying with location (Drinkwater 2006; Fig. 5). When the NAO index increased in the 1970s it remained in a persistent positive phase for much of the 1980s and 1990s (Parsons and Lear 2001), accounting for a substantial part of the observed cooling in the northwest Atlantic (Hurrell and van Loon 1997). Also in response to the oscillations in the NAO, ocean climate conditions in the NLSE during the 1990s experienced some of the most extreme variations since measurements commenced in the mid-1940s (Colbourne 2002). Annual air temperatures increased from near record lows during the early 1990s to above normal values in 1996, and to record highs in 1999 (Drinkwater et *al.* 2000; Colbourne 2002) and again in 2006 (Wells et *al.* 2007). In 2007 and 2008 the index returned to slightly above normal, indicating cooling conditions relative to 2006 (Colbourne et al 2009).

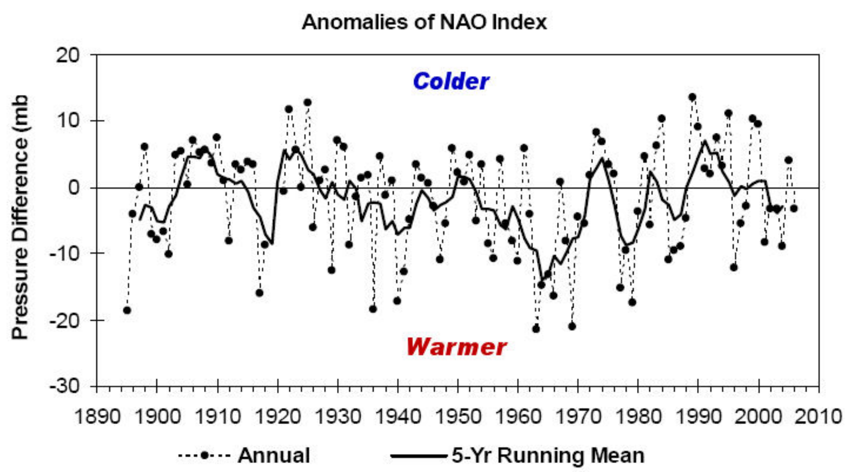


Figure 5. Anomalies of the NAO Index relative to the 1971-2000 mean (Adapted from DFO 2007d).

Variations in the NAO are related to many climatic, oceanographic and ecological features in the marine ecosystems of Newfoundland and Labrador, including iceberg flows, ocean temperatures, the strength of the Labrador Current, and the distribution and biology of many species, and provides a useful index of ocean conditions related to warm and cold periods in the North Atlantic and Newfoundland and Labrador Waters (Rose 2007).

From a summary of marine ecosystem impacts of climate variability in the North Atlantic (Parsons and Lear 2001), the NAO has been linked to:

1. The paths and intensity of Atlantic storms (Rogers 1990; Hurrell 1995b);
2. Significant wave heights (Bacon and Carter 1993);
3. Evaporation and precipitation patterns (Cayan and Reverdin 1994; Hurrell 1995a);
4. Transport of the Labrador Current (Marshall et *al.* 1997);
5. Extent of Arctic sea-ice (Fang and Wallace 1994);
6. Davis Strait ice volume (Deser and Blackmon 1993; Marko et *al.* 1994); and,
7. The iceberg flux past Newfoundland (Drinkwater 1996).

Physical Oceanography

The ocean over the NLSE continental shelf is generally cold. On an annual basis, water temperatures are 7-10°C lower than at corresponding latitudes on the west coasts of North America and Europe (www.heritage.nf.ca/environment/ocean.html). This is primarily due to the cold Labrador Current which flows southward along the east coasts of Newfoundland and Labrador. In general, water mass characteristics within the NLSE undergo seasonal modification due to corresponding seasonal cycles of heat flux, wind forced mixing, and ice formation and melting that lead to intense vertical and horizontal gradients in the water column (Colbourne et *al.* 2007).

Two of the most widely used indices of ocean climate for NLSE waters have been the annual vertically-averaged temperature, proportional to the total heat content of the water column, and summer upper-layer averaged salinity, a measure of the magnitude of the freshwater pulse from melting sea ice on the Labrador Shelf (Myers et *al.* 1990; Colbourne 2004). However, bottom temperature, more seasonally stable than vertically averaged temperature, is also an important oceanographic component to consider due to its influence on benthic fish and invertebrate communities.

Currents

The cold Labrador Current and the warm Gulf Stream (Fig. 6) are the prominent oceanographic currents in the northwest Atlantic (Petrie and Isenor 1985). However, it is the Labrador Current that dominates the oceanographic regime of the NLSE (Rose 2007).

The Labrador Current is divided into inshore and offshore branches. The offshore branch originates from the West Greenland Current, skirts the continental shelf and the Grand Banks, carries ten times more water than the inshore branch, and is saltier and warmer (Rose 2007). The colder, fresher inshore branch originates from the Canada high Arctic, receives freshwater input from rivers along its way, and hugs the northeast coast of Newfoundland and Labrador and the Avalon Channel, and turns west along the south coast of the island, penetrating Placentia Bay before entering the Gulf of St. Lawrence (Rose 2007). Overall, the Labrador Current waters are relatively fresh and do not sink deeper than 150-200m. However, since many of the banks are shallower than this, the current waters dominate from top to bottom (Rose 2007), having a significant influence on spatial distribution of fish species off Labrador and the north half of the Grand Banks due to the current-related differences in inner and outer shelf temperatures.

The Gulf Stream begins upstream of Cape Hatteras and ends in the North Atlantic, providing a major polar-ward transport of warm saline water. The exact position of the current in relation to the coast changes with seasonal effects, where it generally shifts south in the winter and spring and shifts north in the fall (Frankignoul et *al.* 2001). By the time the Gulf Stream reaches the Grand Banks it has formed a meandering front with multiple branches (Johns et *al.* 1995). Two branches occur at approximately 38°30'N 44°W (Mann 1967); one curves northward along the continental slope and turns into the North Atlantic Current, while a second branch flows southeast towards the Mid-Atlantic Ridge and becomes the Azores Current.

The westward flow of the Labrador Current around the tail of the Grand Banks is influenced by the Gulf Stream and slope waters (Colbourne et *al.* 1997). The circulation in the area where the Labrador Current and North Atlantic current meet is very complex and results in an interaction along the southeast Grand Banks that is responsible for creating unique oceanographic conditions in the area. In turn, this area supports biological communities that are more closely representative of those on the adjacent Northeast Scotian Shelf, as opposed to those on the rest of the Grand Bank.

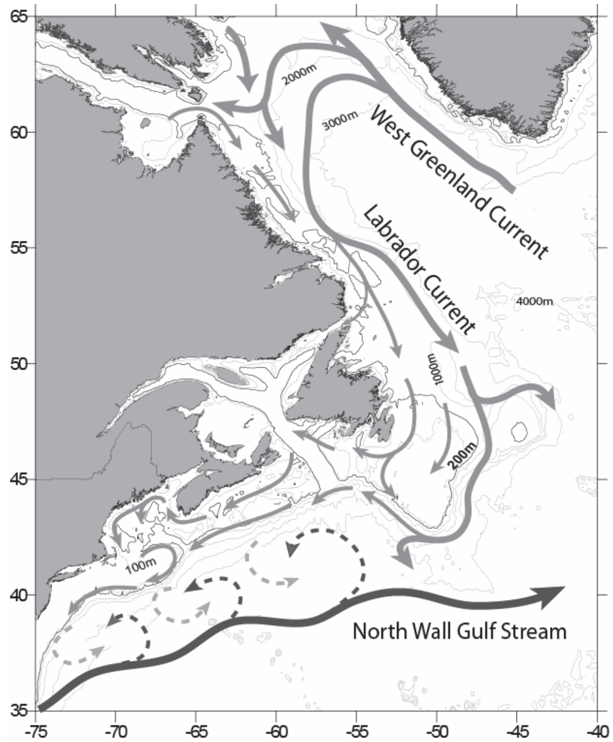


Figure 6. Surface circulation in the North Atlantic. Dark arrows indicate warmer, more saline waters from the Gulf Stream while the lighter arrows indicate cooler, less saline waters of the Labrador Current (taken from Townsend and Ellis 2006).

Water Temperature

Water temperature has a very important influence on the distribution of marine animals in the NLSE. Since species are adapted to specific temperature ranges, temperature changes are likely to have an effect on species' life histories and distribution. Biological changes might include changes to growth rates, reproduction, or biochemistry, and in turn, affect population structure, recruitment, and mortality. Distribution changes may result in the expansion or contraction of previous spatial distributions and result in new combinations of species interactions.

Changing bottom temperatures over the last 4 decades (Fig. 7) are believed to be responsible for some of the major changes in distribution and abundance of important commercial species such as cod and haddock (Scott 1982; Colbourne and Murphy 2002), among others. Similarly, shallow coastal waters can create warm and sunny places for plants and animals to grow, but temperatures can vary greatly in time and space, changing drastically between days and even short distances near the shore.

Vertically-Averaged and Bottom Temperatures

A proxy for the amount of heat within the water column, vertically averaged temperatures at Station 27 off eastern Newfoundland were above average in the 1950s and 1960s and were below normal from the mid 1980s until the mid 1990s (Colbourne et *al.* 2004; Fig. 6). Continuing the warming trend experienced since the mid to late 1990s, water temperatures in the NLSE remained above normal in most areas in 2008, but cooled compared to the 61-year high experienced in 2006 (Wells et al 2007; Colbourne et *al.* 2009).

Bottom temperatures at Station 27 (Fig. 7) during 2007-2008 were less than the year previous but remained above normal for the 13th consecutive year (Colbourne et *al.* 2009). However, during the same year, bottom temperatures varied between normal values off Labrador, below normal values in the southwestern area of St. Pierre Bank, and both above and below normal during spring and fall, respectively, on the Grand Banks (Colbourne et *al.* 2009). Notably, the area of the bottom on the Grand Banks covered by <0 ºC water during the spring decreased from near 60% in 1991 to <5% in 2004 but increased to near-normal at about 30% in 2007-08 (Colbourne et *al.* 2009).

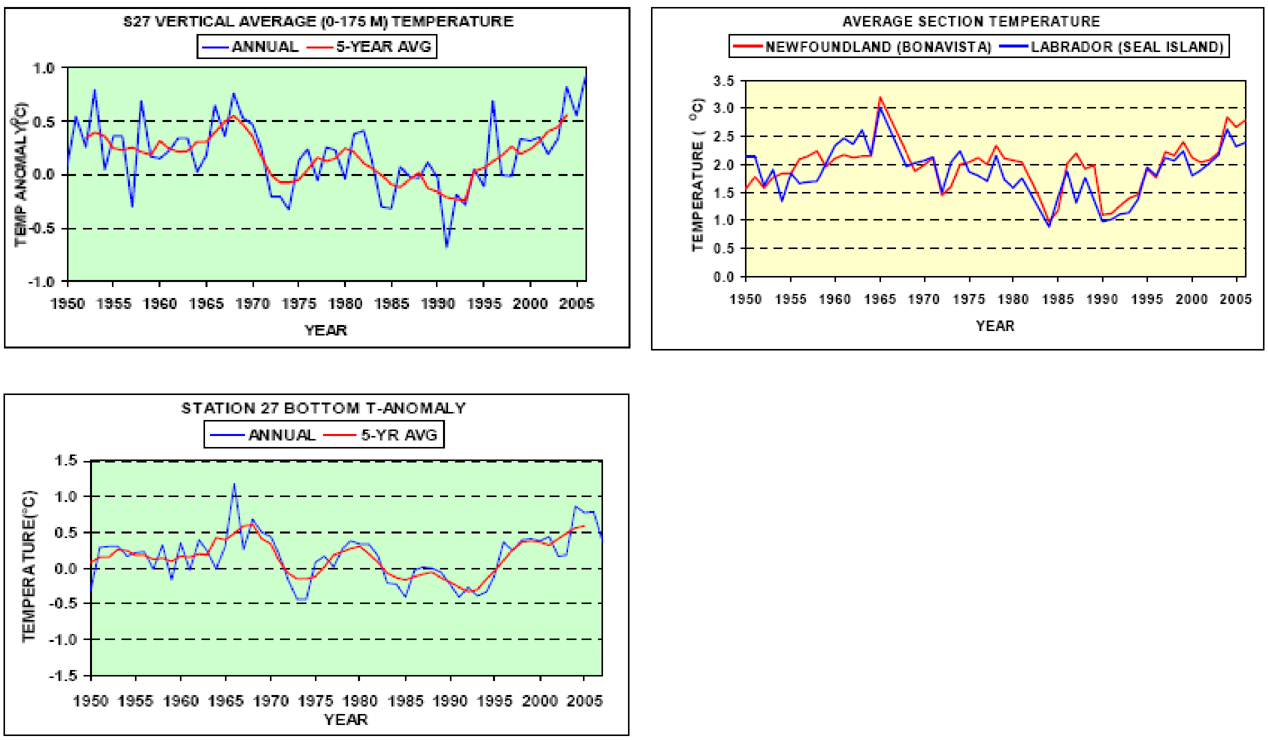


Figure 7. Time series of the vertical average temperature at Station 27, outside of St. John's, and average temperature along the Bonavista Section off eastern Newfoundland and the Seal Island Section of southern Labrador. and bottom temperature anomalies at Station 27(DFO 2007d).

Cold Intermediate Layer

A key feature of the temperature structure on the Newfoundland and Labrador Shelf, particularly during the summer, is the layer of cold <0°C water, commonly referred to as the Cold Intermediate Layer (CIL) (Fig. 8). This winter-cooled water mass remains isolated during the summer and early fall months between the seasonally heated surface layer and warmer near bottom water originating from the continental slope region (DFO 2007d) and is an important mechanism in defining the parallel benthic ecosystems represented by larger (often commercially important) species that inhabit the outer shelf and the smaller cold water species nearer the coast.

The CIL is generally regarded as a robust index of ocean climate conditions off the eastern Continental Shelf (Colbourne et *al.* 2007). Low CIL areas correspond to warm oceanographic conditions (DFO 2007d) while the inverse is true for high CIL areas. While the cross sectional area of the CIL water mass undergoes significant annual variability, the changes are highly coherent from the Labrador Shelf to the Grand Banks (Colbourne et *al.* 2009), In 2006, the CIL area was below the long-term mean along all sections sampled from Labrador to southern Newfoundland. Notably, the CIL along the Bonavista section during this time was below normal for the 12th consecutive year ranking 3rd lowest in 58 years of observations (DFO 2007d).

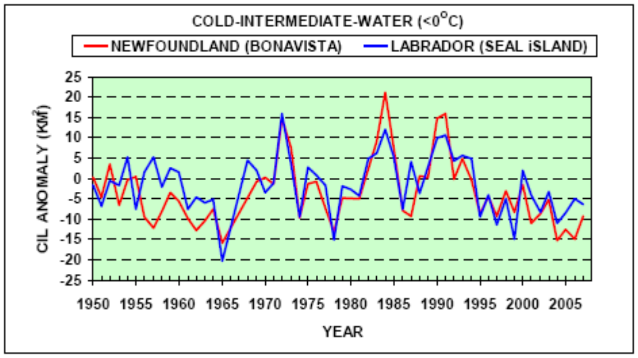


Figure 8. Time series of Cold Intermediate Layer (CIL) area anomalies based on summer surveys across the Bonavista (Newfoundland) and Seal Island (Labrador) oceanographic sections. Low CIL areas correspond to warm oceanographic conditions (DFO 2008d).

<u>Salinity</u>

Due to seasonal ice melting, there is a large and variable flux of freshwater through the region, with the annual surface salinity (Fig. 9) minimum in the south occurring in late summer. Generally, coastal waters are less saline than bank waters which are less saline than slope and deep waters.

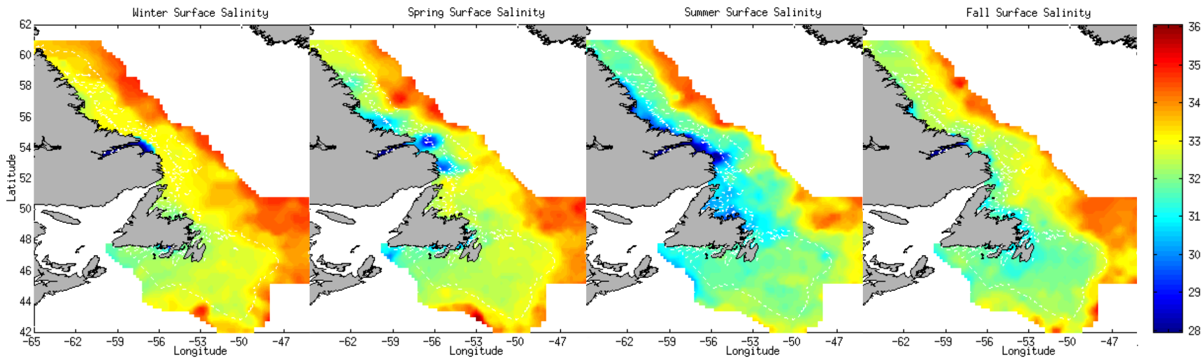


Figure 9. Seasonal salinity across the NLSE (http://www.mar.dfo-mpo.gc.ca/science/ocean/nfld/nfld_hydro.html).

Over the last several decades, cold ocean temperatures and fresher waters have been associated with strong positive NAO anomalies, colder winter air temperatures, and heavy ice conditions (Colbourne et *al.* 2007). Salinities on the Newfoundland and Labrador Shelf, as taken from Station 27 (Fig. 9), which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal since that time (Colbourne et *al.* 2009).

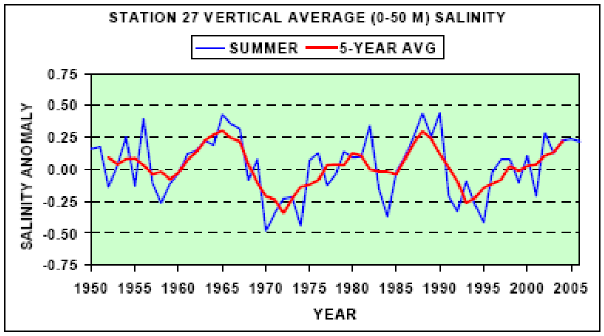


Figure 10. Time series of vertical average (0-50 m) salinity at Station 27 in the NLSE (DFO 2008d).

<u>Sea Ice</u>

The water of the Labrador Current is less saline (salty) than that of the main North Atlantic Ocean and therefore freezes more easily. By the end of the average winter coastal Labrador inlets and the northern bays of the island are frozen. Beyond this land-fast ice, Arctic and sub-Arctic floes (pack ice and icebergs) are carried by the current as far south as the Grand Bank (http://www.heritage.nf.ca/environment/ocean.html). During spring and summer the ice pack retreats northward and by the end of July all coastal waters are normally ice-free. (http://www.heritage.nf.ca/environment/ocean.html).

Fast ice, formed by low temperatures and still waters, is frozen to the shore at high water level and rises and falls with the tides. This ice has little detrimental effect on flora and fauna, and can actually serve the protective function of shielding organisms from the low winter air temperatures and protecting from loose pieces of ice (Steele 1983).

Pack ice or sea ice is important to the local climate and ocean ecosystem: it limits heat transfer between the atmosphere and the ocean, protects the waters from wind, can influence plankton and fish distributions, and provides seasonal breeding habitat for hooded and harp seals (Rose 2007). However, when loose along the coastline, this ice can cause considerable, but quite variable degrees of abrasion of the shore fauna as the pieces of ice are hurled at the shore by waves (Steele 1983). In addition, this loose ice may serve as a nucleus for the freezing of supercooled fish that overwinter in some of the bays (Templeman 1965)

Icebergs, mostly calved from Greenland glaciers, drift with the surface circulation (i.e., the Labrador Current) along the edge of the banks, often reaching the northern Grand Banks, but sometimes drifting further south. The number of icebergs passing Newfoundland varies annually and depends on the number calved, air temperatures, pack ice conditions, and prevailing winds (Steele 1983).

Compared to long-term averages, sea ice coverage was more extensive, arrived earlier, and stayed longer in the early 1970s, mid-1980s, and early 1990s (Drinkwater 1994). In some years during these cold periods, over 1500 icebergs were observed south of 48°N with an all time record of 2,202 in 1984 (Colbourne et *al.* 2009).

Winter sea-ice extent and duration on the Newfoundland and Labrador Shelf (Fig. 11) remained below average for the 14th consecutive year in 2008, but was up slightly from the lowest extent of sea-ice observed since records began in 1963 occurring in 2006 (Wells et *al.* 2007; Colbourne et *al.* 2009). Compared with the 106-year average of 477, 976 icebergs drifted south of 48°N onto the Northern Grand Bank, up from 324 in 2007 and 0 in 2006 – the only other year besides 1966 with no icebergs sighted in the time series (Petrie et *al.* 2007; Colbourne et *al.* 2009).

Ice cover provides an index that can be related to the initiation and maintenance of the spring phytoplankton bloom. In addition, ice cover and ice thickness (ice volume) can distinguish winters with above or below normal heat losses (Petrie et *al.* 2007).

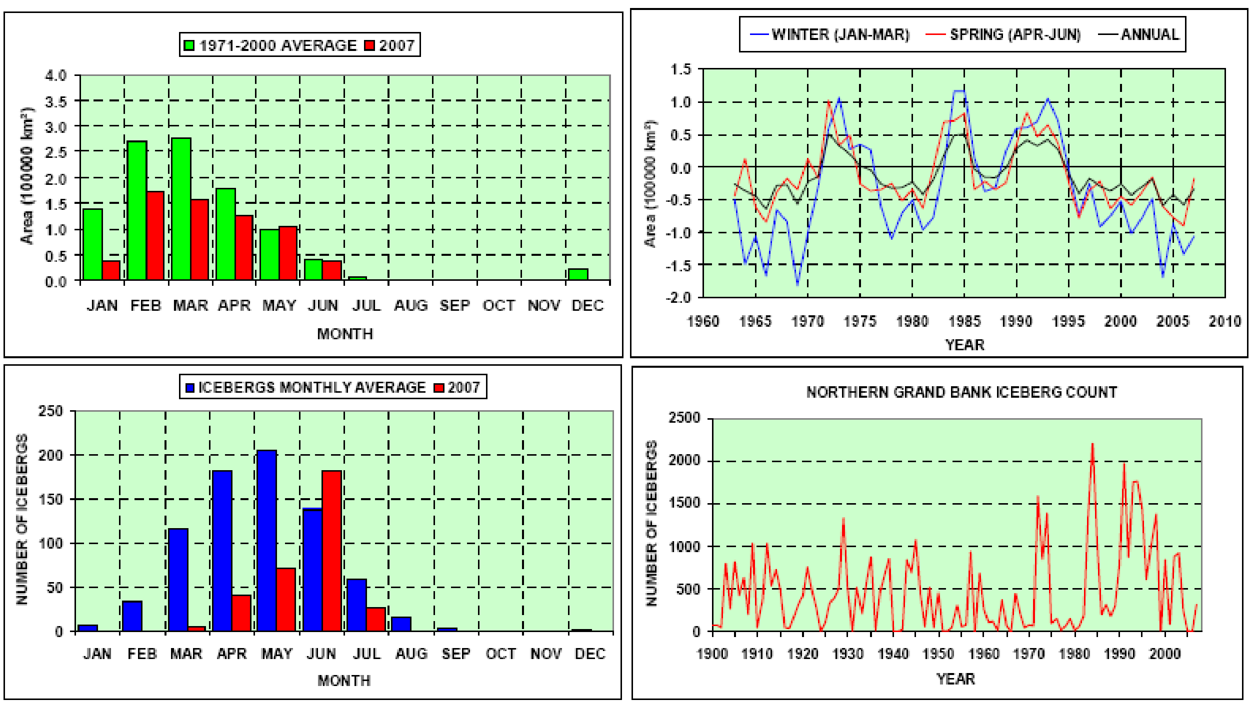


Figure 11. Monthly and seasonal (winter and spring) sea-ice extent off Newfoundland and southern Labrador (top panels) and monthly and annual iceberg counts for the northern Grand Banks (bottom panels). No icebergs were detected in 2006. (DFO 2008d).

<u>Sea level and Tides</u>

Long-term modification of sea-level is due to factors such as climate change, glaciation, and alteration in the shape of ocean basins, while short term variability is due to factors such as wind effects, tidal oscillations, geostrophic adjustments, and wind waves. Seasonal effects are also observed and are largely due to freshwater runoff and changes in temperature and salinity profiles (Cazenave and Nerem 2004; Ross 1977). Mean sea level (MSL), when all motions such reported at St. John's harbor over the last 50 years shows an average trend of increasing MSL at ~2.5 mm.year^{-1}. This increase is in agreement with the rest of eastern Canada and is attributed to tectonic motions (land subsidence) (Hilmi et *al.* 2002).

Tides are periodic short-term changes in the sea surface height that are caused by a combination of gravitational forces of the moon and sun as well as the rotation of the Earth. The region of the Atlantic surrounding this area is characterized mainly by a semidiurnal tidal (two high and two low) cycle. Tidal ranges on Newfoundland and Labrador coasts are fairly small (0.8 to 1.6 m) but consistent. Tides provide much of the energy for the mixing that takes place in coastal bays and estuaries and therefore affects the ecology of many species in those areas.

SPECIES COMPOSITION

Species composition in the NLSE has changed dramatically over the last 30 years (e.g. Lilly 1994; Carscadden and Nakashima 1997; Lilly et *al.* 2000 DFO 2006). Direct evidence of the large compositional change in the biological community and the decadal diet shifts observed in some species suggests that the fluxes of energy/biomass between components in the food web of the NLSE have also changed over time. The reasons for these changes are still under debate, but overfishing, climate changes and trophodynamics are some of the hypotheses used to explain them. Likely, the scenario involves some combination of all these driving forces.

Species Diversity

Species diversity is generally interpreted over broad areas, such as eco-regions, but may vary spatially over time at much smaller scales. The biological environment of the NLSE is as diverse as is its physical environment in many respects. For example, within the area of the NLSE, species that prefer cooler waters, such as Arctic cod, alligator fish, and shannies are often found off Labrador and the northeastern Newfoundland, while more temperate water species such as yellowtail flounder and sandlance are found in the more southerly areas of the Grand Banks. However, the northern portion of the Grand Bank is recognized as a region of mixing between cold water and temperate communities, and the system as a whole shares many species including key trophic and commercially important species such as Atlantic cod, capelin, Greenland Halibut and American plaice.

When comparing research vessel (RV) survey data for the time periods 1978-84 and 1990-95 for the Newfoundland and Labrador Region spatial patterns, including that for richness, were also highly variable across the different sub-areas (DFO 2007a).

Species and Trends

Large-scale changes in species composition and abundance in the NLSE over the last 30 years have involved, among others, the collapse of major commercial fish stocks such as cod, redfish, witch flounder and American plaice, and the dramatic increase of some shellfish species such as northern shrimp and snow crab (Lilly et *al.* 2000, DFO 2006). The period from 1985-95 saw a large reduction in overall fish biomass and abundance, and a lack of significant recovery since that time – this occurred not only in commercial species, but also in non-target species (DFO 2006).

Plankton

The distribution of plankton (bacterioplankton, phytoplankton, transitional plankton and zooplankton) is largely a function of major circulation patterns in the NLSE environment. Variations in temperature, nutrient concentrations, turbidity, and light penetration also have major direct and indirect impacts on both phytoplankton and zooplankton populations.

Bacterioplankton

Bacterioplankton play a vital role in regenerating nutrients from decomposing organic matter and are found at all latitudes and at every depth within the ocean. However, they are usually found at high numbers in coastal euphotic zones and at very low concentrations in deeper offshore water masses. Little is known about the dynamics of these bacteria in the North Atlantic.

Phytoplankton

Phytoplankton are represented by a wide variety of taxa in the NLSE and are present throughout the photic zone; including under sea ice. However, diatoms and dinoflagellates are the most dominant phytoplankton at high latitudes, including the NLSE.

The average decadal phytoplankton colour index (PCI) has increased over the available time series since 1961 (Pepin et al. 2008). At the same time, the abundance of dinoflagellates has increased during the available time series while diatoms, which typically dominate the spring phytoplankton bloom in the NLSE, have increased but to a lesser degree than dinoflagellates (Pepin et al. 2008). In recent years, the relative abundance of CPR phytoplankton taxa has remained relatively stable (Pepin et al. 2008).

Harmful Algal Blooms

Particularly important to areas where shellfish are harvested and consumed by humans (mainly coastal areas) are those phytoplankton which form harmful algal blooms (HABs). Evidence exists for the increase and spreading of HABs globally, and it is suggested this increase may be attributed to the dispersal of harmful species by currents and storms, anthropogenic nutrient enrichment of waters, climate shifts, and ballast water discharge by ships. However, a significant increase in HABs has not been observed in the NLSE, likely due to the fact that the causative organisms are currently near their northern tolerance limit. Still, should water temperatures continue to increase, yearly blooms that are experienced in the Maritimes, particularly for *Alexandrium fundyense* (PSP (paralytic shellfish poisoning) causing) and *Pseudo-nitzschia* (ASP (amnesic shellfish poisoning) causing), have increased potential to occur within the NLSE.

Zooplankton

Nearly 160 species of zooplankton have been identified on the Grand Banks in the NLSE, although such estimates are probably much lower than the total species assemblage present in the region (Movchan 1963; Buchanan and Foy 1980; Tremblay and Anderson 1984).

Zooplankton abundance in the NLSE shows a distinct seasonal cycle, with a gradual increase throughout the year until late fall with there is a substantial decrease following a reduction in phytoplankton production (DFO 2008c). Spatially, most small species occur closer to shore and on the Southeast Shoal (Southeastern Grand Banks), and larger species are distributed further offshore across the Newfoundland Shelf (DFO 2008c). Variations in ocean circulation are hypothesized to influence the distribution and recruitment of these zooplankton populations in the region (Maillet and Colbourne 2007). Aside from spatial and temporal variations, copepods are the dominant zooplankton in the NLSE and consititute a very important part of the food web in the region. Species of small copepods (*Pseudocalanus* spp., *Oithona* spp., *Centropages* spp., *Acartia* spp.) dominate in the spring and fall, while larger species of the genus *Calanus* reach similar levels of numerical abundance by early to mid-summer (DFO 2008c; Pepin et *al.* 2008; e.g., Fig 12).

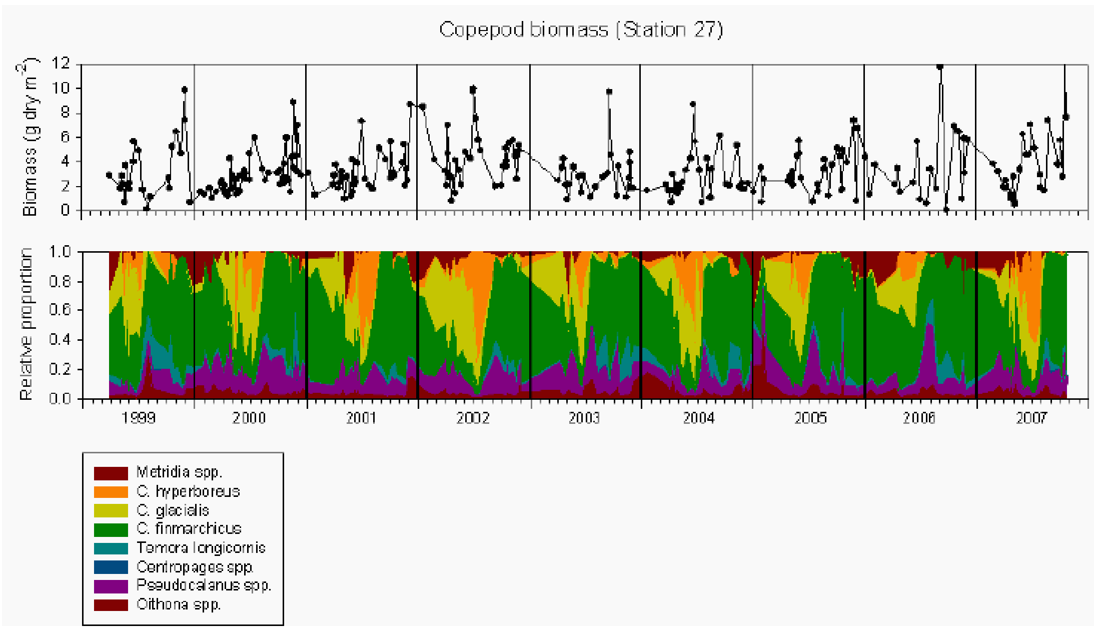


Figure 12. Seasonal cycle of total biomass and species distribution of the dominant copepods at Station 27 for the period 1999- 2007. The vertical order of the species in the lower panel is the same as in the legend (Pepin et al. 2008).

In 2007, the overall abundance of zooplankton at Station 27 was above the long term average in 10 of the 16 dominant species groups – the second highest biomass of zooplankton recorded since the start of monitoring activities (DFO 2008c). However, there exists substantial interannual variation in the abundance of zooplankton in the NLSE (Pepin et *al.* 2008).

Ichthyoplankton

Ichthyoplankton include the larvae of marine worms, molluscs, crustaceans and fish. During this phase, individuals are extremely vulnerable to starvation, predation and unfavourable transport, and it has long been realized that the larval phase may have a potentially disproportionate influence on the local abundance of adult populations (Heath 1992).

At least 45 species of fish have been identified as early life stages in the ichthyoplankton of the Grand Banks and inshore waters of Newfoundland, with the most frequently reported being: Atlantic herring, capelin, Atlantic cod, sand lance, redfish, seasnail, witch flounder, American plaice, and yellowtail flounder (Petro-Canada 1996).

Ichthyoplankton abundance has two peaks: the first in April and May which is dominated by sand lance on the Continental Shelf and redfish on the slopes and in the deep water off the slope; the second in August primarily in waters close to shore which is dominated by capelin, cod and flatfish larvae (Petro-Canada 1996). Eggs are found predominantly in the surface waters, but plaice, cod, redfish and witch flounder larvae are more concentrated in depth-integrated samples, and capelin and sand lance larvae are consistent through surface and depth samples (Petro-Canada 1996).

The concentration of fish eggs and larvae in the water column is subject to considerable interannual variability and may be affected by variables such as parent stock size, environmental factors at the time of spawning, strength and direction of currents, water temperature and salinity and abundance of prey and predators.

Benthic Communities

Benthic plants and invertebrates live on top of sediments, rocks, logs or plants (epibenthos) or live in the sediments (infauna). Benthic community structure is related to temperature, water depth, food supply, predation, and natural and anthropogenic disturbances.

Microalgae (Epiphytes)

Epiphytes, small algae that grow on the surface of other marine plants, are most common along the coastlines and are often driven by the addition of nitrogen to coastal water bodies. These algae may interfere with the sunlight necessary for plants, including eelgrass, to photosynthesize and therefore, have been linked to the decline and loss of eelgrass beds during periods of excess growth.

Macrophytes

Macrophytes have been well studied but there is no recent update on their species diversity in the NLSE as a whole. In the 1960s, it was determined that 720 varieties (species and sub-species) existed on the Atlantic coast of Canada (Cardinal 1968). The dominant macrophytes of the NLSE (Table 1) shoreline are the large brown seaweeds (especially the bladder, forked and knotted wracks, and winged and sugar kelps), although there are also a number of red and green seaweeds present (Newfoundland and Labrador Heritage website 1997).

Table 1. Macrophytes occurrence within the NLSE

Seaweed	**Location**	**Example(s)**
Brown algae	Mainly intertidal and immediate subtidal zones of hard-bottom shores (areas of high activity)	Rockweeds; kelps
Red algae	Mainly intertidal zones and below the low-water mark on rocky shores; deepest occurring macrophyte (up to 100m)	Coralline algae
Green algae	Higher intertidal levels, or subtidally in shallow water (in light)	Sea lettuce

Eelgrass (*Zostera marina L.*) is a vascular marine macrophyte found rooted in sandy or muddy substrates along the coastline. The presence or absence of eelgrass seems to follow a narrow range of conditions, where temperature, salinity, currents, nutrients, and bioturbation rates must be optimal for successful habitation (Vandermeulen 2005). Distribution of eelgrass in the NLSE (e.g., Fig. 13) is constrained by coastal features and the extent of ice scour – occurring around the entire island of Newfoundland with the greatest abundance on the southwest coast; and identified as far north as Nain (Labrador) with extensive distributions in Lake Melville (DFO 2009c).

Eelgrass meadows have extremely high levels of primary production, ranking among the most productive ecosystems on the planet (DFO 2009c), and can form extensive subtidal, perennial beds of important nearshore habitat for juvenile (and adult) invertebrates and fish, and provides cover from predators. By being sufficiently abundant and widely distributed, eelgrass often constitutes a dominant habitat feature and has a measurable influence on the overall ecology of adjacent terrestrial and marine ecosystems, and as such, eelgrass in eastern Canada has recently met the criteria of an Ecologically Significant Species (DFO 2009c). While eelgrass is dying off along many Atlantic coasts, in Newfoundland, there appears to be a general increase in eelgrass abundance in the last decade based on local knowledge – possibly due to improved conditions (milder temperatures, more favorable sea ice conditions) (DFO 2009c).

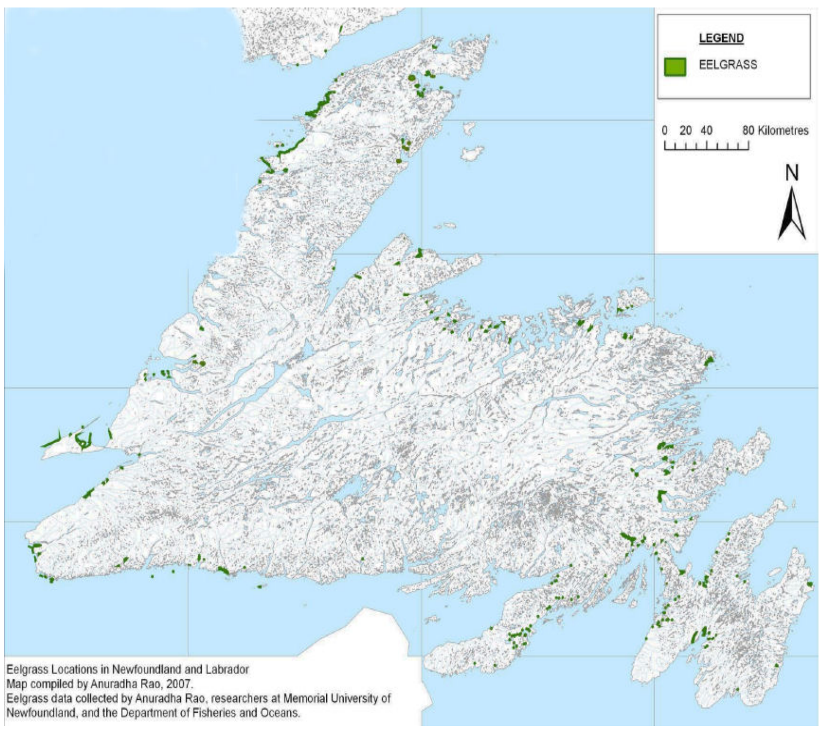


Figure 13. Map of eelgrass locations (green) in Newfoundlaknd and Labrador – map by Anuradha Rao (2007) (modified from Environment Canada 2009).

Infauna

Infaunal animals that live in, on, or attached to the sea bottom and occur in both inshore and offshore areas, and include filter feeding animals (such as bivalves) that feed directly on plankton, detritovores (such as marine worms) which feed on the bacteria associated with detritus, and carnivores which feed on other benthic animals. In Newfoundland and Labrador waters, while many benthic invertebrates have been examined specifically, especially in response to commercial and economic requirements, their broader spatial-temporal patterns in the regions have not (Gilkinson 1986). However, samples from a 3-year otter trawling experiment on a sandy bottom ecosystem on the Grand Banks of Newfoundland from 1993 to 1995 contained 246 taxa, primarily polychaetes, crustaceans, echinoderms, and molluscs.

Biomass was dominated by the propeller clams and sand dollars, while abundance was dominated by the polychaete, *Prionospio steenstrupi* and the mollusc, *Macoma calcarea* (Kenchington et *al.* 2001).

Deep-water Corals

Deep-water coral species have been shown to occur in eastern Canada on the continental slope, in submarine canyons, and in channels between offshore banks (e.g. Verrill 1922; Deichman 1936; Breeze et *al.* 1997; MacIssac et *al.* 2001; Mortensen et *al.* 2002; Edinger et *al.* 2007). Within these areas they are locally abundant on hard substratum including cobbles and large boulders and in high current areas (Tendal 1992). In the NLSE there are at least 35 species from 4 Orders (Pennatulacea, Scleractinia, Alcyonacea, Antipatharia) (Vonda Wareham, pers comm.).

Corals have been found to be distributed fairly regularly along the shelf edge and slope in most of the ecozone, especially along the Grand Banks. Within the NLSE, coral hotspots have been identified from bycatch and scientific surveys to occur near Funk Island Spur, the Southwest Grand Banks, and the southeast portion of the Southeast Baffin Shelf (Edinger et *al.* 2007; Figure 14).

Deep-sea corals are important components of benthic habitats and contribute to structure and species diversity. They provide shelter and rest areas for other smaller species, forage and nursery areas for young, and act as barriers between predators and prey. Due to their attachment to the substrate and to low growth rates, anthropogenic impacts to corals include immediate physical damage with subsequent slow recovery rates, as well as the potential for alterations in associated benthic and fish communities. It can be expected that our understanding of these species and their inter-relationships with other species in deep-sea eco systems will increase substantially in the near future through expanding research in the area of ecology of deep-sea corals in Newfoundland and Labrador waters, including research in the areas of coral biogeography, life history, biogeochemistry, and their role as critical habitat.

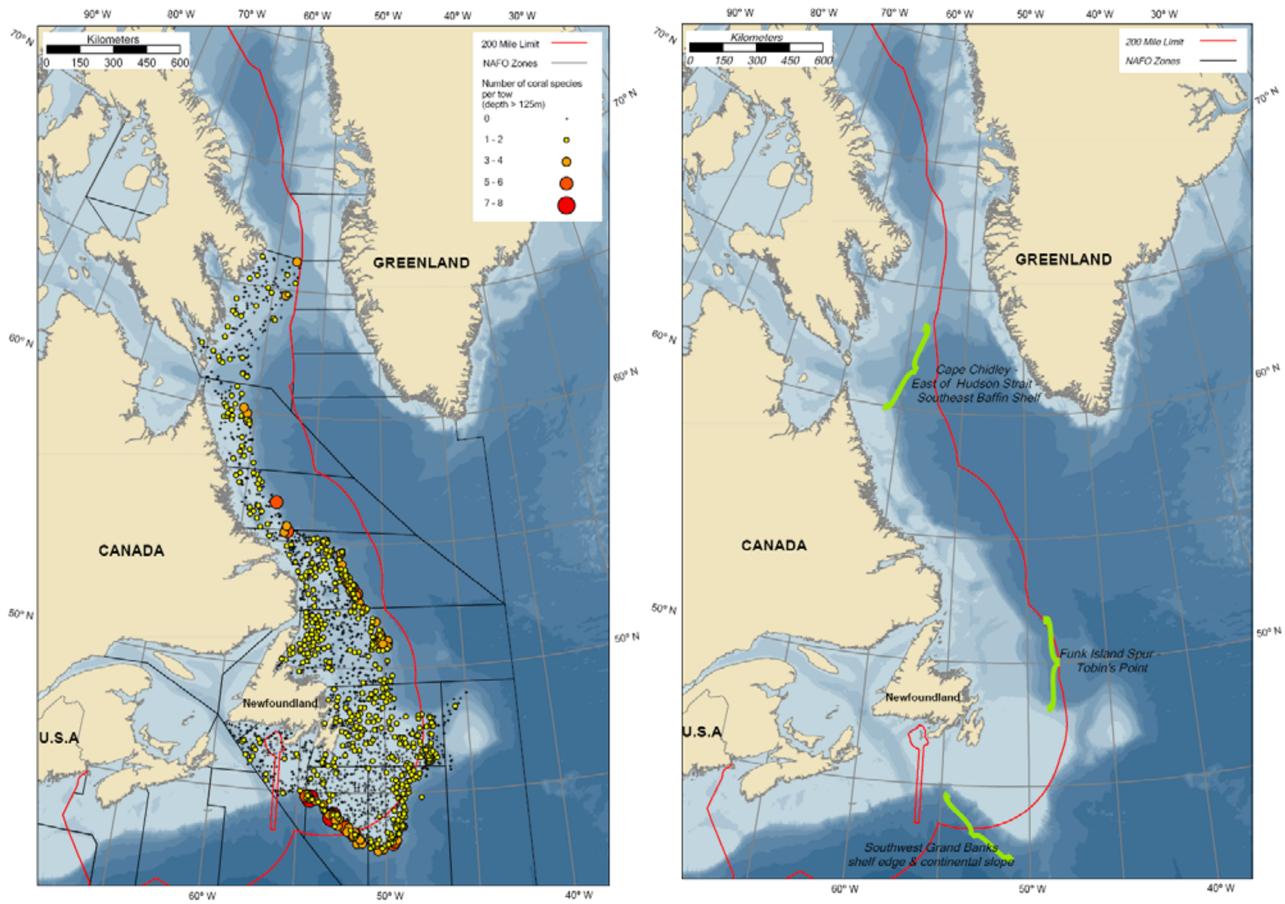


Figure 14. Coral species richness (left) and 'hotspots' within the NLSE (taken from Edinger et al. 2007).

<u>Shellfish</u>

In parallel with the last collapse of groundfish stocks, some shellfish populations, such as northern shrimp and snow crab, have increased within the NLSE. This increase has been linked to large scale environmental forcing (e.g. Parsons and Colbourne 2000; Colbourne 2000; Koeller 2000). However, there is still a question as to what extent the groundfish collapse and subsequent reduction in predation may have contributed to the increase in these species in the area (Lilly et *al.* 2000).

Lobster

American lobster, *Homarus americanus,* in the NLSE occupies nearshore rocky bottoms around the island of Newfoundland and along the Strait of Belle Isle portion of Labrador's south coast. A long-term downward trend in lobster landings reversed unexpectedly in many areas during the 1970s, likely due to a widespread period of strong recruitment associated with favourable environmental/ecological factors, and persisted in some areas through the 1980s, partially due to increases in effort. Landings, summed over the whole island, have remained relatively constant for more than 50 years, with relative variability in individual fishing areas being considerably greater (DFO 2009a; Fig. 15). However, "A Conservation Framework for Atlantic Lobster" pegged lobster egg production in the 1990s at 1-2% of what would be expected in an unfished population (FRCC 1995).

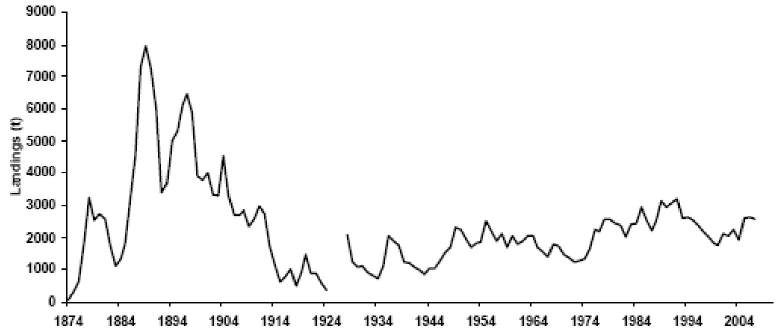


Figure 15. Historical landings for the Newfoundland lobster fishery. Value for 2007 is preliminary (DFO 2009a).

Crab

Snow crab (*Chionoecetes opilio*) distribution in the NLSE is contiguous over a broad depth range. During the 1990s there was a dramatic increase in the abundance of the crab within the NLSE, and the fishery for the crab expanded. Scientific surveys indicate that the overall exploitable biomass in the NLSE declined from the late 1990's to 2003, but has since increased (DFO 2009b).

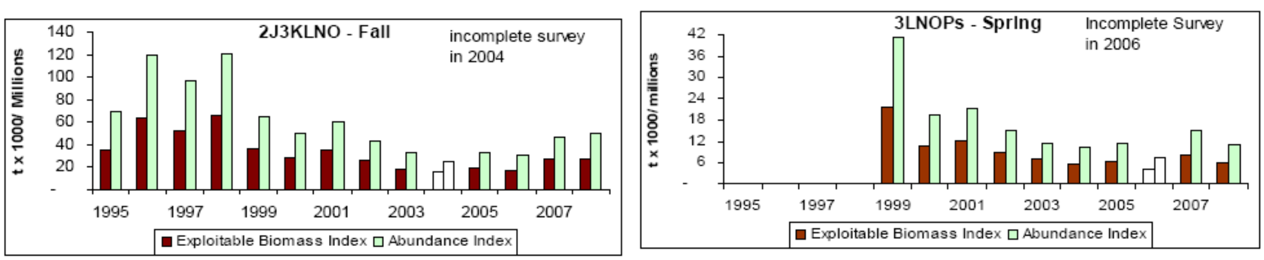


Figure 16. Trends in the multi-species survey exploitable biomass and abundance indices, for Div. 2J3KLNO during fall (above) and for Div. 3LNOPs during spring (below) (DFO 2009b).

Shrimp

More than 30 shrimp species are found off Newfoundland and Labrador, but Northern shrimp (*Pandalus borealis*) is the most commercially important species in terms of biomass. Northern shrimp are distributed mainly along shelf edges throughout the NLSE and undergo large vertical migrations from near the substrate during the day to the pelagic zone to feed on zooplankton during the night (Orr et *al.* 2003).

Despite a life history (slow growth and living up to 8 years) that suggests relatively low population growth, northern shrimp landings have increased through the 1990s in concurrence with the decline of groundfish stocks, and survey abundances in the region are near all-time highs (DFO 2008b; Orr et *al.* 2004; Fig. 17).

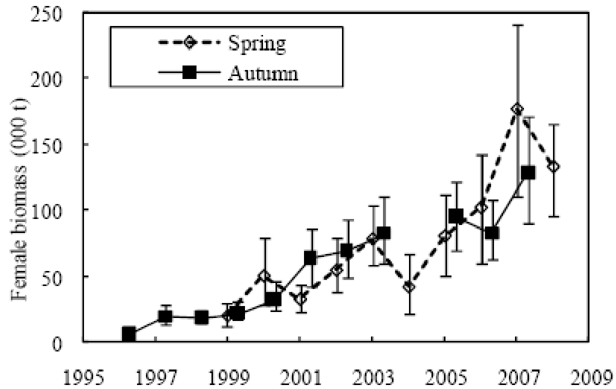


Figure 17. Female shrimp biomass indices for the Newfoundland Shelf (Divs 3LNO) from Canadian spring and fall surveys from 1996-2008 (NAFO 2008).

Fish

The North Atlantic has fewer species of fish than most other major marine and freshwater ecosystems. While the North Pacific has 482 known species of fishes, the North Atlantic has only 318 species of fishes, and Newfoundland and Labrador waters have been generously estimated to house only 188 inhabitant and migrant marine fish species (Rose 2007). However, this number could be somewhat higher if all slope and vagrant species could be accounted for. Still, although the number of species in the system may be fewer, these species can achieve great abundance due to the comparative productivity of shelf ecosystems (Rose 2007).

During the late 1980s and early 1990s much of the fish community in the NLSE collapsed. This collapse was more dramatic in the northern regions and involved commercial and non-commercial species (DFO 2009d). Since 2002-03 there has been an increasing trend in the fish biomass in 2J3K and 3LNO, and some components of the fish community (e.g. piscivores such as Atlantic cod, turbot, and Atlantic halibut) and large benthivores (e.g. American plaice) appear to be showing some positive signals, but still remain at a significantly lower biomass levels in comparison to the pre-collapse period (DFO 2009d). These are the first significant changes observed in ecosystem structure since the collapse (DFO 2009d).

Demersal (Ground) fish

Demersal fishes spend much of their life near the ocean bottom. Many medium to large commercial and non-commercial demersal species in the NLSE, including Atlantic Cod, American plaice, Greenland halibut, grenadiers, and wolffishes, among others, declined in the mid 1980s to reach very low levels by the mid 1990s. As with Atlantic cod, most of these stocks have shown little indication of recovery since then.

During the time of demersal species decline, cold water temperatures coincided with high fishing pressures. While most demersal fish were declining, some other demersal cold water species, including the northern alligator fish and arctic cod, increased in the NLSE, often exhibiting southern expansions of their distributional ranges. These same species then began to decline during the warming period that started in the mid 1990s.

American Plaice

American plaice (*Hippoglossoides platessoides*) are probably the most abundant flatfish in the Northwest Atlantic, and are fairly contiguous through the NLSE, although greatest concentrations occur on the Grand Banks (DFO 2008e).

There has been a reduction in numbers, size and age of maturity of American plaice landed since the 1980s within the NLSE, and biomass remains low compared to historic levels. Notably, while there has been a moratorium on fishing American plaice since 1995, bycatch of American Plaice from the yellowtail flounder fishery still exists. However, Kulka (2009) found that even though plaice (and cod) distributions overlap on the Grand Bank to a considerable degree, a spatio-temporal management strategy, namely a strategic shift of effort, could result in a reduction in bycatch of plaice (and cod) without a significant impact on yellowtail catch rates.

Canadian and Spanish surveys have indicated that population abundance and biomass of American Plaice in the NLSE declined fairly steadily from the mid 1970's but have been slowly increasing since the moratorium in 1994 (Dwyer et *al.* 2009; Fig. 18). In general, there has been an increase in biomass in Divs. 3NO since the mid-1990s where abundance may be at or near levels of the late 1980s-early 1990s, while the area having shown the largest decrease in biomass and abundance over time, Div. 3L, has been stable since the mid-1990s (Dwyer et *al.* 2009).

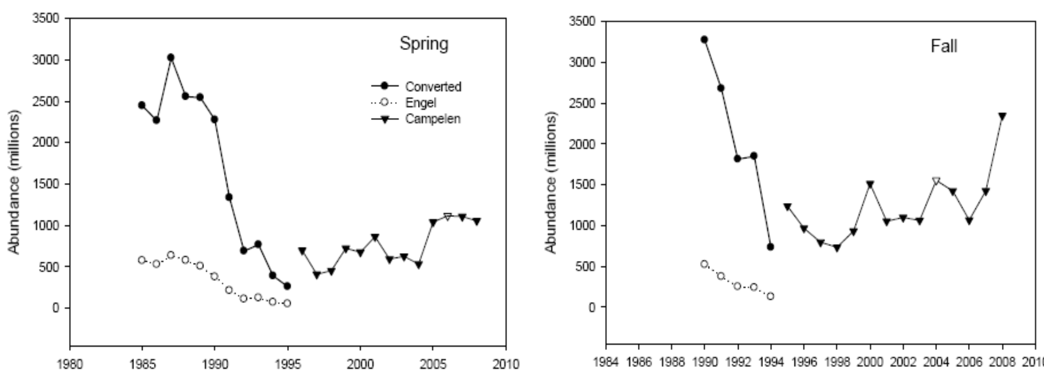


Figure 18. Abundance (millions) of American plaice from spring and fall Canadian surveys in Div. 3LNO (Grand Bank) combined. Open symbol represents years when survey coverage was poor (Dwyer et al. 2009).

Atlantic Cod

There are three main Atlantic cod stocks in the NLSE waters – "Northern" cod, "Grand Banks" cod, and "South Coast" cod – generally distinguishable environmentally and by NAFO area. A fourth stock, the "Northern Gulf" cod also overwinter in a small area along the south. Generally, Atlantic cod occur contiguously in the Northwest Atlantic and the NLSE in both offshore and coastal areas, and historically, many cod overwintered in deep water (300-500 m) on the outer slopes of the shelf and migrated during spring-autumn to feeding areas near the coast or on the plateau of Grand Bank (Scott and Scott 1988).

The relationship between offshore and inshore 'bay' stocks is debatable, but it has been hypothesized that such populations are functionally distinct from one another through the use of unique nursery habitats (Laurel et al. 2003), limited egg/larval dispersal (Bradbury et al. 2001) and multi-year homing to the same spawning grounds (Robichaud and Rose 2001), and historically, these bay populations of cod were likely small relative to offshore stocks. However, recent offshore tagging of Northern cod has indicated that a substantial portion of cod from the offshore aggregation migrated to the inshore of 3KL during the summer, and that some of theses fish were caught during inshore fisheries (DFO 2009f). Since exploitation of these offshore cod in the inshore was estimated at 6%, this new evidence of inshore migration indicates that the moratorium in the offshore is no longer sufficient to protect the offshore stock until recovery is well established (DFO 2009f).

All cod stocks in the NLSE declined significantly in the late 1980s and early 1990s, although to varying extents. Similarly, trends in abundance, biomass and condition are variable across stock and area (inshore vs. offshore). However, current biomass of all offshore stocks remains extremely low compared to historical means. In contrast, some populations in inshore waters appear to have fared better where there is a good representation of larger and older individuals, and densities are high in some times and places (e.g., DFO 2009f).

South coast cod generally grow faster than those from areas further northward and rebuilt relatively quickly in the 1990s compared to other areas. However, cod in this area have been in decline since 2001, with 2008 biomass estimated less than 50% of the average for 1997-2008 (DFO 2009f; Fig. 19). Spawning stock biomass is also near the lowest levels observed (DFO 2009d). While there is no clear trend in recent condition, values remains lower compared to those in the 1980s when the stock was considered more productive (DFO 2009d).

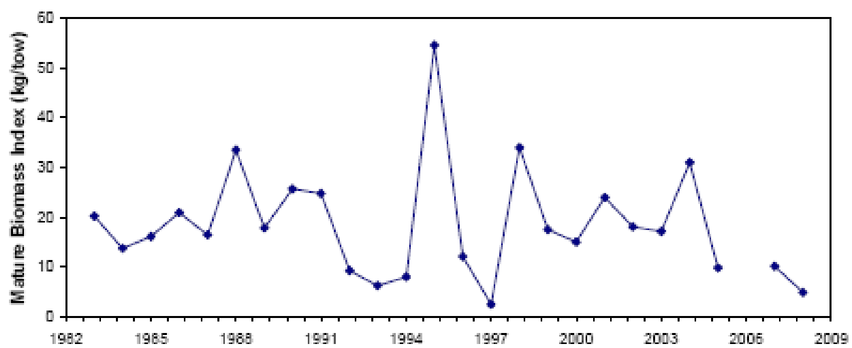


Figure 19. Mature south coast cod biomass index from offshore DFO RV surveys (DFO 2009d)

Northern cod biomass of ages 3+, about 3 million t in the early 1960s, collapsed to about 0.5 million t by the late 1970s after the introduction of foreign fleets to harvesting, but recovered slightly in the mid-1980s after the extension of jurisdiction in 1977 (DFO 2009f). However, the stock declined again during the late 1980s and collapsed to extremely low levels by the early to mid-1990s, after which a moratorium on directed commercial fishing was declared in 1992. Recent trends in Northern cod offshore abundance and biomass have been positive since 2003 and spawning stock biomass (SSB) has been increasing since 2005 (DFO 2009f; Fig. 20). Similarly, condition has shown some positive trends from the 1990s and 2000s (DFO 2009f). However, current autumn offshore abundance and biomass is concentrated (50% and 75%) adjacent to the 3K/3L boundary (14% of the survey area), compared to 20% abundance and biomass in the same area in the 1980s; and current average abundance, biomass, and SSB of offshore cod over the last 3 years are still only 8% of the average during the 1980's (DFO 2009f).

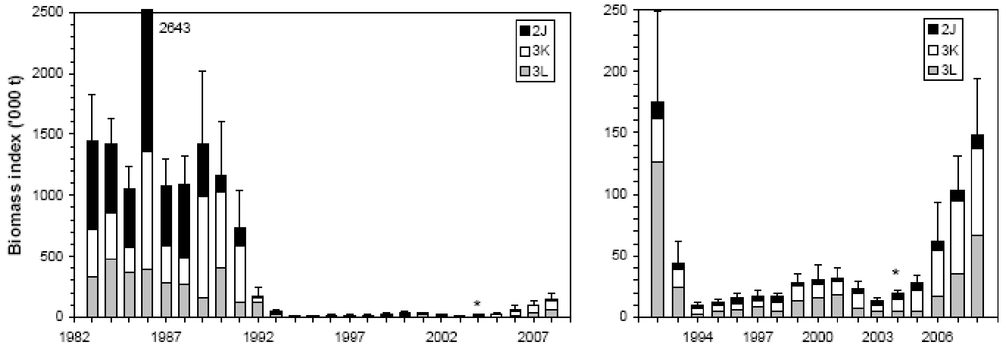


Figure 20. Biomass index (+2 SE's) of Northern cod from autumn RV surveys in offshore 2J3KL. The right panel is expanded to show trends from 1992 onwards. Asterisks indicate partial estimates from incomplete survey coverage of 3L in 2004 (DFO 2009f).

Grand Bank cod occupies the southern part of Grand Bank and are found over the shallower parts of the bank in summer, particularly in the Southeast Shoal area (Div. 3N), and on the slopes of the bank in winter as water cooling occurs. Grand Bank cod were placed under moratoria on directed fishing in 1994 following the collapse of the stocks in late 1980s and early 1990s. However, although there was no directed fishery during this time, catches in this area increased steadily during the moratorium up to 2003 (NAFO 2007). Recent trends in Grand Banks cod show a general decrease in biomass between 2002 and 2005, and an increase since then, especially in 2006 and 2008 (González-Troncoso et *al.* 2009). However, total and spawning biomass still remain at extremely low levels and is paired with low recruitment and high mortality (NAFO 2007; Fig 21). There is significant concern that fishing mortality of Grand Banks cod is now at levels comparable to those during periods in the past when substantial fisheries existed, even though the stock is currently under moratorium (NAFO 2007).

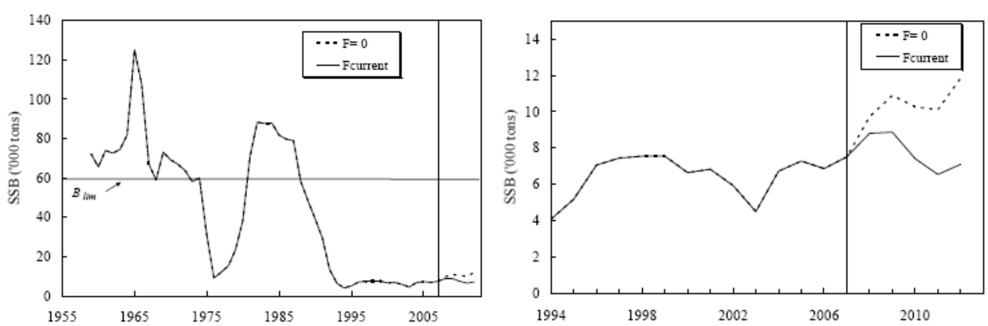


Figure 21. Spawning biomass of "Grand Bank" Atlantic cod in NAFO Divs. 3NO (NAFO 2007).
Historically there has been no consistent research vessel survey to monitor the cod off Labrador (2GH), although catch and by-catch information indicate their status is currently at a low level as well (DFO 2005).

With respect to key life history processes, juvenile cod have been linked to a variety of structured habitats (macrophytes, cobble, sponges, etc.) during their first year of life, likely as a means of reducing predation (Lindholm 1999; Laurel et *al.* 2003) and physical exposure (Lough et *al.* 1989) while possibly increasing feeding opportunities (Gregory and Laurel unpub. data). Larger juvenile cod (age 1-2 yrs) gradually move into deep water but often associate with kelp beds near eelgrass nursery areas (Keats et *al.* 1987; Keats 1990; Cote et *al.* 2003). Three-year old fish also have been shown to associate with a variety of substrates (Gregory and Anderson

1997), but they are typically much more widely distributed amongst a greater range of depths (Dalley and Anderson 1997).

Greenland Halibut

Greenland halibut (*Reinhardtius hippoglossoides*), also called turbot, are widely distributed throughout the waters off Labrador and eastern Newfoundland, and historically occurred in relatively high abundance along the deep slopes of the continental shelf, and in deep channels between banks rather contiguously into and through the 1980s (Healey 2009). However, in the early 1990s, northern distribution was greatly reduced and most of the fish existed in the northeastern Grand Bank area (Healey 2009).

Biomass of Greenland halibut was relatively stable until the mid-1980s after which it declined substantially to reach an all time low in the early 1990s – this increased briefly from 1995-1999, but declined again and it reached its lowest point since the early 1990s in 2002 (Fig. 22; Healey 2009). Biomass has also been declining in recent years and the 2004-2008 estimates are amongst the lowest in the time series (NAFO 2009).

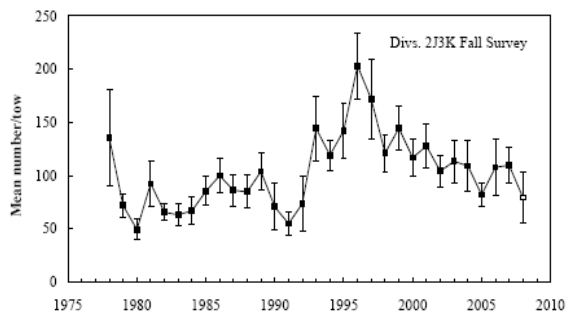


Figure 22. Campelen (or equivalent) stratified mean number and weight (kg) per tow of Greenland Halibut from fall surveys in NAFO Divisions 2J3K combined during 1978-2008 (Healey 2009).

Haddock

Haddock (*Melanogrammuus aeglefinus*) within the NLSE has a range that typically occupies only the southern portion of the Grand Banks (i.e., is at the northernmost extent of its range). Here, haddock occur from nearshore areas to the shelf break moving to the edges of banks and basins to occupy warmer, deeper waters to overwinter (Scott and Scott 1988).

Similar to other groundfish species, haddock numbers have been severely depleted relative to historical levels and their peak in the early 1960s (Fig. 23). Currently, haddock numbers are very low, and very few mature fish make prospects for recovery unlikely.

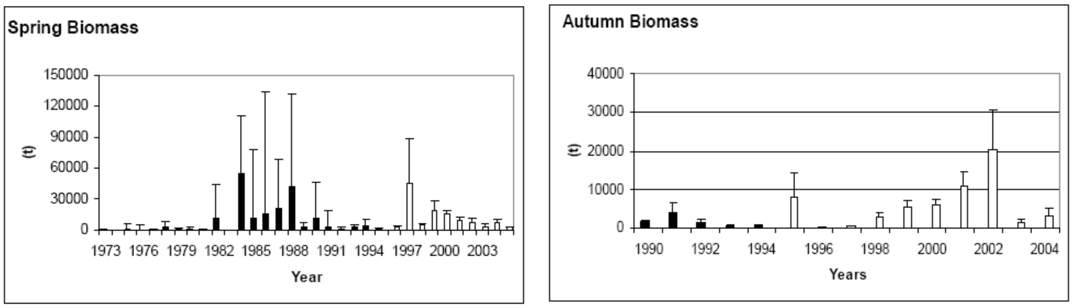


Figure 23. Biomass estimates for haddock from spring Canadian Research Vessel Surveys Divisions 3LNO. The clear bars are with the Campelen 1800 shrimp trawl. Data in shaded bars have not been converted and are not directly comparable (DFO 2005).

Redfish

Three species of redfish are present in the Northwest Atlantic: *Sebastes mentella*, *S. fasciatus* and *S. marinus*, but these are not separated commercially. Redfish inhabit deep cool waters along the slopes of banks and in channels contiguously throughout the NLSE, making extensive diel vertical migrations off the bottom during the night before returning to near contact distance with the bottom during the day (Gauthier and Rose 2002). Notably, redfish are slow growing and long lived (aged to at least 80 years), and unlike most groundfish, bear live young. Redfish feed on a combination of small pelagic invertebrates (mostly euphausids and shrimp) and small fish and are preyed upon by such species as cod and Greenland halibut.

The status of redfish stocks in the NLSE vary between being higher and lower than in the early 1990s, with recent fluctuations in stock status emphasizing the need for further research in the area. For example, trends in redfish on the northeastern shelf area (3LN) have been positive, such that abundance and biomass in 2006 were at levels higher than in the early 1990s (NAFO 2007), while redfish biomass indices have remained stable since 2001 but at a lower levels than the mid-1990s in the southern area of Grand Bank (3O) (NAFO 2007; Fig. 24).

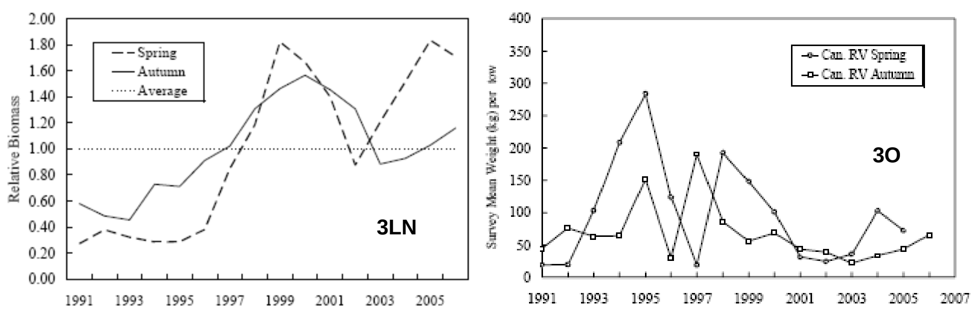


Figure 24. Trends in redfish biomass in 3LN (left) and 3O (right) from 1991-2006 (NAFO 2007).

Yellowtail flounder

Yellowtail flounder (*Limanda ferruginea*) occur in the Northwest Atlantic from the Strait of Belle Isle to Chesapeake Bay, although distribution throughout Canadian waters is rather sparse outside of the Grand Banks, the area which is considered to be the central area of their range and where they are most abundant and occur at the highest densities (DFO 2008f). These flounder almost exclusively occupy shallow regions (< 100 m) with sandy or muddy bottoms and temperatures ranging from 2 to 6ºC (Scott and Scott 1988). Therefore, on the Grand Bank, yellowtail is concentrated mainly in south central areas.

Yellowtail abundance and geographic range declined during the mid-1980s to mid-1990s. However, since the moratorium (1994-1997), stock size has steadily increased to a level well above that of the mid-1980s (NAFO 2008), with 2006 and 2007 estimates of biomass at the highest in the time series (Maddock-Parsons and Brodie 2008; Fig. 25). Yellowtail has also shown a recent northward range expansion within its habitat on the Grand Bank (Maddock-Parsons and Brodie 2008).

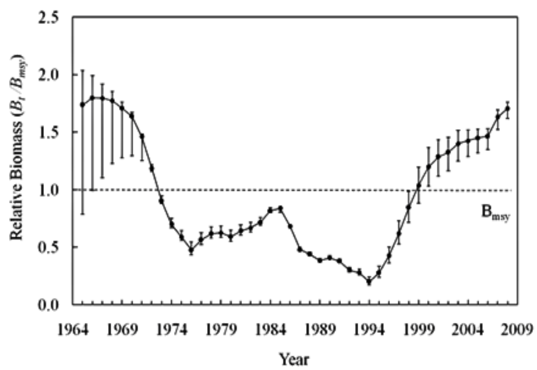


Figure 25. Biomass estimates of Yellowtail Flounder in NAFO Divs. 3LNO from 1964-2008 (NAFO 2008).

Pelagic fish

Pelagic fishes are those that live in the water column and at the surface. Pelagic fishes of the NLSE include many highly migratory species that winter in southern latitudes and migrate up the Atlantic coast in spring and early summer, often to feed, as the waters warm. Large pelagic species such as sharks, tunas and swordfish do not spawn in the region, but instead reproduce in warmer southern waters. Other smaller pelagics, such as capelin, herring and some small sharks, i.e., porbeagle and dogfish both reside and reproduce within the NLSE.

Atlantic Herring

Herring (*Clupea harengus*) is distributed in the Northwest Atlantic from Cape Hatteras to southern Labrador, where they are at the northern extent of their geographic range. Herring from regional stocks migrate extensively on an annual basis from near shore shallow spawning grounds to feeding areas throughout the bays and on the continental shelf before returning to over winter in deep coastal inlets.

Historically, these stocks supported commercial fisheries for both food and bait, but were closed in the early 1980's due to declining stock sizes and were reopened in the mid 1980s with the recruitment of the moderately large 1982 year class. Some eastern stocks have improved since then, but abundance is still considered to be low. However, for some southern stocks, abundance has clearly decreased. Status is not available the Conception Bay – Southern Shore since this area was not assessed and there is a limited fishery and a lack of scientific information.

Capelin

Capelin (*Mallotus villosus*) is a small pelagic schooling species with major populations occurring throughout the North Atlantic. Three of the four North Atlantic stocks occur within the NLSE. The largest capelin stock is distributed throughout the eastern shelf area and spawns inshore, on or near beaches. An offshore capelin stock spawns only on the Southeast Shoal; and a south coast stock occurs on St. Pierre Bank and spawns predominantly on beaches on the south coast of Newfoundland.

Among forage fishes, capelin has a dominant role in the NLSE food web – serving as core links in the transfer the energy from primary and secondary production to the upper trophic levels. They constitute important food items for large demersal fish such as Atlantic cod, Greenland halibut and American plaice, marine mammals such as harp seals and large whales, and a range of seabirds.

Hydroacoustic surveys indicate offshore capelin abundance was high in the 1980s, decreased dramatically in the early 1990s, and remained low for several years (DFO 2008a). While there is an increasing trend in capelin abundance offshore in the most recent years (2007-08), abundance still remains considerably less than that observed in 1988-90 (DFO 2008a; Fig. 26). In addition, size and age of capelin continue to reflect changes that occurred in the early 1990s – that is, immature and mature capelin continue to be smaller (DFO 2008a; Fig. 27). Also notable, are changes in behaviour, such that spawning times continue to be about four weeks later than observed prior to 1991, and capelin are not undertaking diurnal migrations to the extent observed in the 1980s (DFO 2008a).

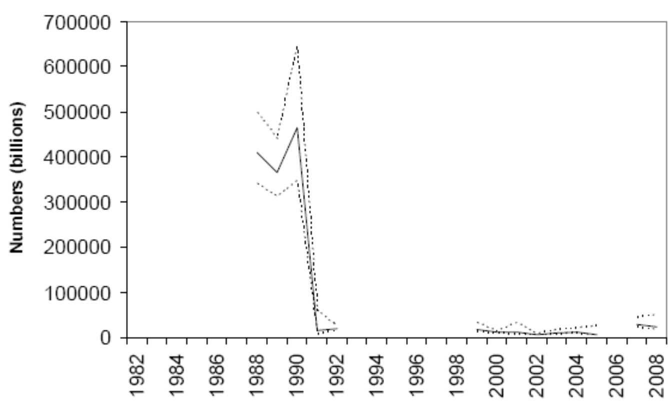


Figure 26. Simulated spring offshore abundance estimates (line) with 95% confidence intervals (broken lines) for an index area comparable to Div.3L on the Grand Bank of the NLSE (DFO 2008a).

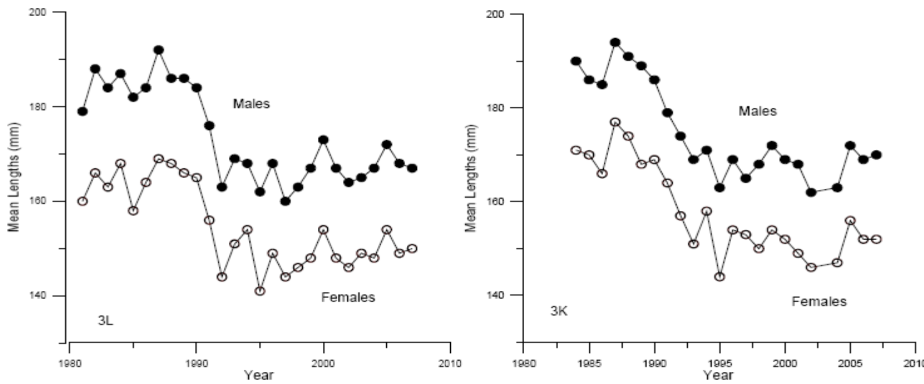


Figure 27. Mean total lengths of males (closed circles) and females (open circles) in Divs. 3L and 3K on the Grand Bank of the NLSE (8 DFO 2008a).

Diadromous fish

Diadromous fishes are those that spend part of their lives in freshwater and part in salt or brackish water. Diadromous species occurring within the NLSE include American eel, Atlantic salmon, and brook, steelhead, and brown trout. These fish are migratory – hatched in fresh water but spending their juvenile and adult life in the sea, returning to freshwater to only spawn.

Atlantic salmon

The Atlantic salmon can be found in lakes and rivers and in the ocean over much of the Eastern Canadian seaboard and are very common around Newfoundland and Labrador. Salmon that have hatched within rivers stay the first three or four years there before entering estuaries and coastal waters, spend some time there as postsmolts, and go to sea where they spend 1, 2, or more years before returning to freshwater to spawn. Some adults may spend all or most of their lives at sea within the Grand Banks area while others may overwinter in the Labrador Sea and/or spend summer/fall in the west Greenland/Davis Strait area.

Ocean-going salmon once supported extensive commercial fisheries in much of eastern Canada; however these have been closed since 1992. In addition, salmon have been exploited through river angling fisheries and fisheries by Aboriginal people for food, social, and ceremonial purposes. The survival of Atlantic salmon stocks at sea remains low throughout the region despite the drastic reduction in directed fishing since 1992, and overall, stock size continues to be lower now than during the commercial salmon fishery moratorium (DFO 2009e; Fig. 28).

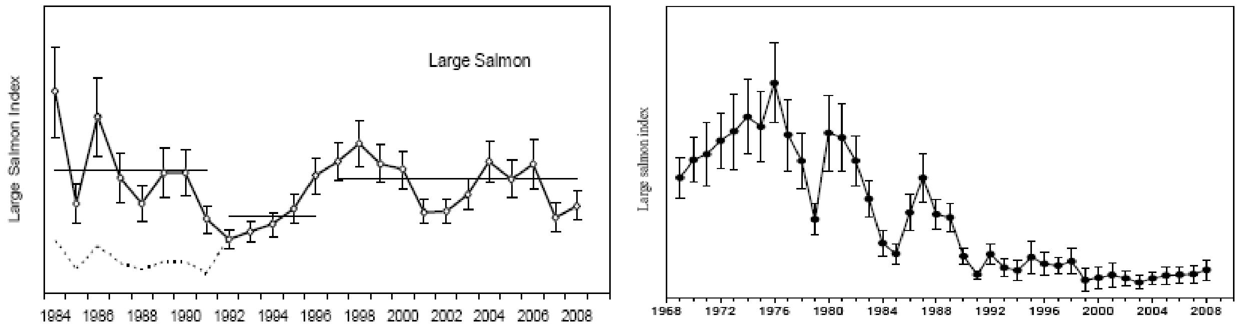


Figure 28. Trends in abundance of large Atlantic salmon in Newfoundland from 1984-2008 (left), and in Labrador from 1969-2008 (right). Returns have been corrected to account for marine exploitation. Horizontal lines illustrate the mean abundance index for those periods. Vertical lines represent ±1 standard error. The fine dashed line represents returns unadjusted for exploitation. (Modified from DFO 2009e).

<u>Marine Mammals</u>

Marine mammals occurring in the NLSE can be divided into two groups: 1) cetaceans (i.e., the whales, dolphins, and porpoises); and 2) pinnipeds (i.e., seals, walruses, sea lions). Marine mammals are generally highly migratory, moving extensive distances to feed and reproduce to take advantage of favourable environmental conditions. Cetaceans complete their entire life history in the aquatic environment whereas pinnipeds haul out on land or ice to give birth and nurse their young. Few marine mammals spend their entire life cycle in the ecozone.

In contrast to many whale species, pinnipeds such as grey seals and harp seals have shown high population growth and long term resilience to anthropogenic impacts. Such high population growth rates have been linked to optimal environmental conditions (i.e., temperature, foraging conditions) that may not be typical in all years.

Cetaceans (Whales, Dolphins, and Porpoises)

The coastal waters of Newfoundland and Labrador are among the best suited places in the world for cetaceans – of the approximately 80 species of cetacea, about 20 can be found in the Northwest Atlantic. Table 3 lists information on the description, distribution, feeding habits and status for each species of cetacean regularly occurring in the NLSE. Species that occur rarely or have uncertain distributions are not included.

Although finite information on whale distributions in the NLSE is not available, whale distribution in general seems to correlate well with other species, and usually in areas of particularly high primary productivity. Whale distributions have been linked at relatively small scales with concentrations of zooplankton, herring, and other prey.

Given that cetaceans are long-lived and have very low reproductive rates, they are particularly vulnerable to exploitation and other population stress. For example, populations for many whale species have still not returned to historical levels since whaling from the 19th and early 20th century reduced populations to very low levels.

During a 2007 aerial survey, the most commonly-sighted cetacean in the NLSE was the humpback whale, with relatively large numbers of sightings of Atlantic white-sided dolphins, fin whales, and whitebeaked dolphins, with most sightings, and a higher sighting rate, occurring in the south and with relatively few (n=19 sightings) along the Labrador coast (Lawson and Gosselin 2009; Table 2).

Table 2. Estimated density (/km^2) of individuals (D), abundance (N), coefficient of variation (CV) and model degrees of freedom (DF) using the model providing the best fit according to AIC for species with more than 20 sightings in the Newfoundland survey strata. Too few sightings were made in the Labrador stratum to obtain reliable abundance estimates (Lawson and Gosselin 2009).

Species	D	N	%CV	95% CI	DF
Minke Whale	0.0024	1,315	22.5	855-2,046	86.8
Fin Whale	0.0037	890	24.5	551-1,435	128.0
Humpback Whale	0.0019	1,427	20.4	952-2,140	104.0
White-sided Dolphin	0.0020	1,507	22.5	968-2,347	64.2
Common Dolphin	0.0010	576	31.2	314-1,056	77.1
White-beaked Dolphin	0.0077	1,842	22.4	1,188-2,854	105.1
Harbour Porpoise	0.0016	1,195	32.2	639-2,235	75.3
Unk. Dolphin	0.0038	276	52.8	102-748	51.7

Pinnipeds (Seals and Walruses)

There are three families of pinnipeds; the true seals (Phocidae), the eared seals, such as sea lions and fur seals, (Otariidae) and the walrus (Odobinidae). There are no fur seals or sea lions in the North Atlantic, and walruses are occasionally seen along the coast of Labrador and only rarely in Newfoundland waters. The six species of true seals commonly observed in the area include the harp, hooded, grey, harbour, ringed and bearded seals.

Table 3. *Cetacean species occurring on the within the NLSE (Modified from Breeze et al. 2003; Jack Lawson pers.comm.).*

COMMON NAME SCIENTIFIC NAME	**SIZE AND BEHAVIOUR**	**DISTRIBUTION (WORLDWIDE AND LOCALLY)**	**POPULATION AND CONSERVATION STATUS (COSEWIC)**
Baleen Whales (Mysticeti)			
Blue whale *Balaenoptera Musculus*	▪ largest whale (25 m) ▪ observed rarely	▪ worldwide distribution ▪ along south and east coasts during winter-spring	▪ at least 308 in NW Atlantic ▪ special concern (COSEWIC)
Humpback whale *Megaptera novaengilae*	▪ up to 13 m long ▪ occur singly or groups of 2-8	▪ worldwide distribution ▪ NL waters (summer); south and east coasts	▪ ~10,600 in N Atlantic ▪ special concern (COSEWIC)
Fin whale *Balaenoptera physalus*	▪ up to 24 m long ▪ occur in groups of 2-8	▪ from cold to temperate waters worldwide ▪ shelf edges off NL in summer	▪ ~2,200 in NW Atlantic ▪ special concern (COSEWIC)
Sei whale	▪ up to 15 m long ▪ occur singly or groups of 2-10	▪ temperate waters worldwide ▪ offshore NL during spring-fall	▪ ~40,000-60,000 worldwide ▪ not evaluated (COSEWIC)
Minke whale	▪ up to 10 m long ▪ occur singly or in groups	▪ temperate waters worldwide ▪ common in NL bays spring-fall	▪ ~3,800 Atlantic Canada ▪ under review (COSEWIC)
Toothed Whales (Odontoceti)			
Sperm whale *Physeter macrocephalus*	▪ largest toothed whale (18 m) ▪ occur singly or in small groups	▪ temperate waters ▪ usually in deep water and shelf edges	▪ ~ 4,700 individuals from Gulf of St. Lawrence to Florida ▪ not evaluated (COSEWIC)
Northern bottlenose whale *Hyperoodon ampullatus*	▪ up to 9 m long ▪ occur in small groups	▪ usually in deep water (canyons and shelf edges) ▪ occasionally in shallow areas feeding on squid	▪ >40,000 in North Atlantic ▪ special concern (COSEWIC)
Short-beaked common dolphin *Delphinus delphis*	▪ up to 2.5 m long ▪ occur in groups of 50-200+	▪ worldwide distribution ▪ usually in deep water and shelf edges	▪ ~ 30,000 individuals in NW Atlantic ▪ not at risk (COSEWIC)
White-beaked dolphin *Lagenorthnchus albiorostris*	▪ up to 3 m long ▪ occur in groups up to 25	▪ Cape cod to Davis Strait ▪ often associated with ice edges in spring in NL	▪ unknown population estimate ▪ not at risk (COSEWIC)
Atlantic white-sided dolphin *Lagenorhynchus acutus*	▪ up to 2.8 m long ▪ occur in groups of 50-500+	▪ Cape Cod to Davis Strait ▪ throughout the Region	▪ tens of thousands in NW Atlantic ▪ not at risk (COSEWIC)
Long-finned pilot whale *Globicephala melas*	▪ up to 6 m long ▪ occur in small groups of 5+	▪ North Carolina to Greenland ▪ inshore in summer; offshore in summer and winter	▪ 15,000-25,000 in NW Atlantic ▪ not at risk (COSEWIC)
Killer whale *Orcinus orca*	▪ up to 10 m long ▪ occur in small groups of 3-25	▪ temperate waters worldwide ▪ infrequent in eastern Canadian waters	▪ no estimate for NW Atlantic ▪ insufficient data (COSEWIC)
Harbour porpoise *Phocoena phocoena*	▪ up to 1.5 m long ▪ occur singly or groups of 2-10	▪ temperate waters worldwide ▪ coastal (summer) and shallow offshore (winter)	▪ likely >100,000 in NW Atlantic ▪ special concern (COSEWIC)

Unlike whales, the seals have a terrestrial phase where they haul out on land or ice to give birth and nurse their young. Seals are also typically more fecund than whales, with females generally maturing earlier and producing one or two pups per year. However, because of their potential impact to commercial fish species (i.e. cod), population estimates and distributions of seal populations in the northwest Atlantic are better known than other marine mammals.

Harp seals

Harps are the most abundant and widely distributed seals throughout the NLSE, where they migrate annually between Arctic and sub-Arctic regions of the ecozone. Harp seals summer in Arctic waters, and migrate into the Grand Banks area in late fall to feed, pup and breed (March) and then moult (April/May) before heading back north. This birthing and breeding occurs mainly in two areas; the northern and southern Gulf of St. Lawrence ('Gulf') and an area referred to as the 'Front' off southern Labrador and northeastern Newfoundland. During this time females nurse a single pup for about 12 days, after which they mate and disperse.

The diet of harp seals is relatively well-studied due to the possible indirect and direct competition that the species has on commercially important groundfish stocks. These studies have concluded that harp seal diet varies considerably with age, season, prey availability and area. On the Grand Banks, capelin is the most important prey species, followed by sand lance, Greenland halibut and other flatfish species (Wallace and Lawson 1997; Lawson et *al.* 1998). Arctic cod are also an important source of food, but their availability varies with oceanographic conditions between years (DFO 2000). Studies concluded that Atlantic cod were a relatively unimportant prey item on the Grand Banks, although harp seals in nearshore waters do eat more Atlantic cod relative to offshore individuals (Hammill and Stenson 2008). Still, given its large population size and the small size of the remnant Atlantic cod population, the predation pressure that harp seals may exert on Atlantic cod can still be significant. Therefore, the role of harp seals in preventing the recovery of Atlantic cod after the last collapse remains under active investigation.

The harp seal population declined during the 1960s, reaching a minimum of less than 2 million in the early 1970s. Following the introduction of the quota system for the harvest of harp seals, also in the 1970s, the population tripled by the mid 1990s to a very high level (~ 5.5 million). Since that time, the population has continued to increase at a slower rate (likely due to large harvests in recent years) of approximately 1.5% annually up to its last assessment in 2009, where Northwest Atlantic harp seals numbers were estimated at 6.9 million (95% CI=6.0 to 7.7 million) (DFO 2010; Fig. 29).

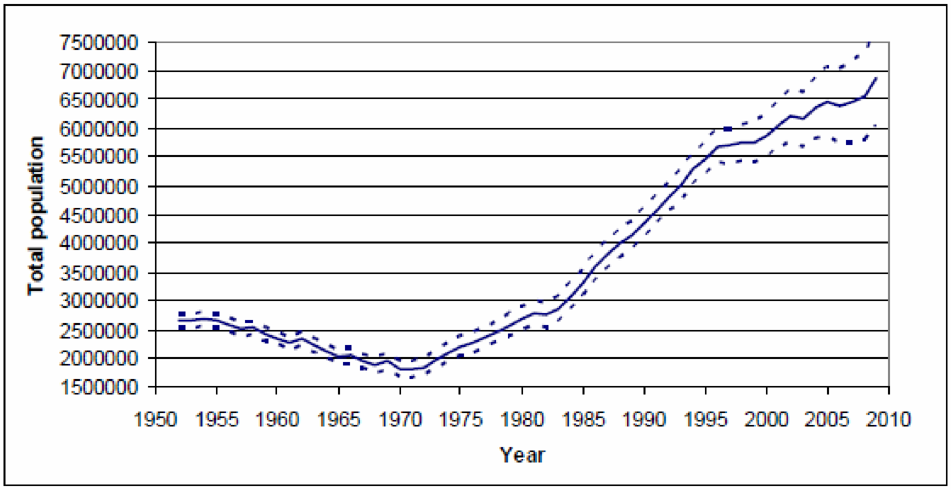


Figure 29. Estimates of total population for Northwest Atlantic harp seals for 1952-2009 (±1SE), using the visual estimate of pup production at the Front in 2008 (DFO 2010).

<u>Marine Birds</u>

Newfoundland and Labrador marine ecosystems are home to numerous resident and transient marine bird species. The diversity of seabirds occurring in the NLSE is high since the continental shelf serves as an important feeding area to many and offshore waters are critical wintering areas for several other species. Nearly all pelagic birds found in the NLSE also breed in the province (see Important Bird Areas, Fig. 30). Gaston et *al.* (2008) identify the Great Cormorant, Northern Gannet, Herring Gull, Great Black-backed Gull, Black-legged Kittiwake, Common Murre, Razorbill, Atlantic Puffin, Arctic Tern, Common Tern and Leach's Storm-Petrel as potential indicator species for the NLSE.

Seabird distributions often reflect areas of high productivity that support dense zooplankton patches and small fish schools (e.g., herring or capelin). These areas are often found along steep shelf edges where upwelling events bring nutrients into the surface layers of the water column. One such area is where the Labrador Current flows over the northern edge of the Grand Banks, known to be associated with dense aggregations of seabirds (Brown 1986). Areas of high fishing activity are also important since many species (e.g., gulls) feed on fish discards. Some of the species of seabirds have demonstrated a corresponding change in the diet following the groundfish moratorium on the Grand Banks (e.g. great black-backed and herring gulls) (Tasker et *al.* 1999), while others show trends that can be compared largely pre- and post-1990 (e.g., changes in the diet from that of mainly mackerel, a warm water species, to capelin, a cooler water species) over the environmental regime shift (see Table 4).

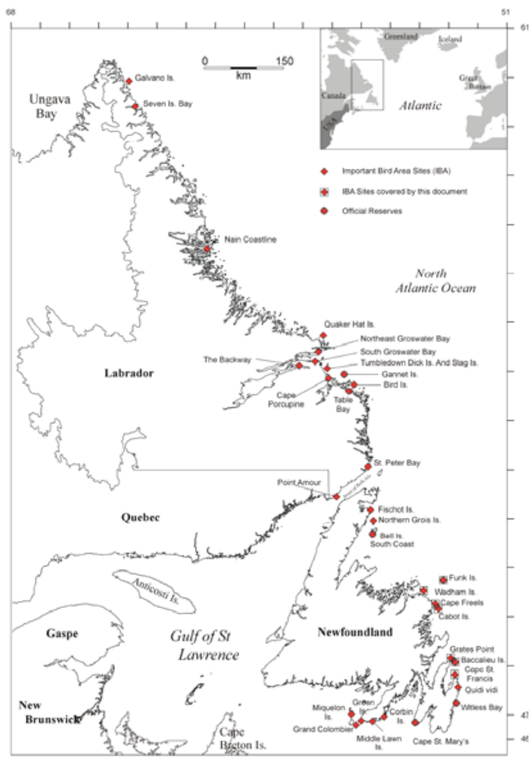


Figure 30. Location of Important Bird Areas (IBA) in eastern Newfoundland and Labrador (Taken from Russel and Fifield 2001).

The sharp discontinuity in oceanography and food webs that occurred in the early 1990s resulted in some negative trends in marine bird populations (Gaston et *al.* 2008). Decreases in large gulls and Black-legged Kittiwakes may relate to the reduction in inshore fisheries activity (which provided fish offal and discards) following the groundfish moratorium of 1992 (Gaston et *al.* 2008). At the same time, terns generally decreased throughout NLSE, probably as a result of human influences on their terrestrial breeding habitat (Gaston et *al.* 2008). However, species such as the Northern Gannet and Razorbill continued to increase from the 1970s onwards, as have most Atlantic Puffins in Southeast Newfoundland. Additionally, the closure of gill-net fisheries that were drowning many auks had positive consequences for this species and likely other populations of underwater divers (Gaston et *al.* 2008). It is possible that positive trends in other seabirds prior to the 1990s reflect recovery from egging and plumage harvesting prevalent before the institution of the Migratory Bird Protection Act after Newfoundland's amalgamation with Canada in 1949.

Although it is likely that overall incidental catch of seabirds in gillnet fisheries in Newfoundland and Labrador has decreased over time due to decreased effort, based on data mainly from nearshore gillnet fisheries for Atlantic cod, total numbers of incidentally caught seabirds in nearshore and offshore Newfoundland waters from 2001 to 2003 totalled as many as 2000 to 7000 murres, over 2000 shearwaters (various species), and tens to hundreds of northern fulmars (*Fulmarus glacialis*), gannets (*Morus bassanus*), double-crested cormorants (*Phalacrocorax auritus)*, loons (genus *Gavia*), eider ducks (*Somateria mollissima*), razorbills (*Alca torda*), puffins (*Fratercula arctica*), black guillemots (*Cepphus grille*) and dovekies (*Alle alle*) were estimated to have been captured annually in the area during the period (Benjamins et al. 2008).

Seabirds are also particularly vulnerable to the effects of oil spills since 1) they have low reproductive rates; 2) they rely on the air-water interface; and 3) they are often densely concentrated.

Table 4. Trends in some seabirds of the NLSE (summarized from Gaston et al. 2008).

Seabird Species	Location	Timing	Trends	Driver
Atlantic Puffin	Witless Bay, Newfoundland	**1979-1984**	**Decreased population (small)**	Bycatch (large)
		1984-2003	**Increased population (rapid)**	Bycatch (decrease); Oceanography
	Gannet Islands, Labrador	**1978-1983**	**Increased population**	
		1983-1999	**Decreased population**	
	Grosswater Bay, Labrador	**1978-2002**	**Decreased population**	
Auks (except common murres)	Newfoundland and Labrador	**1970-current**	**Stable**	
Black Legged Kittiwake	Newfoundland and Labrador	**Pre-1990**	**Increased population**	Groundfisheries; offal and discards
		Post-1990	**Decreased population**	Groundfisheries; offal and discards
Common Murre	Newfoundland and Labrador	**Pre-1990**	**Increased population**	Oceanographic conditions
		Post-1990	**Decreased population**	Oceanographic conditions
	Funk Island, Newfoundland	**1990s**	**Decreased chick condition**	Diet – gravid capelin
Large gulls	Newfoundland and Labrador	**1990s-current**	**Decreased population**	Groundfisheries; offal and discards
Leach's Storm Petrel	Newfoundland	**1970-current**	**Stable**	Diet – large zooplankton
Northern Gannet	Newfoundland	**Post-1950s**	**Increased population**	
		1980s 1990s	**Diet change in forage fishes**	Oceanographic conditions
Razorbills	Labrador	**1978-1983**	**Decreased population**	Increased Labrador Current temp.
		1983-1999	**Increased population**	Decreased Labrador Current temp.

Species at Risk

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is scientific advisory body that, based on the best available information, assesses the biological status of a species. The purpose of the *Species at Risk Act* (SARA) is to prevent species from becoming, endangered, extirpated or extinct; and to allow for the recovery and management of listed species and species of special concern. Based on assessments provided by COSEWIC, and feedback from public consultations, it is the responsibility of the responsible federal Government department to decide whether or not a species is listed under SARA. Although not all up for formal protection under Schedule 1 of SARA, the following COSEWIC and SARA-listed species (Table 5) occurring in the NLSE can be considered Valued Ecosystem Components (VECs) based on their various assessments:

Table 5. SARA and COSEWIC species occurring within the NLSE as of 2009.

Common Name	Scientific Name	Taxon	COSEWIC Status	SARA Schedule	SARA Status
SARA-LISTED SPECIES					
Blue Whale	*Balaenoptera musculus*	Mammals	Endangered	Schedule 1	**Endangered**
North Atlantic Right Whale	*Eubalaena glacialis*	Mammals	Endangered	Schedule 1	**Endangered**
Leatherback Sea Turtle	*Dermochelys coriacea*	Reptiles	Endangered	Schedule 1	**Endangered**
Ivory Gull	*Pagophila eburnea*	Birds	Endangered	Schedule 1	**Endangered**
Piping Plover	*Charadrius melodus melodus*		Endangered	Schedule 1	**Endangered**
Harbour Porpoise	*Phocoena phocoena*	Mammals	Special Concern	Schedule 2	**Threatened**
Northern Wolffish	*Anarhichas denticulatus*	Fishes	Threatened	Schedule 1	**Threatened**
Spotted Wolffish	*Anarhichas minor*	Fishes	Threatened	Schedule 1	**Threatened**
Atlantic Wolffish	*Anarhichas lupus*	Fishes	Special Concern	Schedule 1	**Special Concern**
Fin Whale	*Balaenoptera physalus*	Mammals	Special Concern	Schedule 1	**Special Concern**
Humpback Whale	*Megaptera novaeangliae*	Mammals	Not at Risk	Schedule 3	**Special Concern**
Sowerby's Beaked Whale	*Mesoplodon bidens*	Mammals	Special Concern	Schedule 3	**Special Concern**
Harlequin Duck	*Histrionicus histrionicus*	Birds	Special Concern	Schedule 1	**Special Concern**
NON SARA-LISTED SPECIES					
Atlantic Cod	*Gadus morhua*	Fishes	**Endangered**	No schedule	No Status
Porbeagle	*Lamna nasus*	Fishes	**Endangered**	No schedule	No Status
Roundnose Grenadier	*Coryphaenoides rupestris*	Fishes	**Endangered**	No schedule	No Status
White Shark	*Carcharodon carcharias*	Fishes	**Endangered**	No schedule	No Status
American Plaice	*Hippoglossoides platessoides*	Fishes	**Threatened**	No schedule	No Status
Cusk	*Brosme brosme*	Fishes	**Threatened**	No schedule	No Status
Shortfin Mako	*Isurus oxyrinchus*	Fishes	**Threatened**	No schedule	No Status
Blue Shark	*Prionace glauca*	Fishes	**Special Concern**	No schedule	No Status
Roughhead Grenadier	*Macrourus berglax*	Fishes	**Special Concern**	No schedule	No Status
Killer Whale	*Orcinus orca*	Mammals	**Special Concern**	No schedule	No Status

ECOSYSTEM FUNCTIONS AND PROCESSES

Supporting services are those that are necessary for the production of all other ecosystem services. In the NLSE, some key examples include primary production, nutrient cycling, oxygen production, biomass production, and provisioning of habitat.

Potential overall productivity of an area depends on the amount of energy fueling the base of the food web. On the continental shelf, phytoplankton are responsible for this ‘primary production’, whereas in shallower waters, where sunlight reaches the bottom, larger plants, including seaweeds and sea grasses, are also important primary producers. The world’s continental shelves contribute only 8% of the global sea surface (Kaiser et al 2005). However, much of the shelf is within the euphotic zone, and therefore, primary production in shelf areas fuels 90% of the world’s fisheries (Pauly and Christensen 1995).

Primary Production

Primary production in the NLSE largely depends on phytoplankton. The rate of converting inorganic materials into organic compounds through photosynthesis varies based on the available light and nutrients, and therefore is often related to depth, proximity to the coast, and oceanographic features such as upwellings. However, the availability of nitrogen is hypothesized to be limiting to the growth of phytoplankton in the Northwest Atlantic (Pepin et *al.* 2007)

The NLSE region regularly experiences two blooms, a spring bloom and a smaller fall bloom. Small, localized blooms regularly occur at other times of the year if conditions are favourable, for example, if wind-induced upwelling brings nutrients to surface waters.

Regional differences in primary production are evident within the NLSE. The highest levels are found in the immediate nearshore areas, along the shelf edges near upwelling zones, and in estuaries where nutrients from land essentially fertilize the sea water.

The northwest Atlantic, as a whole, and its continental shelves in particular, are considered relatively productive areas of the global oceans. The area of the Newfoundland and Labrador Shelf is considered a moderately productive (150-300 gC/m^2-yr) ecosystem based on SeaWiFS global primary productivity estimates (http://na.nefsc.noaa.gov/). Satellite measurements taken over the course of the spring bloom have been found to be in the order of 1000 mg C m^{-2} d^{-1} and about 300 mg C m^{-2} d^{-1} during the rest of the year, giving an annual primary production rate of about 200 mg C m^{-2} yr^{-1} (Prasad and Haedrich 1993; Townsend and Ellis 2006). Figure 31 provides an example of annual primary productivity in the NLSE.

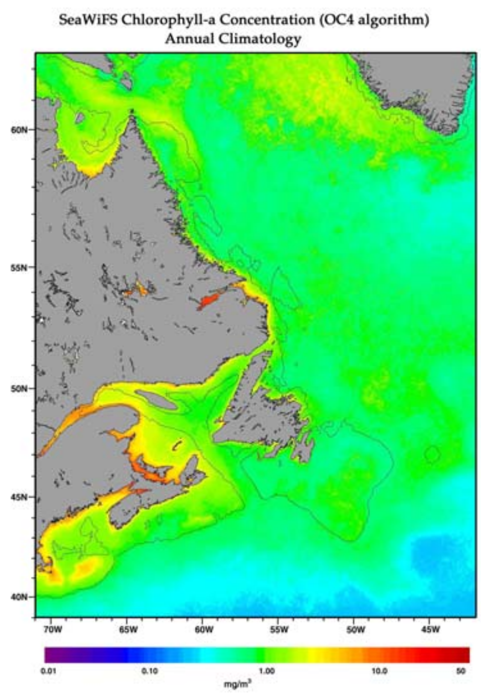


Figure 31. Illutrative figure of annual primary productivity in NLSE based on averaged near surface Chlorophyll-a (mg/m3) during 2007 (SeaWiFs 2007).

Nutrient Cycling

Nutrients (nitrate, phosphate, and silicate) are incorporated into phytoplankton during photosynthesis. These nutrients move through the food web as grazers and predators consume smaller prey items. Nutrients are recycled in the water column by excretion and microbial breakdown of detritus.

In the NLSE, the vertical distributions of key nutrients show a strong seasonal co-variation (Petrie et *al.* 1999). Nitrate inventories in the upper 50 m show seasonal trends with winter and fall maximums, rapid depletion during the spring bloom, and occasional periodic intrusions during the late summer – early autumn, likely due to various mixing (Pepin et *al.* 2007). Deep water (50 -150 m) levels of silicate and nitrate are much greater than surface levels, and only vary slightly over the seasons (Pepin et *al.* 2003)

Oxygen Production

Surface waters of the ocean are constantly supersaturated with oxygen. This is partially due to the release of oxygen during photosynthesis, but mainly due to air bubbles that form at the crests of waves and enter the water column.

The percentage saturation of oxygen in seawater depends on temperature and salinity. Further, physical processes such as stratification of the water column will prevent gas exchange in deeper water layers and thus can cause a decrease in oxygen saturation on a seasonal scale (Brown et *al.* 1989).

Key trends in the pattern of oxygen saturation in waters overlaying the continental shelf include:

1. A surface layer that is near equilibrium with the atmosphere;
2. Surface waters that have elevated O_2 production due to photosynthesis;
3. Decreased O_2 throughout the water column due to biological respiration;
4. Intermediate and deeper waters with decreased O_2 due to bacterial degradation and oxidation of organic material

Oxygen levels are generally high in the winter months due to strong vertical mixing. However, during the annual phytoplankton bloom surface oxygen levels reach their maximum in early May. The lowest saturation in the surface layer is found in the beginning of autumn, when the water is rapidly cooled and the gas flux between ocean and atmosphere is too slow to keep the saturation at 100%. Thus, according to the season, the surface water may act either as an oxygen source or sink (Lalli and Parsons 1993).

Hypoxia

Hypoxia is becoming a concern in many coastal regions globally. Low oxygen can limit the distribution of certain organisms and may also interfere with nutrient release from sediments and therefore affect primary production (Plante et *al.* 1998). In addition, many species of fish and shellfish become stressed or can no longer survive when oxygen gets below 2 mg/l, resulting in significant modification of the benthic community structure (http://www.eps.mcgill.ca/~sundby/MarineGeochemistry/hypoxia.html).

In offshore areas there is significant mixing of highly oxygenated cold water, and hypoxia is generally not a major consideration. However, there have been some incidences of low oxygen levels along Northeastern Newfoundland where levels in the 1990s were the lowest in a 70-year time series (Kiceniuk and Colbourne 1997), and were so low in certain regions (60% sO_2) that it was approaching the lethal level previously reported for Atlantic cod (Chabot and Dutil 1999).

While hypoxia is not currently reported as significant issue within the NLSE, occurring mainly in small fjords with restricted circulation and soft organic bottoms, it is likely that many NL harbours, not just the largest, St. John's Harbour, could experience hypoxic conditions at least at some times of the year due to organic loading from nearby fish plants or other forms of development (e.g., mines, lumber mills, sewage and agricultural run off). Although relatively less significant than occurrences of hypoxia in other eastern Canadian areas, impacts of localized hypoxia in the NLSE can be severely detrimental in its outward effects should it harm or destroy 'significant' species (e.g. eelgrass).

Biomass production

Energy is greatest at the base of the food web where primary producers (mainly phytoplankton) turn sunlight into plant life. Energy is then transferred through successive trophic levels, where the amount of energy available at each step is progressively less (e.g., Fig. 32).

Secondary producers, including zooplankton, tiny crustaceans, and some shellfish (e.g. filter feeding bivalves) consume phytoplankton, turning plant tissue into animal material. Zooplankton are fed upon by a number of different species, including schooling fishes such as herring and mackerel, but also by some types of whales. Schooling fish, in turn, are preyed upon by piscivores, fish-eating fish like cod and dogfish. These piscivores are then prey to yet higher level predators such as seals and tuna. Humans prey on a number of these trophic levels.

Trophodynamics

A prominent feature of the NLSE is the fairly direct food chain (Rose 2007). In general terms, energy from primary production is transferred to forage fishes, including capelin, Arctic cod and sandlance, through the various major groups of zooplankton.

Among top fish predators, Atlantic cod is a key species, and was the most important fish predator in the Newfoundland and Labrador Shelf system until its collapse. Cod preys on a diversity of species, but mainly on forage fishes, and large zooplankton. Like most fishes, its diet changes with size, being more concentrated on crustaceans at smaller sizes, and becoming more intensively piscivorous as it grows.

Greenland halibut is another important top fish predator. This flatfish is highly piscivorous, feeding on capelin and redfish, but also on other flounders and Atlantic cod. American plaice also feed on fish, most commonly capelin, but benthic invertebrates constitute an important part of its diet as well. Other flatfishes like yellowtail and witch flounder feed mainly on benthic invertebrates.

Among marine mammals, harp seals are the single most abundant species in the NLSE. Its main prey species are capelin and Arctic cod, but it also feeds on a large set of species including flatfishes, Atlantic cod, and shrimp.

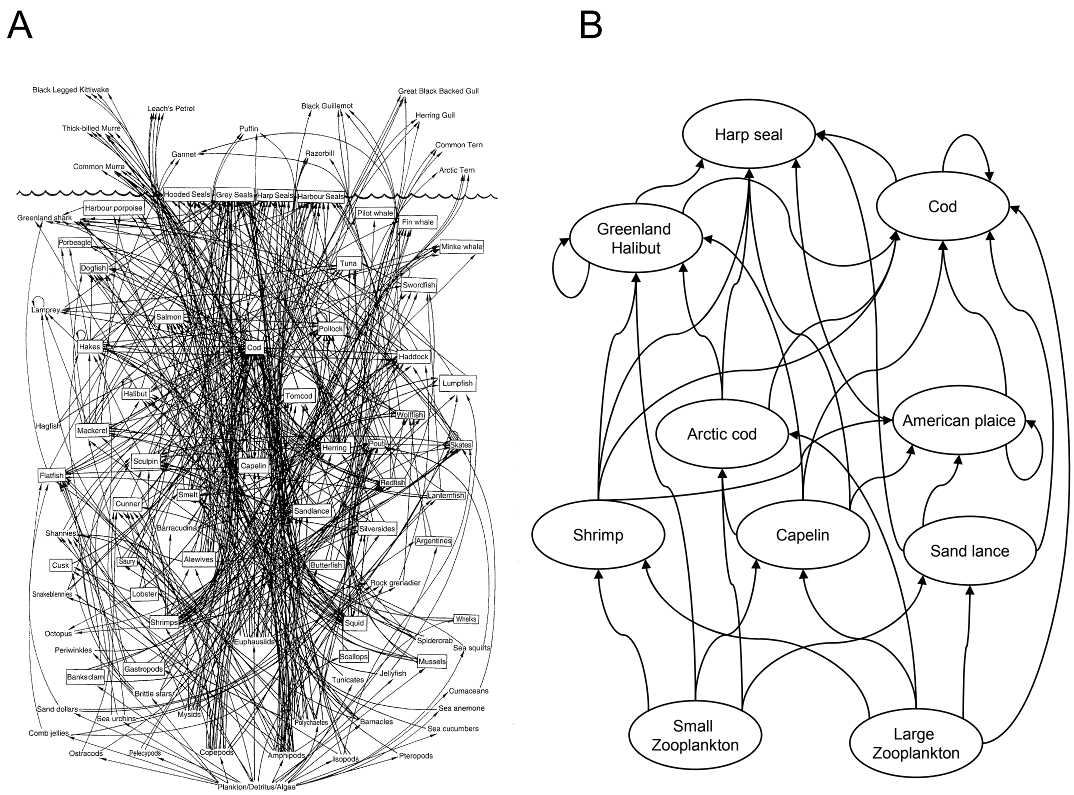


Figure 32. Two different representations of food webs of the Northwest Atlantic with different levels of resolution. A) Highly resolved food web of the Scotian Shelf food web reprinted from Lavigne (1996). B) Schematic representation of the Newfoundland and Labrador Shelf food web focused on core components of the system.

Habitat

Functional areas for marine species in the NLSE are widely variable over both space and time. Species distributions have been linked to the oceanographic environment, including currents and temperature (e.g. Bradbury et *al.* 2000, Han and Kulka 2007), bottom habitat (e.g. Gregory and Anderson 1997; Kulka et *al.* 2004), and availability of food (e.g. Houde 1987). In addition, temporal patterns in distribution are dynamic; varying yearly, seasonally and daily (Grant and Brown 1998; Methven et *al.* 2001; Kulka et *al.* 2003; Laurel et *al.* 2003). Distribution patterns also vary throughout species development and are often associated with the functions/processes of mating, spawning and breeding, rearing, foraging and feeding and migration.

Rearing Areas

Most groundfish species settle into demersal habitats whereas pelagic species remain in the water column. It is also likely that many juvenile fish species, e.g. Atlantic cod, in the NLSE move into complex coastal habitats (e.g., eelgrass, kelp) for their first year of life, reducing predation and increasing food availability for several groundfish species, (Laurel et *al.* 2003). As such, coastal regions have been proposed as important nursery areas for juvenile groundfish. There is evidence off the northeast coast of Newfoundland that juvenile cod are found at a greater and greater distances from the coast as they mature, moving to offshore banks as adults (Anderson et *al.* 2000). Other species or populations likely complete their entire life-cycle in suitable habitat offshore (e.g., Koeller et *al.* 1989).

Critical Habitat under SARA

The *Species at Risk Act* (SARA) makes it illegal to destroy the critical habitat of species at risk. The habitat may be an identified breeding site, nursery area or feeding ground. For species at risk, these habitats are of crucial importance, and are intended to be identified and included in species specific recovery strategies and action plans. However, to date, and for several reasons, critical habitat has not been defined for any demersal fish species assessed at risk by COSEWIC. Marine species are generally widespread and under go wide fluctuations in abundance and area that they occupy. Under these circumstances, what constitutes habitat critical to survival is uncertain since the species can survive within a fraction of the area that they occupy at high abundance (e.g. Kulka et *al.* 2004). In addition, the benthic habitat over wide areas, particularly within the NLSE is poorly studied. Without a clear understanding of the habitat of demersal species, it is difficult to determine locations critical to survival. While not all SARA species are permanent residents of the NLSE, their transient habitats could also be deemed critical and protected as such.

Ecologically and Biologically Significant Areas

Ecologically and Biologically Significant Areas (EBSAs) are areas that have particularly high ecological or biological significance, such that, if perturbed severely, the ecological consequences (in space, in time, and/or outward through the food web) would be substantially greater than an equal perturbation of most other areas, and should therefore receive a greater-than-usual degree of risk aversion in management of activities in order to protect overall ecosystem structure and function within a Large Ocean Management Area (LOMA) (DFO 2007b).

In 2007, DFO Science identified 11 EBSAs for the Placentia Bay-Grand Banks (PBGB) LOMA contained within the NLSE (Fig. 33; DFO 2007b). Based on a prioritization exercise, EBSAs 1-3 were deemed high priority for conservation, EBSAs 4-7 were deemed medium priority, and EBSAs 8-11 were deemed low priority. Based on stakeholder and public consultations, these areas are those that are currently being considered for next steps in applying additional spatial and/or temporal based management measures within the NLSE in support of integrated management within the LOMA.

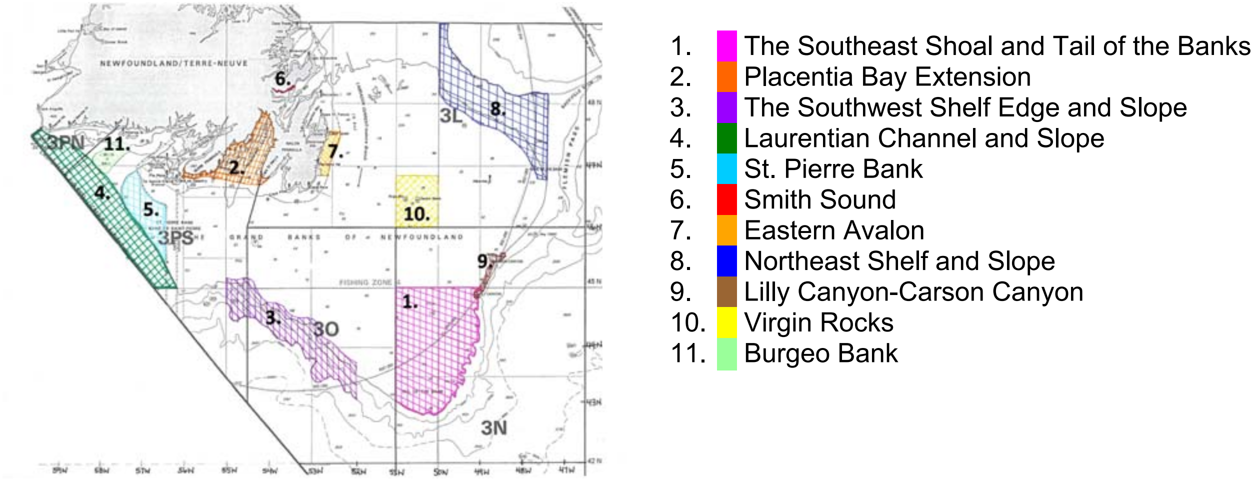


Figure 33. Placentia Bay Grand Banks Large Ocean Management Area: Ecologically and Biologically Significant Areas (DFO 2007b).

<u>Natural Disturbances</u>

Newfoundland and Labrador waters are among the stormiest in North America. During the summer and early fall, the weather is typically less stormy, but later in the fall, tropical storms originating near the equator can bring windy, wet weather as they pass through the NLSE. Over the past 35 years, an average of one tropical storm per year has passed within 300 km of Newfoundland, and in the fall and winter, hurricanes and fast-moving storms (up to 80 km/h), bring abundant and varied precipitation, and are likely to occur at least three or four times per year (Environment Canada 2006).

Ecologically, wind and storm events are a significant factor in modifying seasonal stratification patterns within the water column as they often result in the upwelling of cold nutrient rich water from lower depths.

<u>Major Human Stressors on Function and Processes</u>

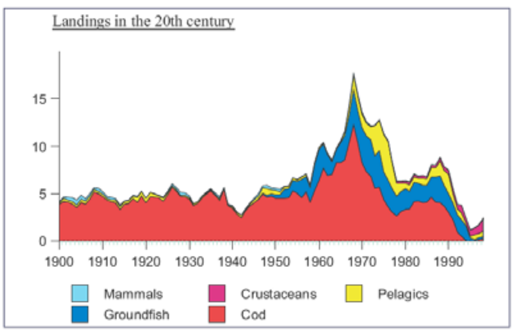
There are a multitude of activities taking place within the NLSE. However, many can be considered minor use of the area or are not anticipated to have significant impacts on marine ecosystem functions and processes (e.g. recreational boating and fishing; search and rescue; tourism). On the other hand, activities such as commercial fishing, petroleum production and exploration, shipping, and aquaculture have the greatest potential to interact with and influence the ecological function of the NLSE and its coastal regions. Petroleum production and exploration, shipping, and aquaculture are also those activities that are anticipated to continue to increase in frequency and effort in the area over time.

<u>Commercial Fisheries</u>

After an extended period of relatively consistent landings, fisheries yield from the NLSE increased starting in the 1950s and peaking in the 1970s with the expansion and deployment of long distant offshore fleets to the area. Landings steadily declined until 1977 when the 200 mile limit was implemented, increasing briefly followed by a further decline. At present, total yields are less than half of historical long-term averages from 1750 to 1950 (Rose 2003). Over time, the composition of the yield also changed from a historical exploitation of the upper trophic levels (seals and cod), with minor bait and food fisheries for capelin and herring, to mid-trophic levels in the mid-20th century (cod, haddock, flatfish, redfish), to lower trophic levels and pelagic and demersal planktivores and detritivores in the late 20th century (herring, capelin, shrimp, and crab) (Fig. 34a; Rose 2003).

Since the groundfish moratoria of the early 1990s, that affected most of the major commercial fish species, there has been a reorientation in the fishery towards shellfish due to the rapid increase of shrimp and crab populations (Fig. 34b). Due to the greater unit value of the invertebrate species, values of the landings are currently near or above record levels despite reduced tonnages. Commercial fisheries for large pelagic species such as swordfish, tuna and sharks are also carried out in the region (although at reduced levels in recent years), while commercial seal hunts are carried out each year primarily along the northeast coast of Newfoundland.

(a)



(b)

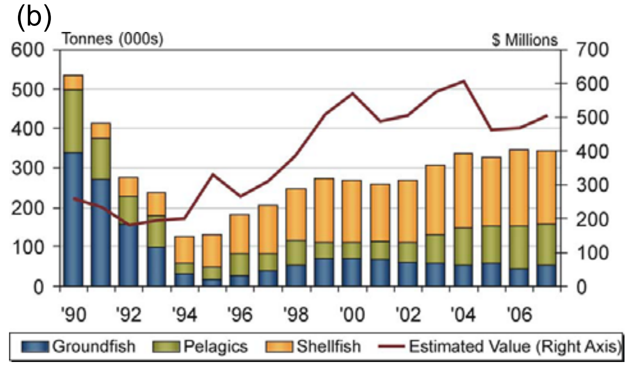


Figure 34. (a) Newfoundland and Labrador landings from 1900 to 2000 (landings in 100,000 t). (Rose, 2003), and (b) annual fishery landings volume and value for Newfoundland and Labrador for the period 1990-2006 (Government of Newfoundland and Labrador 2007).

Potential stressors resulting from the commercial fisheries include biomass removal (particularly overfishing and illegal fishing leading to unsustainable removal of biomass), bycatch and habitat destruction.

Unsustainable Biomass removal

Preliminary analysis of commercial landings of all groundfish, pelagic and shellfish species in the NLSE from 2004-2007 (Table 6) indicates average annual catches totalled 340,421 t – composed of 188,133 t of shellfish species, 188,133 t of pelagic species, and 49,486 t of groundfish species.

Table 6. Volume and of fisheries occurring in Newfoundland and Labrador for 2004-2007 (Department of Fisheries and Aquaculture; Department of Fisheries and Oceans Canada).

Target Species 2004-2007	Average Landings (tonnes/yr)	Target Species 2004-2007	Average Landings (tonnes/yr)	Target Species 2004-2007	Average Landings (tonnes/yr)
Cod	16,349	Shrimp	105,845	Mackerel	42,726
Turbot	10,649	Queen Crab	49,254	Capelin	36,420
Flounder	10,133	Surf Clams	16,255	Herring	23,263
Redfish	5,696	Other Shellfish	4,420	Other	394
Hake	1,852	Squid	2,476	**Total Pelagics**	**105,851**
Skate	1,326	Lobster	2,442		
Lumpfish Roe	1,080	Whelks	1,902		
Monkfish	898	Sea Scallops	1,616		
Pollock	691	Icelandic Scallops	1511	**Total Landed**	
Halibut	400	Propellor Clams	1,281	**(all species)**	**340,421**
Haddock	227	Other Crab	744		
Grenadier	108	Sea Urchin	388	Seals (number)	279,597
Other	80				
Total Groundfish	**49,486**	**Total Shellfish**	**188,133**		

Of the eleven fish and shellfish species in the NLSE managed by NAFO (cod, redfish, American plaice, witch flounder, yellowtail, Greenland halibut, white hake, skate, capelin, squid and shrimp) six are currently under partial to full closures in certain areas to prohibit directed fishing. Still, illegal take of some of these species protected by moratoria (often under the guise of permitted bycatch) remains a significant issue for conservation attempts.

Bycatch

A prime concern with fishing is often not directed fishing itself, but the elimination of many other species that are not primary targets (Myers and Ottensmeyer 2005). Beyond the concern of bycatch of untargeted fish species, fishery bycatch of large marine animals and seabirds within the NLSE has also been gaining attention in recent years, and observations collected by fishery observers has provided the information required to quantify bycatch of these species (e.g. Benjamins et *al.* 2008; Cooper et *al.* 2000). Although bird bycatch can be quite high locally, it appears that the effect at the population level is not severe at this time.

In the NLSE, fishery observers have been collecting information on bycatch over a wide range of fisheries since the 1980s and even more so since the 1990s when observer coverage expanded to many inshore fisheries. Non targeted species of bycatch include many species of invertebrates (e.g., corals and sponges), fish (pelagic and demersal), marine mammals (especially smaller species), reptiles (e.g., seaturtles), and seabirds. While the available data on bycatch has become increasingly important for the inclusion in management plans and recovery strategies for many species in the NLSE, a problem still lies with obtaining existing observer data for fisheries outside the 200 mile limit (EEZ). Recently, bycatch occurring just outside of the EEZ (and the NLSE), in NAFO Division O, has become a significant issue where excessive bycatch of cod has undermined a moratorium imposed in 1994, by peaking in 2003, when bycatch amounts were estimated to be over 80 per cent of the remaining cod stock (WWF 2009).

Still, an example of success in protecting non-target species in the NLSE exists in the Northern Shrimp fishery where the industry and DFO worked together to minimize bycatch (Kulka 1995; Kulka 1997; Orr et *al.* 2001). Through a combination of fishery observers to collect geo-referenced bycatch data, gear modification (introduction of the Nordmore grate with full implementation in 1993) and time-area closures, the Canadian northern shrimp fleet has become the most conservation-oriented offshore shrimp fleet in the world – reducing its by-catch levels of cod, Greenland halibut (Fig. 35), redfish (Fig 35), and American plaice to negligible levels (less than one tenth of one percent) in the very sensitive southern stock areas (FCC 2008).

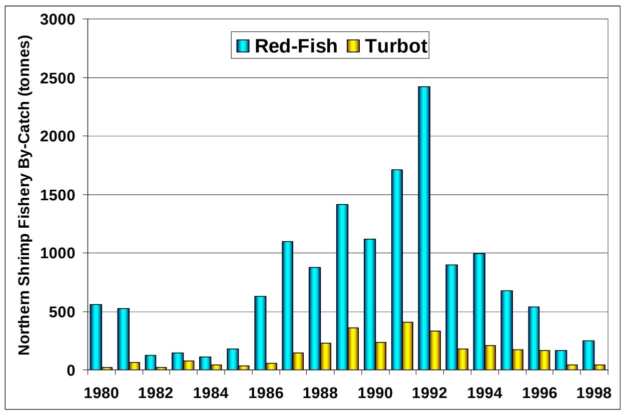


Figure 35. Biomass of redfish and turbot bycatch from Northern Shrimp fisheries from 1980-1998. A significant decrease in bycatch occurs after the introduction of Nordmore grates in 1993.

Illegal fishing

Previously, illegal capture from the sea had been common in Eastern Canada and incidences of dumping illegal bycatch at sea were difficult to quantify prior to the deployment of fishery observers. By the 1980s, outside of Canada's 200 mile limit, widespread problems of nets with illegal mesh size, illegal gear, high catches of juveniles, misreported catches, exceeded catch quotas and ships ignoring North Atlantic Fisheries Organization (NAFO) regulations were reported just outside of the NLSE (Walsh et *al.* 1995; Brodie 1996). However, total foreign effort declined from over 50 vessels per day prior to 1995 to 4-10 vessels per day in 2000 (DFO 2001).

Habitat destruction and accidental bycatch

Both fixed and mobile fishing gear is used in the commercial fishery within the NLSE. Fixed gears commonly include conical baited traps (crab), set and fixed gill nets, handlines and longlines, while mobile gears commonly include otter trawls, Danish seine, Scottish seine, midwater trawls, scallop dredges, hydraulic dredges and shrimp trawls/beam trawls. Both mobile and fixed forms of commercial fishing cause disturbance of the environment ranging from removal of target and bycatch species to alteration of the proximate benthic habitat and communities.

Of the fixed gears, conical baited traps are considered to have minimal impact on the seabed; gill nets (set and fixed) come into contact with the seabed but are not intended to penetrate the surface beyond where they are anchored; and handlines and longlines have little potential for habitat impact. However, conical and gill nets can ghost fish if they become detached, and gill nets and long lines can cause incidental harm or death to sea birds and marine mammals.

Mobile gears are generally more invasive on seabed habitat, but specific effect is largely related to the type of gear used, the level of exposure to natural disturbance, frequency, and the sensitivity of benthic flora and fauna. The structure and function of benthic communities can easily be changed by such disturbance (Gubbay and Knapman 1999; Hall-Spenser 1999; Jennings and Kaisier 1998; Greenstreet and Rogers 1999; Environment Canada 2001; Frid et *al.* 1999). Bottom otter trawls interact physically with the bottom sediment, and may result in removal or damage of sedentary living organisms (including seaweed or coral); Danish and Scottish seiners are less invasive than otter trawls, as they still make contact with the seabed, but do not use doors or rollers. Shrimp trawls or beam trawl impacts are similar to that described for the otter trawl (Kaiser and Spencer 1995). Kulka and Pitcher (2001) showed that about 20% of the shelf waters off Canada are trawled annually (1999-2000).

Scallop dredging penetrates the first few centimetres of seabed to force scallops out of the substrate, while hydraulic dredging uses pressurized water jets to wash clams out of the sand. Both forms of dredging have the potential to alter existing physical structures and communities (Bradshaw et *al.* 1999; Hall-Spencer and Moore 1999; Gilkinson et *al.* 2003; NOAA 2001).

Midwater trawls and purse seines are used for pelagic species and little or no contact with the seabed occurs. However, like all forms of fishing, accidental bycatch of non-target species is still possible although bycatch is generally very low in mid-water catches.

Petroleum Industry Activity

In the forty years since its initiation on the east coast shelf, petroleum industry activity has become a significant element of the NLSE landscape. To date, 23 significant discoveries have been made in the offshore area, including 5 on the Labrador Shelf and 18 on the Grand Banks (Figure 15). The total seabed under CLNOPB licenses as of September 2006 was 66,897 km^2, including 36 active exploration licenses (65,159 km^2), 44 significant discovery licenses (1,330 km^2) and 6 production licenses (408 km^2) (CNLOPB 2007). Table 7 provides and overview of petroleum production projects currently operating in the NLSE.

Average oil production rates for offshore Newfoundland and Labrador from 2003-2005 were near 320,000 barrels/day or 116.3 million barrels/year. The province's three producing offshore fields - Hibernia, Terra Nova and White Rose - reached a major milestone in early 2009, producing the province's one billionth barrel of oil.

Table 7. Overview of petroleum production projects currently operating in the NLSE.

Production Project	Start Date	Proven reserves – combined oil and natural gas liquids (million barrels)	Statistics up to August 2009		
			Development wells (to date)	Barrels oil produced	Cubic meters gas produced
Hibernia	1997	1442	66	650 273 395	26 577 377 000
Terra Nova	2002	357	35	278 881 012	9 177 694 000
White Rose	2003	379	24	131 822 978	3 020 186 000

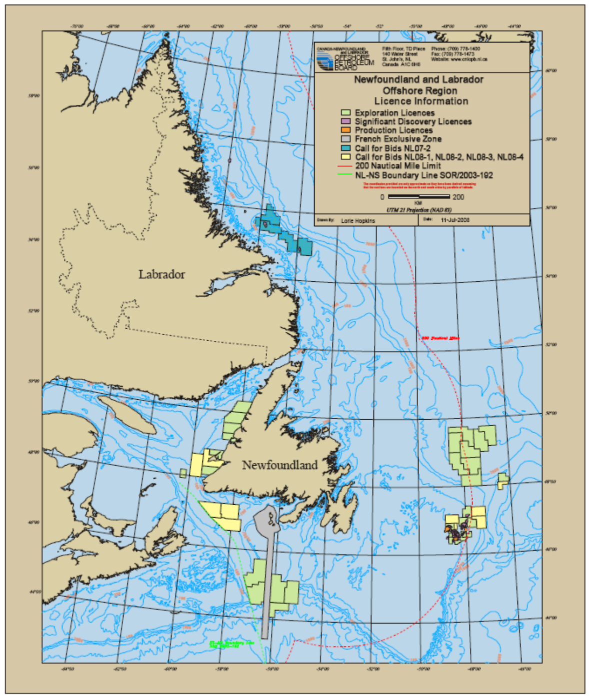


Figure 36. Petroleum areas of discovery and activity occurring in the NLSE (CNLOPB 2008).

Discharges

Discharges regularly associated with petroleum production and exploration include drill mud and cuttings, produced water, bilge water, ballast water, storage displacement water, deck drainage, cooling water, domestic waste, sewage, and air emissions.

Some studies (e.g. CAPP 2001; Husky Oil 2000) have confirmed that drill mud and cuttings from small scale drilling have no significant effect on the marine environment. However, others have found the effects of drill waste on organisms and benthic communities appear to vary with volume of mud cuttings discharged and proximity to the point of discharge, and are dependent on a number of local environmental variables (Hurley and Ellis 2004).

The largest volume of waste from oil and gas production, produced water, contains residual oil and often, trace metal concentrations which is usually discharged back into the marine environment. Regulations require that produced water be treated to 30 mg/L oil before discharge. However, the overall toxicity of produced water varies from non-toxic to toxic based on its chemical composition and the organisms considered. The remaining discharges - bilge, ballast, storage displacement and deck drainage waters, must be treated to 15 mg/L or less prior to discharge into the marine environment.

Blowouts and spills

Blowouts and spills occur as accidental events. From 1997 to 2005, a spill occurrence of rate of 1.6 spills (greater than or equal to 1000 bbl) per Bbbl oil production was estimated for the Newfoundland and Labrador offshore oil industry (JWL 2006). The fate and transport of a blowout or spill is dependant on size and environmental conditions.

The acute toxicity of a specific oil type is the result of the additive toxicity of individual compounds (JWL 2006). Sublethal effects following acute or chronic exposure include disruption in energetic processes, interference with biosynthetic processes and structural development, and direct toxic effect on developmental and reproductive stages; including impaired feeding mechanisms, growth rates, development rates, energetics, reproductive output, recruitment rates and increased susceptibility to disease and other histopathological disorders, where early developmental stages can be especially vulnerable (Capuzzo et *al.* 1988 in JWL 2006).

Birds are especially susceptible to direct contact with oil, with diving birds being the most susceptible. Most birds that come in contact with oil subsequently die since the presence of oil on a bird's feathers can destroy their waterproofing, insulating, and buoyancy capability, leading to hypothermia or drowning. Those that do not die from hypothermia or drowning may die from ingestion of significant quantities of oil during preening.

Other disturbances

Other disturbances incurred during the production and exploration phases include platform and associated infrastructure installation; including drills, glory holes, well heads, valves, pipes, sub-sea flowlines, etc., and are mainly associated with localized noise (discussed under 'Seismic activity') and dredging. Additionally, lights and flares associated with offshore installations have been shown to attract seabirds to the drilling and production platforms. On the Grand Banks, seabird concentrations have been found to be 19-38 times higher than on survey transects leading to the platforms (Weise and Montevecchi 2000), increasing the likelihood of accidental death during collision with structures.

Petroleum refining and storage – transportation

The North Atlantic Refining Limited oil refinery and the Transshipment Terminal are both located in a single bay, Placentia Bay, within the NLSE. The refinery has storage capacity for 7.2 million barrels of crude and product while the transshipment terminal has a capacity of 3 million barrels (Government of Newfoundland and Labrador 2005).

Transportation of petroleum to and from these facilities significantly increases ocean-going traffic and associated stressors in the area. The Brander-Smith Report in 1990 determined - *"the risk of spills is highest in Eastern Canada, particularly in Newfoundland. Placentia Bay is considered by many to be the most likely place in Canada for a major spill."* (CCMC 2004).

Seismic activity

Seismic exploration is used to determine the location and extent of possible hydrocarbon bearing formations (Hurley and Ellis 2004), and has been conducted in Newfoundland and Labrador waters since 1964. Since then, over 1,000,000 km of seismic survey tracks and 226 wells have been drilled within the Grand Banks region alone (CNLOPB 2006).

It can only be concluded that seismic sounds in the marine environment are neither completely without consequence, nor are certain to result in serious and irreversible harm given the available evidence to date (DFO 2004c). Loud noise does have the potential for detrimental effects on animals by imparting physical damage to sensitive organs (i.e., ear structures in vertebrates), by increasing stress or by causing behavioral changes (Christian et *al.* 2003). However, serious physiological and anatomical damage may also occur in the field, and lead to effects such as delayed mortality, increased susceptibility to disease and predation or impairment of egg quality (J. Payne, DFO pers. comm.). To date, it is not clear if any of these potential effects are significant at a population level.

Since marine mammals use sound to communicate and gain information anthropogenic noise does have the potential to interfere with an marine mammal's ability to detect sound (Richardson et *al.* 1995), cause a temporary reduction in hearing sensitivity (Kastack et *al.* 2005), and induce behaviors such as avoidance, deviation from normal migration routes, interruption of feeding, moving away from the noise sources, reduced surface interval, reduced dive duration, and lower numbers of blows (JWL 2006), and varies between species and individuals and space and time (NRC 2003).

<u>Marine Transportation</u>

The strategic location of Newfoundland and Labrador and its surrounding waters on the Great Circle Route between eastern North America and Europe makes it important for domestic and international shipping (e.g. Fig. 37). The Cabot Strait links trans-Atlantic shipping routes to the St. Lawrence Seaway and the Great Lakes, with over 6,000 commercial vessel transits annually.

Cargo and tanker vessels

The amount of cargo handled at major ports within the NLSE has increased significantly in recent years, driven by the production and movement of oil, demand for supply services by the offshore oil and gas industry, exports by manufacturers, and imports of consumer goods. The primary commodities being moved in the Atlantic region include crude oil, minerals and chemicals, paper and forest products, coal and coke, and various container goods.

Four locations involved with the movement of oil (Come By Chance, Whiffen Head, Hibernia and Holyrood) accounted for over 82% of total shipments in 1999 (Statistics Canada 2006b). The Ports of St. John's and Corner Brook are also major ports for shipments of consumer and industrial goods and handled 1.55 (96.9% domestic) and 2.29 (56% domestic) million t respectively in 2003 (Statistics Canada 2006b). The port of Come By Chance handled 43.69 million t (44 % domestic) in 2003, while the Newfoundland Offshore handled 17 million t (98.6% domestic) (Statistics Canada 2006b).

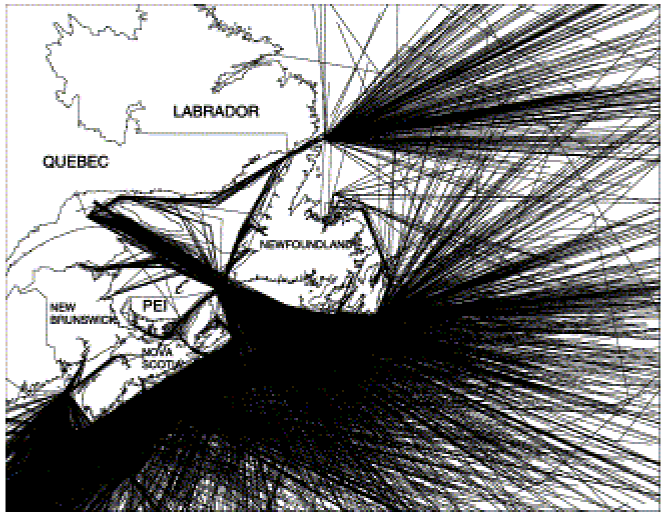


Figure 37. Typical annual ship track pattern of container, cargo and tanker vessels travelling to or through Atlantic Canada destined to Canadian ports in 1995. Patterns were similar in 1990–2000 (taken from Weise and Ryan 2003 - adapted from ECAREG).

Other vessels

In addition to large cargo vessels, the marine transportation sector includes ferries, tugs/barges, recreational boating, and cruise ship traffic.

Within the NLSE there are several ferry service routes: two operating between the island of Newfoundland and Nova Scotia, and several intra-provincial ferries operating between Newfoundland and nearby residential islands, and between Newfoundland and Labrador, where traffic has remained fairly static over time. Tug and barge activities and recreational boating are also common and tend to be restricted to coastal, inland and harbour waters. However, cruise ship traffic in and around the NLSE is on the increase, with over 148 port calls in 36 different ports in 2004 (CANAL 2005).

Bilge discharge

Currently, oil pollution prevention regulations authorize the controlled discharge of oily water at prescribed rates and at concentrations of 15 ppm in offshore waters (CCG 2001). However, the illegal release of oil into the marine environment from vessel engine room spaces is thought to be responsible for over 90% of deaths due to oil pollution in seabirds (CCG 2001). While some reports suggest as many as 100,000 or more birds perish each year as a result of oil in the marine environment in this area, other studies suggest actual mortality may be as high as 300,000 sea birds (CCG 2001). The short and long term impacts of oily waste discharges in the marine environment also impacts marine environmental quality, where offshore conditions have the ability to disperse oil on water over substantial areas in relatively short periods of time.

Ballast water

Ballasting and de-ballasting of vessels can introduce aquatic organisms and pathogens harmful to the marine environment as well as contribute to oil pollution. The increased volume of shipping in and around the NLSE coupled with the diverse international origins of many vessels makes this issue particularly important since some species of phytoplankton are known to impose detrimental effects on fish species when introduced into ecosystems (Coffen-Smout et *al.* 2001). Recently, experts met to identify alternative ballast water exchange zones for vessel traffic approaching Newfoundland and the Arctic for Transport Canada regulators, focusing on those that may pose a lower risk to fisheries resources and to the marine ecosystem (http://www.dfo-mpo.gc.ca/CSAS/Csas/Schedule-Horraire/Details/2009/01/01_13-14_e.htm).

Other impacts

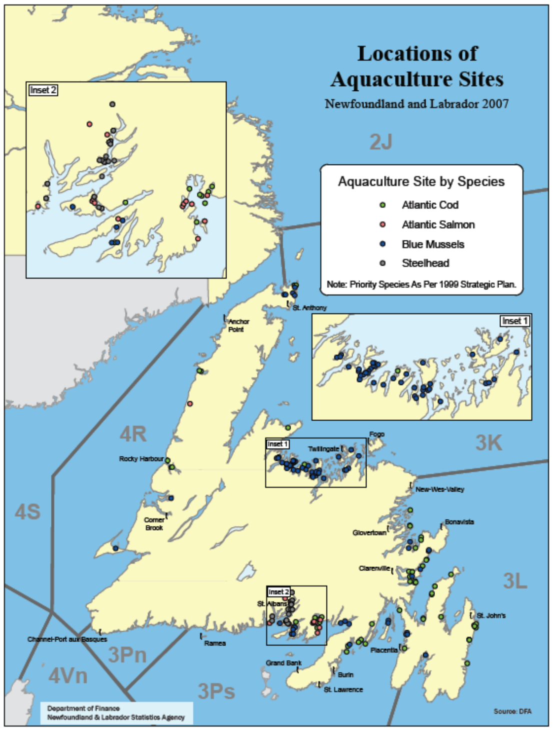
Increased marine transportation within the NSLE also increases the amount of anthropogenic noise in the environment, as well as the occurrence of collisions with marine mammals. In addition, the possibility always exists for vessels to collide with obstacles such as submerged objects, least depths, and other vessels, especially in embayments, coastal areas, and areas of high traffic.

Aquaculture

All aquaculture sites within the NLSE are situated around the island of Newfoundland, and all are located very near the coastline, usually no further than 5 nm from shore (Fig. 38). The primary aquaculture species in the area are Blue mussels, Atlantic salmon, Steelhead trout, and Atlantic cod. The largest concentration of aquaculture sites in the NLSE is located in the Bay d'Espoir region (Atlantic salmon and steelhead trout).

Aquaculture has increased rapidly in the NLSE over the last decade (Fig 38), and there is still much potential for development. The Newfoundland aquaculture industry experienced significant growth in recent years, increasing 112% from 1998 to 2004. In 2008, aquaculture production rose to record levels – from 8,300 tonnes in 2007 to an estimated 11,545 tonnes in 2008, largely reflecting the harvesting and processing of salmon on the south coast, and the result of significant investment in recent years (Government of Newfoundland and Labrador 2009).

Cod aquaculture is relatively new, but continues to be a high priority with a significant level of potential for rural communities in the province. Cod is recognized as an emerging opportunity worldwide and full-cycle cod aquaculture is proceeding with positive results in Newfoundland and Labrador.



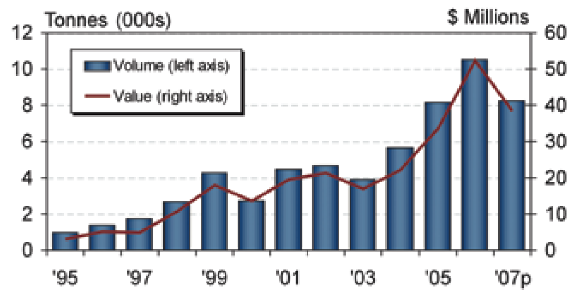


Figure 38. Location of Aquaculture sites occurring in Newfoundland and Labrador (Left); and Volume and value of Aquaculture in Newfoundland and Labrador 1995-2007 (Right) (Source: Department of Fisheries and Aquaculture, Government of Newfoundland and Labrador).

Environmental quality

Environmental issues relating to aquaculture are not currently a concern for interest groups in Newfoundland and Labrador, except in the Bay D'Espoir area where finfish farming is prevalent. Impacts to the environment surrounding aquaculture sites typically occur in the benthos rather than the water column, and heavily impacted areas can have a benthic shadow 10 to 22 times the area of the cages (Tlusty et *al.* 2000). Excessive fish loading can increase ammonia and deplete oxygen, while excess food and fish droppings can build up harmful sediments on the sea floor that can release lethal hydrogen sulphide. So far, the gases and dissolved chemicals in this region are well within safe limits.

Habitat changes

Habitat change for local species can be direct, such as displacement of individuals from actual farm locations, or more indirect such as alteration of an aspect of their habitat, life cycle, or food source. Habitat change can also include the attraction of many aquatic species to aquaculture operations due to feeding opportunities and cover offered by structures such as cages and anchors (AMEC 2002). Newfoundland and Labrador growers indicate that many opportunistic species such as lobster, urchin, cod, and starfish typically increase in number near cage/long line sites (AMEC 2002).

Genetic diversity

There is considerable concern regarding the deleterious effects of escapees of normally farmed fish and genetically modified organisms. The genetic diversity of wild stocks can threatened by escapes and accidental release of individuals that can out-compete wild fish. A reduction in genetic diversity then has the potential to lower the resistance of wild stocks to stress and disease.

Aquatic Invasive Species

Four aquatic invasive species – coffin box ectoprocts, golden star tunicates, violet tunicates, and green crab – have been confirmed to inhabit NLSE waters. However, given the very recent introduction of these species, the threat of other invasives eventually occupying our waters is significant due to invasives that have been identified in adjacent eastern provinces and New England states in areas with very similar marine environments to the south and east coasts of Newfoundland.

Coffin box ectoprocts have been found island wide, including coastal Labrador. They grow on kelp and have devastated kelp beds on both the west and southwest coasts of Newfoundland. Tunicates interfere with the settlement of bivalve larvae and compete for space and food with young native species. Tunicates can be especially destructive on mussel aquaculture sites where they compete for space and food and subsequently weigh down lines and halt production. Green crabs consume a variety of invertebrates, including mussels, and are extremely efficient predators and colonizers.

Although introductions of species are probably not as important in the open ocean, in coastal environments their effects can be devastating, and might include:

- Destruction of native habitats
- Loss of species biodiversity
- Impacts on fisheries resources
- Introduction of new predators and competitors
- Potential introduction of parasites and disease
- Increased labour and seafood production costs

ECOSYSTEM GOODS AND SERVICES

The economy and culture of Newfoundland and Labrador are intrinsically linked to the Atlantic Ocean and its resources. Therefore, it is important to quantify and appreciate the importance of oceans-related activity to the economy of Newfoundland and Labrador.

Economic value can be derived not only from ocean resources, but also from use of the ocean as a means of movement, operation, business activity, innovation, as well as regulation. Goods and services derived from the NLSE include both private sector industries (i.e., oil, fishery, aquaculture, shipbuilding, boatbuilding, marine tourism, marine transportation, and oceans technologies) and federal and provincial public sector oceans-related departments and agencies.

Value of Marine Resources

The most recent analysis of the value of the marine, coastal and ocean resources of Newfoundland and Labrador was prepared in 2005 by the Economics and Statistics Branch, Department of Finance for Fisheries and Oceans Canada for the period 2001 to 2004. The renewable marine resources of Newfoundland and Labrador are currently in a mix of conditions.

2001 to 2004 ocean related activities contributed $6.36 billion Gross Domestic Product (GDP) (41.3%), 27.0% labour income and 25.0% employment in Newfoundland and Labrador, including;

- 35.4 percent of GDP (including indirect and spin-off impacts), 19.9 percent of labour income, and 18.0 percent of employment from oil and fisheries industries alone,

- 4.4 percent of GDP, 4.3 percent of labour income and 4.7 percent of employment from other oceans-related activity from other private sector industries, such as tourism, transportation, and ship building, were also important, contributing, on average, about

- 1.5 percent of GDP, 2.9 percent of labour income, and 2.2 percent of employment from about 2500 public servants from various departments and agencies working in oceans related activity.

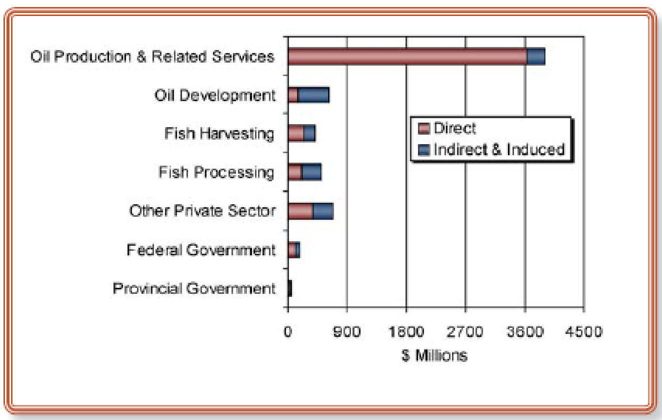


Figure 39. Direct and indirect value of marine, coastal and ocean resources of Newfoundland and Labrador for the period 2001-2004 (Government of Newfoundland and Labrador).

Cumulative Impacts on Ecosystem Properties and Components

Table 8. List of the main stressors resulting from human activities in the NLSE (adapted from GOSLIM EOAR, 2006).

ACTIVITY	SUB-ACTIVITY	STRESSORS																	
		Habitat destructions	Biomass removal	Spills	Wastes / sewage	Parasites / diseases	Invasive species	Nutrients/Org. Mat.	Dredging	Disposal at sea	Freshwater inputs	Collisions	Disturbance (sound, tresp)	Current obstruction	Contaminants	Produced waters	Meteorological Forcing	Currents / water masses	Coastal water levels
Fisheries	Commercial Fishing	X	X	X	X		X												
	Processing plants				X	X	X												
Aquaculture					X	X	X	X						X					
Marine transportation	Shipping			X	X		X					X	X		X				
Human settlement	Municipalities				X	X		X							X				
Industrial activities	Infrastructure				X	X		X							X				
Offshore Oil and gas	Seismic exploration												X						
	Exploratory drilling	X		X	X								X						
	Production	X		X	X			X					X		X	X			
	Coastal Storage/Transfer			X															
Climate change	Multiple activities					X	X				X						X	X	X
Recreational activities	Boating											X	X						
	Eco-tourism												X						
	Recreational fishing		X										X						

Fisheries (including Habitat destruction)	Chemical Contamination (including spills)	Invasive species	Collisions (marine mammals)
Habitat destruction	Wastes/sewage	Coastal Eutrophication	Disturbance
Freshwater inputs	Parasites and diseases	Dredging and At-sea disposal	Climate change

Stewardship and Conservation

The province of Newfoundland and Labrador has recently initiated the development of a province-wide coastal and ocean policy framework and strategic plan to support an integrated approach to coastal and ocean management. These efforts are in addition to, and also support, the goals of Canada's Oceans Action Plan (OAP), a similarly targeted initiative put forward by the Federal Government in 2005.

Several areas of the province of Newfoundland and Labrador have already taken the initiative at a community-level to develop integrated management committees to address coastal and ocean management in their particular region. Currently, two specific areas, the Coast of Bays and Placentia Bay, represent coastal management areas (CMAs) within the NLSE. These areas make use of collaboration among multi-sector oceans users to support environmental and economic well-being.

The *Oceans Act* sets out a management framework for Canada's oceans based on an ecosystem approach, with guiding principles of sustainable development, integrated management, and the precautionary principle. In 2004, under the Oceans Act and Canada's Oceans Strategy, Fisheries and Oceans Canada developed the Oceans Action Plan, intended to serve as a structure under which all ocean activities and management initiatives are to be coordinated.

Large Ocean Management Areas (LOMAs) are geographical areas designated by Fisheries and Oceans Canada, under the Oceans Action Plan, as having high priority for integrated ocean management. One such area, the Placentia Bay-Grand Banks LOMA, exists within the boundaries of the NLSE (Fig. 24).

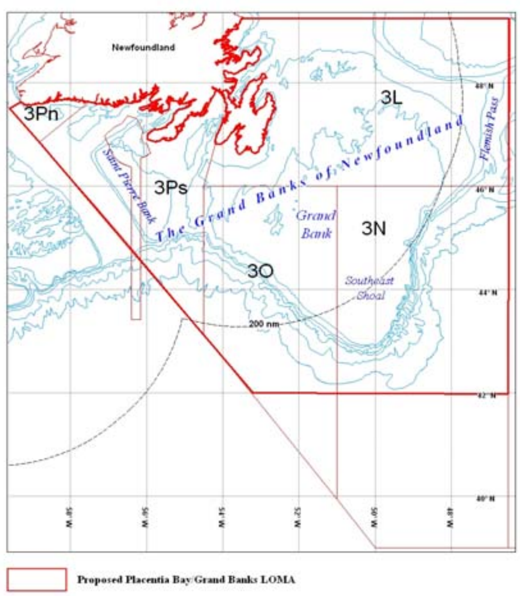


Figure 40. Placentia Bay-Grand Banks Large Ocean Management Area.

In addition, the NLSE is home to numerous ecological reserves, provincial parks, and natural areas representative of stewardship and conservation.

SUMMARY

The abiotic characteristics of the NLSE have changed notably over the past several decades, where the NAO has been a dominant climatic driver of oceanographic characteristics such as the strength of the Labrador Current, ice conditions, and water temperatures. These variations have, in turn, influenced many of the key ecological features of the ecozone.

Biological and ecological changes (e.g. increased mortality, species range expansions and contractions, and changes in fish size, assemblages, and community structure) are occurring in the NLSE; however their impact on ecosystems is not fully understood. A review of the status and trends of many of the biological components of the NLSE highlight notable events such as the major shift in species composition and community structure that occurred along the entire shelf in the early 1990s, including the catastrophic decline of groundfish stocks in the early 1990s after a prolonged period of heavy exploitation, and a decrease in the abundance of capelin, a key forage species, that was high in the 1980s, decreased dramatically in the early 1990s, and has remained low ever since. Knowledge gaps still exist surrounding the population dynamics and the distribution of capelin and other small pelagic species; trophic pathways and interspecies relationships; and information required to assess the status and trends of coastal zones.

Emerging issues in the NLSE include the potential increase in eel grass beds to lead to improved recruitment of fish, while the occurrence and impact of alien invasive species in selected areas of the ecozone could have local and broader, yet undefined, ecosystem impacts. As can be expected with increasing and diversifying ocean usage, industry and development have, or are threatening to, impact various components of the NLSE, where the effects of currently undefined and/or cumulative impacts is of particular concern.

ACKNOWLEDGEMENTS

The composition of this document, covering such a diversity of issues, would not have been possible without contributions from nearly all specialties within the Science Branch of the Department of Fisheries and Oceans, Newfoundland and Labrador Region. While much of the information contained herewithin was extracted from published documents originating within the Branch, its conveyance within the text often did not come without specific guidance from individual authors and/or through consultation with Regional subject experts. Outside of the Branch, the Regional Fisheries and Aquaculture Management and Policy and Economics Branches also personally provided much of the statistics-based information related to fisheries and aquaculture status and trends. Also of significant importance to compiling this document was guidance and review of early draft document versions provided by Henry Lear (DFO, NCR) and Risa Smith (Environment Canada). Much appreciation is also extended to external reviewers – M. B. Davis and D. W. Kulka – for comments and suggestions provided on the final draft.

Contributors: Robin Anderson, Chuck Bourgeois, Roanne Collins, Eugene Colbourne, Joe Craig, Bob Gregory, James Helbig, Mariano Koen-Alonso, Jack Lawson, Henry Lear, Cynthia MacKenzie, Eugene Murphy, Dave Orr, Becky Sjare, and Garry Stenson (DFO); Risa Smith and Tony Gaston (Environment Canada).

REFERENCES

Amos, C.L., 1990. Modern sedimentary processes, Chapter 11. In: Keen, M.J., and Williams, G.L. (eds). Geology of the Continental Margin of Eastern Canada. GSC, Geology Canada, no. 2, 609-673.

AMEC. 2002. Aquaculture information review – An evaluation of know effects and mitigations On fish and fish habitat in Newfoundland and Labrador. Can. Tech. Rep. Fish. Aquat. Sci. No. 2434.

Aquaculture, 2008. In Wikipedia, the free encyclopedia. Retrieved March 10, 2004, from http://en.wikipedia.org/wiki/Aquaculture

Bacon, S. and Carter, D.J.T., 1993. A connection between mean wave height and atmospheric pressure gradient in the North Atlantic. International Journal of Climatology 13, 423–436.

Benjamins, S, D. W. Kulka and J. Lawson 2008. Incidental catch of seabirds in Newfoundland and Labrador gillnet fisheries, 2001-2003. Endangered Species Research Vol. 5:149-160.

Bradbury I.R., Snelgrove P.V.R., and Fraser S. 2000. Transport and development of eggs and larvae of Atlantic cod, Gadus morhua, in relation to spawning time and location in coastal Newfoundland. Can.J. Fish. Aquat. Sci. 57:1761-1772.

Bradbury I.R., Snelgrove P.V.R., Fraser S. 2001. The influence of temperature on the loss of Atlantic cod (Gadus morhua) eggs and larvae from the inshore environment: a combined modelling and observational approach. Fish. Oceanogr. 10: 342-352 p.

Bradshaw, C., Veale, L.O., Hill, A.S., and Brand, A.R. 1999. The effects of scalloping on Gravelly seabed communities. In The effects of fishing on non-target species and habitats: biological conservation and socio-economic issues. Blackwell Science.

Breeze H, Davis D.S, Butler, M., Kostylev, V. 1997. Distribution and status of deep sea corals off Nova Scotia. Marine Issues Committee's special publication number 1. Ecology Action Centre, Halifax, Nova Scotia

Breeze, H., Fenton, D.G., Rutherford, R. J., and Silva, M.A. 2002. The Scotian Shelf: an Ecological Overview for Ocean Planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393.

Brodie, W.B. 1996. Should closed areas be considered as a management measure in future fisheries for cod and flatfish on the Southern Grand Bank. NAFO SCR Doc. 96/63. Serial no. N2739. Northwest Atlantic Fisheries Organization.

Brodie, W. B., Stephen J. Walsh, Morgan, M. J. and Dwyer, K. S. 2004. An Assessment of the Grand Bank Yellowtail Flounder Stock, NAFO Divisions 3LNO, in 2004. NAFO SCR Doc. 04/54

Brown, R.G.B. 1986. Revised altas of eastern Canadian seabirds. 1. Shipboard surveys. Can. Wildl. Ser. Ottawa. 111 p.

Buchanan, R.A. and Foy, M.G. 1980. Offshore Labrador Biological Studies, 1979: Plankton, Nutrients, chlorophyll, phytoplankton and icthyolplankton. ABS Ltd. (LGL-Northland) Report to Total Eastcan Explorations Ltd. 293 p.

CANAL, 2005. CANAL (Cruiseship Assocation of Newfoundland and Labrador) [Online]. Retrieved January 12, 2005 from http://www.cruisenewfoundland.com/cruise sched4.html

CAPP. 2001. Offshore Drilling Waste Management Review. Pub # 2001-0007. 268 p.

CAPP. 2009. The Newfoundland and Labrador oil and gas industry – leveraging opportunities. [Online] Retrieved from http://www.capp.ca/getdoc.aspx?dt=NTV&docID=152432

Capuzzo, J. M., M.N. Moore and J. Widdows. 1988. Effects of toxic chemicals in the marine environment: Predictions of impacts from laboratory studies. Aquat. Toxicol. 11: 303-311.

Cardinal, A. 1968. Repertoire des algues marines benthiques de l'est du Canada. Cahier d'information (Quebec (Province). Station de biologie marine (Grande-Riviere, Quebec)); 48 p.

Carscadden, J. E., and Nakashima, B. S. 1997. Abundance and changes in distribution, biology, and behavior of capelin in response to cooler waters of the 1990s. 457–468. In Proceedings of the Symposium Forage Fishes in Marine Ecosystems AK-SG-97-01. 816 p.

Cayan, D. R., and Reverdin, G. 1994. Monthly precipitation and evaporation variability estimated over the North Atlantic and North Pacific. In Atlantic climate change program: proceedings of PI's meeting, Princeton, May 9–11, 28–32.

Cazenave, A, Nerem, RS. 2004. Present-day sea level change: observations and causes. Reviews of Geophysics. 42: RG3001.

CCG. 2001. Prevention of Oiled Wildlife Project (POW), Phase III, Prevention: The solution. St. John's, Newfoundland, 24 p.

CCMC. 2004. Placentia Bay Information Seaway Pilot Project – Stakeholder Workshop. Proceedings.

Chabot, D., and Dutil, J.D. 1999. Reduced growth of Atlantic cod in no-lethal hypoxic conditions. J. Fish. Biol. 55: 472-491.

Christian, J., Mathieu, A., Thomson, D., White, D., and Buchanan, R. 2003. Effects of seismic energy on snow crab (Chionoecetes opilio). Environmental Studies Research Funds Report No. 144. Calgary. 106 p.

Coffen-Smout., S., Halliday, R. G., Herbert, G., Potter, T., and Witherspoon, N. 2001. Ocean Activities and Ecosystem Issues on the Eastern Scotian Shelf: An Assessment of Current Capabilities to Address Ecosystem Objectives. CSAS Res. Doc. 2001/095.

Colbourne, E. 2000. Oceanographic conditions in NAFO Divisions 2J3KLMNO during 1999 with comparisons to the long-term (1961-1990) average. CSAS Res. Doc. 20008/48.

Colbourne, E. B. 2002. Decadal Changes in the Ocean Climate in Newfoundland and Labrador waters from the 1950s to the 1990s. E-Journal of Northwest Atlantic Fishery Science. 34 (article 4). http://journal.nafo.int/34/34.html

Colbourne, E. B. 2004. State of the ocean: physical oceanography in the Newfoundland and Labrador Region. Ecosystem Status Report. 2004/001..

Colbourne, E. B., J. Craig, C. Fitzpatrick, D. Senciall, P. Stead and W. Bailey. 2007. An Assessment of the Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2006. NAFO SCR Doc. 2007/20.

Colbourne, E. B., de Young, B., Narayanan, S., Helbig, J. 1997. Comparison of hydrography and circulation in the Newfoundland Shelf during 1990-1993 with the long-term mean Can. J. Fish. Aquat. Sci. 54(suppl. 1): 68-80.

Colbourne, E. B., and Murphy, E.F. 2002. Recent trends in bottom temperatures and distribution and abundance of cod (Gadus morhua) in NAFO Subdivisions 3Pn and 3Ps from the winter/spring multi-species surveys CSAS Res. Doc. 2002/001.

Cooper, J., E. Dunn, D. W. Kulka, K. Morgan, and K. S. Rivera 2000. Addressing the problem: seabird mortality from longline fisheries in the waters of arctic countries. In "WS on Seabird Incidental Catch In the Waters of Arctic Countries, Report and Recommendations. CAFF Tech. Rept. No. 7 33-42.

Cote, D., Moulton, S., Frampton, P.C.B., Scruton, D.A., McKinley, R.S. 2003. Habitat use and early winter movements by juvenile Atlantic cod in a coastal area of Newfoundland. J. Fish Biol. 64:665-679.

Dalley, E.L., and Anderson, J.T. 1997. Age-dependent distribution of demersal juvenile Atlantic cod (Gadus morhua) in inshore/ offshore northeast Newfoundland. Can. J. Fish. Aquat. Sci. 54(Suppl. 1): 168-176.

Deichman, E. 1936. The Alcyonaria of the western part of the Atlantic Ocean. Harvard University, Museum of Comparative Zoology Memoirs 53:1–317.

Deser, C. and Blackmon, M.L., 1993. Surface climate variations over the North Atlantic Ocean during winter: 1900–1989. Journal of Climate 6, 1743–1753.

DFO. 2001. Untitled information on NAFO Fishery Operations. NAFO Operations. Conservation and Protection Division. Fisheries and Oceans Canada St. John's, NL. Unpublished.

DFO. 2004a. Conservation Measures for the 16 Aquatic Species under Consideration for Listing under the Species at Risk Act (SARA). [Online]. Accessed at http://www.dfo-mpo.gc.ca/media/back-fiche/2004/sara16-eng.htm

DFO. 2004b. Government of Canada Announces New Measures to Combat Foreign Overfishing. May 6, 2004. [Online]. Accessed at http://www.dfo-mpo.gc.ca/media/npress-communique/2004/hq-ac45-eng.htm

DFO. 2004c. Review of Scientific Information on Impacts of Seismic Sounds on Fish, Invertebrates, Marine Turtles, and Marine Mammals. Habitat Status Report 2004/02.

DFO. 2005. Stock Assessment Update on Groundfish in Newfoundland and Labrador Region. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/051.

DFO. 2006. Final Report of the Fisheries Oceanography Committee 2006 Annual Meeting; 29 -31 March 2006. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2006/033.

DFO, 2007a. Final Report of the Fisheries Oceanography Committee 2007 Annual Meeting; 3-5 April 2007. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/053.

DFO. 2007b. Placentia Bay-Grand Banks Large Ocean Management Area Conservation Objectives. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/042.

DFO. 2007c. Seals and Sealing in Canada: The Canadian Seal Hunt - A Timeline. [Online] http://www.dfo-mpo.gc.ca/seal-phoque/reports-rapports/facts-faits/facts-faits_tl_e.htm

DFO. 2007d. 2006 State of the Ocean: Physical Oceanographic Conditions in the Newfoundland and Labrador Region. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2007/025.

DFO. 2008a. Assessment of capelin in SA 2 + Div. 3KL in 2008. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/054.

DFO. 2008b. Assessment of Divisions 2G-3K Northern Shrimp. Can. Sci. Advis. Sci. Stock Advisory Report 2008/008.

DFO. 2008c. 2007 State of the Ocean: Chemical and Biological Oceanographic Conditions in the Newfoundland and Labrador Region. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/038.

DFO, 2008d. 2007 State of the Ocean: Physical Oceanographic Conditions in the Newfoundland and Labrador Region. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/017.

DFO. 2008e. Underwater World – American Plaice. [Online]. Accessed at http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/plaice/plaice-plie-eng.htm.

DFO. 2008f. Underwater World – Yellowtail Flounder. [Online]. Accessed at http://www.dfo-mpo.gc.ca/zone/underwater_sous-marin/YFlounder/yellow-eng.htm

DFO. 2009a. Assessment of American lobster in Newfoundland. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/026.

DFO. 2009b. Assessment of Newfoundland and Labrador Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/045.

DFO. 2009c. Does eelgrass (Zostera marina) meet the criteria as an ecologically significant species? DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/018.

DFO. 2009d. Stock Assessment of Subdivision 3Ps cod. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/008.

DFO. 2009e. Stock Assessment of Newfoundland and Labrador Atlantic Salmon - 2008. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/063.

DFO. 2009f. Stock Assessment of Northern (2J3KL) cod in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/009.

DFO. 2010. Current Status of Northwest Atlantic Harp Seals, *Pagophilus groenlandicus*. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/074.

Drinkwater, K.F. 1994. Climate and oceanographical variability in the northwest Atlantic during the 1980s and early-1990s. NAFO SRC Doc 94/71.

Drinkwater, K.F., 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early 1990s. NAFO Scientific Council Studies 24, pp

Drinkwater, K.F., 2006. The regime shift of the 1920s and 1930s in the North Atlantic, Progress in Oceanography 68, 134–151.

Drinkwater, K.F., Pettipas, R., and Petrie, L. 2000. Overview of environmental conditions in the Northwest Atlantic in 2000. NAFO SCR Doc. 2001/36.

Dwyer, K.S., Morgan, M.J., Maddock Parsons, D., Brodie, W.B., and Healey, B.P. 2009. An assessment of American plaice in NAFO Div. 3LNO. NAFO SCR Doc. 09/035. Northwest Atlantic Fisheries Organization.

Edinger, E., Baker, K., Devillers, R. and Wareham, V. 2007. Coldwater corals off Newfoundland and Labrador - Distribution and fisheries impacts. World Wildlife Fund (WWF) report, 41 p.

Environment Canada. 2001. Ecological Monitoring and Assessment Network [Online]. Retrieved at http://www.eman-rese.ca/eman/reports/publications/biodiv-sci-asses/biodiv12.htm

Environment Canada. 2006. Atlantic Climate Centre: The Climate of Newfoundland. [Online] Retrieved at http://atlantic-web1.ns.ec.gc.ca/climatecentre/default.asp?lang=En&n=83846147-1

Environment Canada. 2009. "Status and Trends of Eelgrass in Eastern Canada" [Presentation] Northeast Eelgrass Workshop, Portland Maine, February 24, 2009.

Fang, Z. and Wallace, J.M., 1994. Arctic sea-ice variability on a time-scale of weeks and its relation to atmospheric forcing. Journal of Climate 7, 1897–1914.

Farmer, G.H. 1981. The cold ocean environment of Newfoundland. In: Macpherson, A.G., and Macpherson, J.B. (eds.). The Natural Environment of Newfoundland, Past and Present. Memorial University Printing Services, St. John's, 265 p.

Fisheries Resource Conservation Council (FRCC). 1995. A conservation framework for Atlantic lobster. Report to the Minister of Fisheries and Oceans, FRCC95.R.1, Ottawa, Ontario.

Frankignoul, C., de Coëtlogon, G., Joyce, T.M. and Dong, S. 2001. Gulf Stream variability and ocean-atmosphere interactions. J. Phys. Oceanogr. 31: 3516-3529.

Frid, C.L.J., Clark, R.A., and Hall, J.A. 1999. Long-term changes in the benthos on a heavily fished ground off the NE coast of England. Mar. Ecol. Prog. 188: 13-20.

Gaston, A. J., Bertram, D. F., Boyne, A., Chardine, J., Diamond, A. W., Gilchrist, H. G., Hipfner, J. M., Lemon, M. J. F., Mallory, M. L., Montevecchi, W. A., Rail, J. F., and Robertson, G. J. Seabird Ttrends for Canada. 2008. Technical Background Reports: Ecosystem Status and Trends Report for Canada (in preparation).

Gilkinson, K. 1986. Review and assessment of the literature on marine benthic molluscs (Amphineura, Bivalvia, Gastropoda) in Newfoundland and Labrador waters. NAFO Science Council Studies, 10: 93-108.

Gilkinson, K.D., Fader, G.B.J., Gordon, Jr., D.C., Charron, R., McKeown, D., Roddick, D., Kenchington, E.L.R., MacIsaac, K., and Bourbonnais, C. 2003. Immediate and longer-erm impacts of hydraulic clam dredging on an offshore sandy seabed: effects on physical habitat and processes of recovery. Continental Shelf Research.

Government of Newfoundland and Labrador. 2004. Department of Finance: Economic Review Newfoundland & Labrador.

Grant, S.M. and Brown, J.A. 1998. Diel foraging cycles and interactions among juvenile Atlantic cod (Gadus morhua) at a near shore site in Newfoundland), Can. J. Fish. Aquat. Sci. 55: 1307−1316.

Greenstreet, S.P.R., and Rogers, S.I. 1999. Effects of fishing on non-target fish species. In The effects of fishing on non-target species and habitats: biological conservation and socio-issues. Blackwell Science.

Gregory, R. S., and Anderson, J. T. 1997. Substrate selection and use of protective cover by juvenile Atlantic cod Gadus morhua in inshore waters of Newfoundland. Marine Ecology Progress Series 146: 9–20.

Gubbay, S., and Knapman, P.A. 1999. A review of the effects of fishing within European marine sites. English Nature (UK Marine SACs Project). Peterborough, England. 134 pp.

González-Troncoso, D., Gonzalez, C. and Paz, X. 2009. Atlantic cod and Yellowtail flounder indices from the Spanish Survey conducted in Divisions 3NO of the NAFO Regulatory Area. NAFO SCR Doc. 09/009. Northwest Atlantic Fisheries Organization.

Hall-Spencer, J., and Moore, P.G. 1999. Impact of scallop dredging on maerl grounds. In The effects of fishing on non-target species and habitats: biological conservation and socio-economic issues. Blackwell Science.

Han, G. and D.W. Kulka 2007. Dispersion of eggs, larvae and pelagic juveniles of White Hake (*Urophycis tenuis*, Mitchill 1815) on the Grand Banks of Newfoundland in relation to subsurface currents. J. Northw. Atl. Fish. Sci., Vol. 41: 183–196.

Healey, B.P. 2009 Greenland halibut *(Reinhardtius hippoglossoides)* in NAFO Subarea 2 and Divisions 3KLMNO: Stock Trends based on annual Canadian Research Vessel survey results during 1978-2008. NAFO SCR Doc. 09/033. Northwest Atlantic Fisheries Organization.

Heath, M.R. 1992. Field investigations of the early life stages of marine fish. Adv. Mar. Biol. 28: 2–174.

Hilmi, K., Murty, T., El Sabh, M.I., and Chanut, J-P. 2002. Long-Term and Short-Term Variations of Sea Level in Eastern Canada: A Review. Marine Geodesy, Volume 25, Numbers 1-2, 1 February 2002 , 61-78(18)

Houde, E. D. 1987. Fish early life dynamics and recruitment variability.17–29. in R. D. Hoyt, editor. 10th annual larval fish conference. American Fisheries Society, Symposium 2, Bethesda, Maryland.

Hurley, G., and Ellis, J. 2004. Environmental effects of exploratory drilling offshore Canada: Environmental effects monitoring data and literature review- Final Report. The Canadian Environmental Assessment Agency, Regulatory Advisory Committee (RAC).

Hurrell, J.W. 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. Science, 269, 676-679.

Hurrell, J.W., 1995. Transient eddy forcing of the rotational flow during northern winter. Journal of Atmospheric Science 52, 2286–2301.

Hurrell, J.W., and van Loon, H. 1997. Decadal variations in climate associated with the North Atlantic Oscillation. Climatic Change 36(3-4): 301-326.

Husky Oil Operations Limited. 2000. White Rose oilfield comprehensive study. 639 p + Appendices.

JWL (Jacques Whitford Limited). 2006. DRAFT TWO Strategic Environmental Assessment for the Sydney Basin Offshore Area. Prepared for CNLOPB. 269 p. + appendices.

Jennings S., and Kaiser, M. 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34: 201-352.

Johns, W.E., Shay, T.J., Bane, J.M., and Watts, D.R. 1995. Gulf Stream structure, transport And recirculation near 68oW. J. Geophys. Res. 100: 817-838.

Johnson, D.L., Berrien, P.L., Morse, W.W., and Vitaliano, J.J. 1999. American plaice, Hippoglossoides platessoides, Life History and Habitat Characteristics. Essential Fish Habitat Source Document. NOAA Technical Memorandum NMFS-NE-123.

Jury, S.H., Field, J.D., Stone, S.L., Nelson, D.M., and Monaco, M.E. 1994. Distribution an abundance of fishes and invertebrates in North Atlantic Estuaries. ELMR Rep. No. 13. NOAA/NOS Strategic Environmental Assessment Div., Silver Spring, MD. 221 p.

Kaiser, M.J., and Spencer, B.E. 1995. Survival of by-catch from a beam trawl. Mar. Ecol. Prog. 126: 31-38.

Kaiser M.J. Attrill M.J., Jennings, S., Thomas D.N., Barnes D.K.A., Brierley A.S., Polunin N.V.C., Raffaelli D.G., and Williams, P.J. Le B. 2005. Marine Ecology: Processes Systems and Impacts. Oxford University Press. 584 p.

Keats, D.W. 1990. A nocturnal inshore movement of juvenile cod Gadus morhua L. in eastern Newfoundland. Journal of experimental marine biology and ecology 139: 167-173.

Keats, D.W., South, G.R., and Steele, D.H. 1987. The role of macroalgae in the distribution and feeding of juvenile cod (Gadus morhua L.) in inshore waters of eastern Newfoundland. Can. J. Zool. 65: 49-53.

Kenchington, E.L.R., J. Prena, K. Gilkinson, D.C. Gordon, K. MacIsaac, C. Bourbonnais, P. Schwinghamer, T.W. Rowell, D.L. McKeown and W.P. Vass. 2001. Effects of experimental otter trawling on the macrofauna of a sandy bottom ecosystem on the Grand Banks of Newfoundland. Can. J. Fish. Aquat. Sci. 58: 1043-1057.

Kiceniuk, J.W., Colbourne, E. 1997. Relating oxygen levels in the Newfoundland offshore waters to the physiology of Atlantic cod (Gadus morhua). Can. J. Fish. Aquat. Sci. 5 (Suppl): 81-87.

Koeller, P.A. 2000. Relative importance of abiotic and biotic factors to the management of the northern shrimp (Pandalus borealis) fishery on the Scotian Shelf. Journal of Northwest Atlantic Fisheries Science 27, 21–33.

Koeller, P.A., L. Coates-Markle, and Neilson, J.D. 1989. Feeding ecology of juvenile (age-0) silver hake (Merluccius bilinearis) on the Scotian Shelf. Can. J. Fish. Aquat. Sci. 46 1762-1768.

Kulka D. W. 1995. Bycatch of commercial groundfish species in the northern shrimp fisheries, 1980-1994. DFO Atlant. Fish. Res. Doc. 95/48. 16 p.

Kulka, D. W. 2009. Spatial Analysis of Plaice and Cod Bycatch in the Yellowtail Flounder Fishery on the Grand Bank. WWF Tech Rep. In press

Kulka, D.W., and Pitcher, D.A. 2001. Spatial and Temporal Patterns in Trawling Activity in the Canadian Atlantic and Pacific. ICES CM 2001/R:02 57 p.

Kulka D. W., N. C. Antle and J. M. Simms 2003. Spatial Analysis of 18 Demersal Species in Relation to *Petroleum Licence Areas* on the Grand Bank (1980-2000) Can. Tech. Report of Fish. and Aquat. Sciences 2473, 202 p. http://www.dfo-mpo.gc.ca/Library/273513.pdf

Kulka, D. W., M. R Simpson and R. G. Hooper 2004. Changes in Distribution and Habitat Associations of Wolffish (Anarhichidae) in the Grand Banks and Labrador Shelf. Atl Fish. Res. Doc. 04/113 44.

Lalli, C.M. and Parsons, T.R. 1996. Biological Oceanography: An Introduction. Publ. Butterworth/Heinemann, (Oxford) 406 p.

Lavigne, D.M., 1996. Ecological interactions between marine mammals, commercial fisheries, and their prey: unravelling the tangled web. In: Montevecchi, W.A., Editor, 1996. Studies of High-Latitude Seabirds. 4. Trophic Relationships and Energetics of Endotherms in Cold Ocean Systems. Canadian Wildlife Service Occasional Paper 91, CWS, Ottawa, Canada, 59–71.

Lawson, J.W., Anderson, J.T., Dalley, E.L., and Stenson, G.B. 1998. Selective foraging by Harp Seals Phoca groenlandica in nearshore and offshore waters of Newfoundland, 1993 and 1994. Marine Ecology Progress Series 163: 1-10.

Lawson. J.W., and Gosselin, J.-F. 2009. Distribution and preliminary abundance estimates for cetaceans seen during Canada's marine megafauna survey - A component of the 2007 TNASS. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/031. vi + 28 p.

Laurel, B. J., Gregory, R.S. and Brown, J.A. 2003. Predator distribution and habitat patch area determine predation rates on age 0 juvenile cod. Mar. Ecol. Prog. Ser. 251:245-254.

Lilly, G. R. 1994. Predation by Atlantic cod on capelin on the southern Labrador and Northeast Newfoundland shelves during a period of changing spatial distributions. ICES Marine Science Symposia, 198: 600–611.

Lindholm, J.B., Auster, P.J., Kaufman, L.S. 1999. Habitat-mediated survivorship of juvenile (0-year) Atlantic cod Gadus morhua. Mar. Ecol. Prog. Ser. 180:247–255.

Lock, A.R., Brown, R.G.B., and Gerriets, S.H. 1994. Gazetteer of Marine Birds in Atlantic Canada: An Atlas of sea bird vulnerability to oil pollution. Canadian Wildlife Service Atlantic Region, Environment Canada.

Lough, R.G., Valentine, P.C., Potter, D.C., Auditore, P.J., Bolz, G.R., Neilson, J.D., and Perry R.I. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment ype and bottom currents on eastern Georges Bank. Mar. Ecol. Prog. Ser. 56:1–12.

Maddock Parsons, D., and Brodie, B. 2008. Distribution and Abundance of Yellowtail Flounder (*Limanda ferruginea*) on the Grand Bank, NAFO Divisions 3LNO, from Canadian Bottom Trawl Survey Estimates from 1984-2007. NAFO SCR Doc. 08/44. Northwest Atlantic Fisheries Organization.

Maillet, G., and Colbourne, E. 2007. Variations in the Labrador Current Transport and Zooplankton Abundance on the NL Shelf. NAFO SCR Doc. 07/042. Northwest Atlantic Fisheries Organization.

Mann, C.R. 1967. The termination of the Gulf Stream and the beginning of the North Atlantic Current. Deep-Sea Research, 14, 337-359.

Marko, J.R., Fissel, D.B., Wadhams, P., Kelly, P.M. and Brown, R.D., 1994. Iceberg severity off Eastern North America: it's relationship to sea ice variability and climate change. Journal of Climate 7, 1335–1351.

Marshall, J., Kushnir, Y., Battisti, D., Chang, P., Hurrel, J., McCartney, M., & Visbeck, M. 1997. A White Paper on Atlantic Climate Variability. http://geoid.mit.edu/accp/avehtml.html.

MCBI. 2008. From Sea to Shining Sea: Oceanographic and Bathymetric Features [Online]. http://www.mcbi.org/shining_sea/theme_oceanography.htm

Memorial University of Newfoundland. 2008. Newfoundland and Labrador Heritage Website: Post-1949 Communications and Transportation [Online].

Methven, D.A., Haedrich, R.L., and Rose, G.A. 2001. The Fish Assemblage of a Newfoundland Estuary: Diel, Monthly and Annual Variation. Estuar. Coast. Shelf Sci. Vol. 52, no. 6, 669-687.

Mortensen, P.B., Buhl-Mortensen, L., Gordon D.C. Jr, Fader, G.B.J., McKeown, D.L. and Fenton, D.G. 2002. Effects of fisheries on deep-water gorgonian corals in the Northeas Channel, Nova Scotia (Canada). In Thomas, J. and Barnes, P. (eds). Effects of fishing activities on benthic habitats: Linking geology, biology, socioeconomics, an management. AFS Symposium, November 12-14, 2002, Tampa, Florida.

Movchan, O.A. 1963. Quantitiative development of the phytoplankton in the areas of the Newfoundland and Flemish Cap banks and in adjacent waters. p. 205-213. In: Soviet Fisheries Investigations in the Northwest Atlantic.

Myers, R.A., and Ottensmeyer, C.A. 2005. Extinction Risk in Marine Species. in Norse, E.A., and Crowder, L.B. eds. Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity. Island Press, Washington DC (USA).

Myers, R. A., Akenhead, S. A., and Drinkwater K. 1990. The influence of Hudson Bay runoff and ice-melt on the salinity of the Inner Newfoundland Shelf. Atmos.- Ocean. 28: 120 157.

NAFO. 2005. Caution! Subsurface Moorings in Flemish Pass [Online]. Retrieved September 20, 2005 from: http://www.nafo.ca/Info/Web/mooring.pdf

NAFO. 2007. Cod *(Gadus morhua)* in Divisions 3N and 3O. [Online]. Accessed at http://www.nafo.int/fisheries/frames/fishery.html

NAFO. 2008. Report of Scientific Council Meeting, 5-19 June 2008.

NOAA. 2001. Effects of Fishing Gear [Online]. Retrieved May 2006 from: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0201/0201effects.htm

NRC (National Research Council). 2003. Marine Mammals and Low-frequency Sound Progress Since 1994. National Academy Press, Washington DC. 158 pp.

Orr, D. C., D. W. Kulka, P. J. Veitch and J. Firth 2001. Groundfish Bycatch within the inshore vessel (<500 ton; < 100') Shrimp Fishery off the East Coast of Newfoundland and Labrador during 2000. NAFO SCR Doc. 2001/46, Ser. No. N4424 8 p.

Orr, D. C., Veitch, P. J., and Sullivan, D. J. 2003. Northern shrimp (*Pandalus borealis*) off Baffin

Island, Labrador and northeastern Newfoundland. DFO Can. Sci. Adv. Sec. Res. Doc. 2003/050.

Orr, D. C., Veitch, P. J., and Sullivan, D. J. 2004. An update of information pertaining to Northern Shrimp (*Pandalus borealis*, Køyer) and Groundfish in NAFO Divisions 3LNO. NAFO SCR Doc. 04/86.

Parsons, D.G. and Colbourne, E.B. 2000. Forecasting fishery performance for northern shrimp (Pandalus borealis) on the Labrador Shelf (NAFO Divisions 2HJ). Journal of Northwest Atlantic Fisheries Science 27, 11–20.

Parsons, L.S., and W. H. Lear. 2001. Climate variability and marine ecosystem impacts: a North Atlantic perspective. Prog. Oceanogr. 49: 167-188.

Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature (374): 255-257.

Pepin, P., Maillet, G.L., Fraser, S., and Lane, D. 2003. Biological and chemical oceanographic conditions on the Newfoundland Shelf during 2002. CSAS Res. Doc 2003/019.

Pepin, P., Maillet, G.L., Fraser, S., Lane, D., and Shears, T. 2007. Biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf during 2006. DFO Can. Sci. Adv. Sec. Res. Doc. 2007/042, 47 p.

Pepin, P., Maillet, G.L., Fraser, S., Lane, D., and Shears, T. 2007. Biological and chemical oceanographic conditions on the Newfoundland and Labrador Shelf during 2007. DFO Can. Sci. Adv. Sec. Res. Doc. 2008/034.

Pepper, V., and Pepper, B. 1995. Biology 3201: fishery module. Newfoundland Department of Education and Training: Division of Program Development. St. John's, NL.

Petrie, B., and Isenor, A. 1985. The near-surface circulation and exchange in the Newfoundland Grand Banks region. Atmosphere-Ocean. 23(3): 209-227.

Petrie, B., Pettipas R. G., and Petrie W. M. 2007. An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Eastern Canada during 2006. DFO. Can. Sci. Advis. Sec. Res. Doc. 2007/022.

Petrie, B., Yeats, P., and Strain, P. 1999. Nitrate, silicate and phosphate atlas for the Scotian Shelf and the Gulf of Maine. Can. Tech. Rep. Hydrogr. Ocean Sci. No. 203.

Plante, S, Chabot, D, Dutil, J. 1998. Hypoxia tolerance in Atlantic cod. J. Fish Biol. 53(6): 1259 –1284.

Powles, P.M., and Kohler, A.C. 1970. Depth distribution of various stages of witch flounder, Glyptocephalus cynoglossus off Nova Scotia and in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 27: 2053-2062.

Prasad, K.S., and Haedrich, R.L., 1993. Satellite observations of phytolankton variability on the Grand Banks of Newfoundland during a spring bloom. Int. J. Remote Sens. 14:241-252.

Rice, J., 2002. Changes to the Large Marine Ecosystem of the Newfoundland-Labrador Shelf, In K. Sherman and H.R. Skjoldal, eds. Large Marine Ecosystems of the North Atlantic—Changing States and Sustainability. Elsevier. 51-104.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thompson, D.H. 1995. Marine mammals and noise. Academic Press, San Diego, U.S.A.

Robichaud, D., and Rose, G.A. 2001. Multi-year homing of Atlantic cod to a spawning ground. Can. J. Fish. Aquat. Sci. 58: 2325-2329.

Rogers, J.C. 1984. The Association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. Mon. Wea. Rev. 112: 1999-2015.

Rogers, J.C. 1990. Patterns of low frequency monthly sea level pressure variability (1899–1986) and associated wave cyclone frequencies. *Journal of Climate* **3**, pp. 1364–1379.

Rose, G. A. 2007. Cod: An Ecological History of the North Atlantic Fisheries.

Scott, J. S. 1982. Depth, temperature and salinity preferences of common fishes of the Scotian Shelf. J. Northwest. Atl. Fish. Sci. 3: 29-39.

Scott, W. B., and Scott, M. G. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences. 219:1–731.

Steele, D. 1983. Marine ecology and zoogeography. Pp. 421 - 465. In G.R. South (Ed.), Biogeography and Ecology of the Island of Newfoundland. Dr. W. Junk Publishers. The Hague, Netherlands.

Tasker, M.L., Becker, P.H., and Chapdelaine, G. 1999. Exploration of the short and medium-term consequences of a reduction in the amounts of fish discarded. In: R.W. Furness and M.L.

Tasker, eds. Diets of Seabirds and Consequences of Changes in Food Supply. ICES Cooperative Research Report No. 232. Copenhagen: ICES. 42-46.

Templeman, W. 1965. Mass mortality of marine fishes in the Newfoundland area presumably due to low temperature. ICNAF Special Publication 6:137-148.

Tendal, O. S. 1992. The North Atlantic distribution of the octocoral Paragorgia arborea (L., 1758) (Cnidaria, Anthozoa). Sarsia 77:213–217

Tlusty M.F., Hughes Clark J.E., Shaw J., Pepper V.A., and Anderson M.R. 2000. Groundtruthing multibeam bathymetric surveys of finfish aquaculture sites in the Bay d'Espoir estuarine fjord, Newfoundland. Mar. Tech. Soc. J. 34: 59-67.

Townsend, D.W., and Ellis, W.G. 2006. Primary production and nitrogen cycling on the northwest atlantic continental shelf. In: Carbon and Nutrient Fluxes in Continental Margins: A Global Synthesis. 2006. Liu, K.K., L. Atkinson, R. Quinones, and L. Talaue-McManus (eds). Springer-Verlag New York.

Tremblay, M.J., and Anderson, J.T. 1984. Annotated species list of marine planktonic copepods occurring on the shelf and upper slope of the Northwest Atlantic (Gulf of Maine t Ungava Bay). Canadian Spec. Publ. Fish. Aquat. Sci. 69. 12 p.

Vandermeulen, H. 2005. Assessing marine habitat sensitivity: A case study with eelgrass (Zostera marina L.) and kelps (Laminaria, Macrocystis). Canadian Science Advisory Secretariat, Research Document 2005/032, 54 p.

Verrill A.E. 1922. The Alcyonaria of the Canadian Arctic Expedition, 1913-1918, with a revision of some other Canadian genera and species. Reports from the Canadian Arctic Expedition 1913-18, vol VIII: molluscs, echinoderms, coelenterates, etc. Part G: Alcyonaria and Actinaria.

Wallace, S.D. and Lawson, J.W. 1997. A review of stomach contents of Harp Seals (Phoca groenlandica) from the Northwest Atlantic: an update. International Marine Mammal Association 97-01.

Walsh, S.J., Brodie, W.B., Bishop, C.A., and Murphy, E.F. 1995. Fishing on juvenile groundfish nurseries on the Grand Bank: A discussion of technical measures of conservation. In: Shackell, N.L. and J.H. Martin Willison (eds.). 1995 Marine Protected Areas and Sustainable Fisheries. Proceedings of the symposium on marine Protected Areas and Sustainable Fisheries conducted at Second International Conference on Science and Management of Protected Areas, Halifax, Nova Scotia, Canada, 16-20 May 1994. 54-73.

Wiese F.K., Montevecchi W.A., Davoren G.K., Huettmann F., Diamond A.W., Linke J. 2001. Seabirds at risk around offshore oil platforms in the North-west Atlantic. Mar. Poll. Bull. 42 (12), 1285-1290.

Wiese, F. and Ryan, P.C. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984–1999, Marine Pollution Bulletin 46, 1090–1101.

Wells, N., Treble, M., Siferd, T., Brodie, B., and Richard, P. 2007. Canadian research report for 2006. Part A, Newfoundland and Labrador Region. Part 2, Central and Arctic Region. NAFO SCS Doc. 7/12.

World Wildlife Fund (2009, May 7). Excessive Bycatch Of Cod Undermines Moratorium: Cod Bycatch Was At Least 70 Per Cent Higher Than Target Levels. *ScienceDaily*. Retrieved October 23, 2009, from: http://www.sciencedaily.com/releases/2009/05/090502102740.htm#

APPENDIX 1

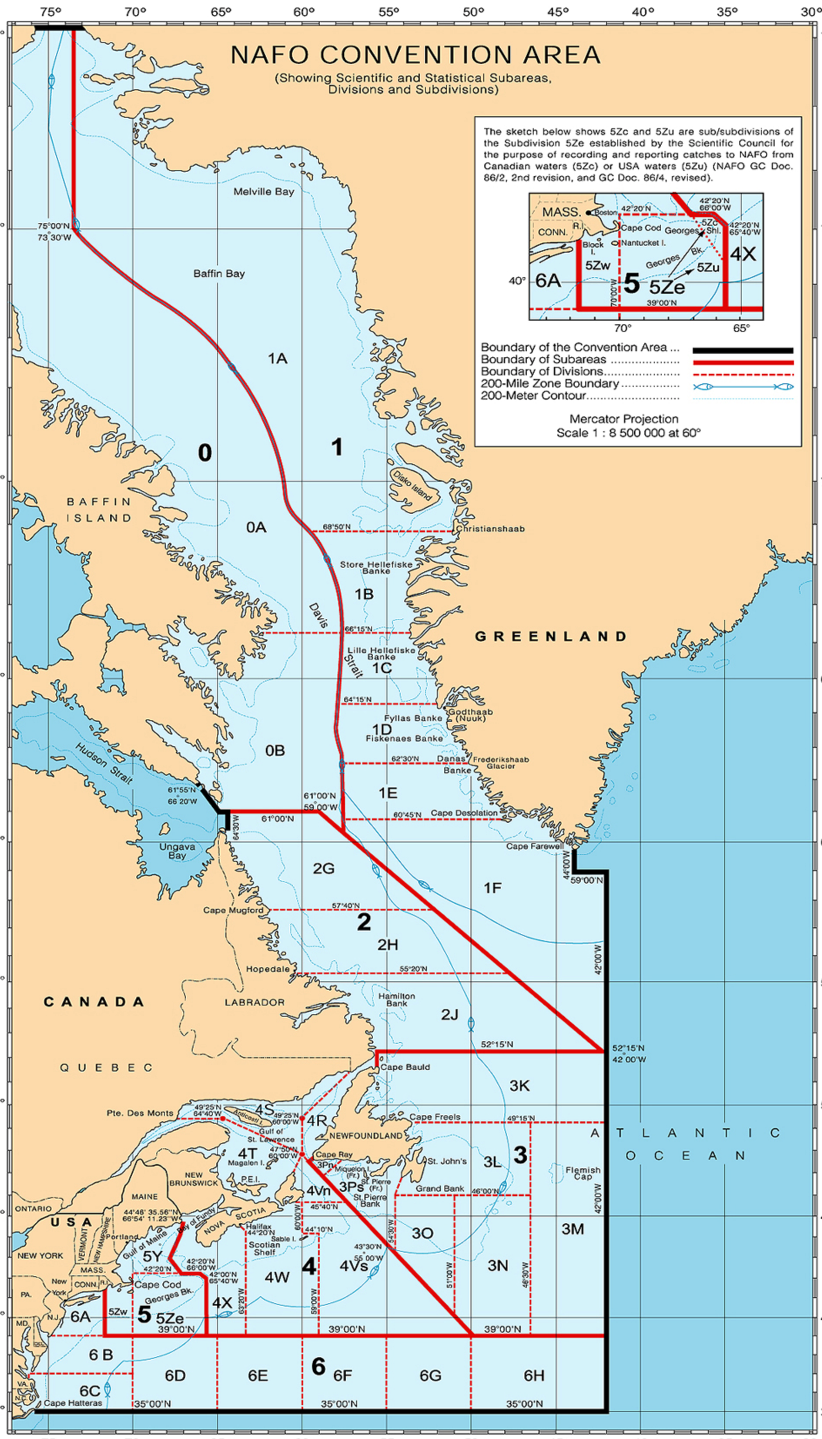


Figure 41. Map of NAFO convention area – showing Areas, Divisions and subdivisions referenced in the text, and the EEZ (blue line), equal to the NLSE boundary (NAFO 2009).