The Scotian Shelf: An Ecological Overview for Ocean Planning

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1 INTRODUCTION[1]

This overview provides a description of the major ecological components of the Scotian Shelf and neighbouring waters, summarizing what is known about the physical environment and the marine life of this large geographic region. It was prepared under the auspices of the Oceans and Coastal Management Division, Maritimes Region, Fisheries and Oceans Canada, primarily to contribute to integrated management, marine protected areas, and marine environmental quality aspects of the region's oceans and coastal management program.

The Scotian Shelf is home to myriad organisms, from tiny invertebrates that live in or attached to the sediments of the ocean floor, to large whales that range over thousands of kilometres and spend only part of the year in the waters off Nova Scotia. The physical features of the shelf are just as diverse. There are basins more than 200 metres in depth and shallow banks less than 50 metres deep. Sable Island is the only offshore island and is the exposed portion of the largely submerged Sable Island Bank. A series of steep-sided submarine canyons indent the shelf slope; the largest, The Gully, is more than two kilometres in depth. Muddy silt overlays some of the shelf while in other areas sand, gravel, or rocks and boulders form the predominant surficial sediment. The oceanographic processes of the shelf are influenced by wind, tides, solar radiation, and major currents such as the Labrador Current, currents flowing from the Gulf of St. Lawrence, and the Gulf Stream. This overview will summarize the major features of the Scotian Shelf and slope and provide references where more detailed information can be found.

Purpose: Why Prepare an Ecological Overview of the Scotian Shelf?

The primary impetus for this ecological overview of the Scotian Shelf was to meet the needs of ocean and coastal managers and planners at Fisheries and Oceans Canada (DFO). DFO is the lead federal department for the conservation, management, and sustainable development of renewable marine resources. Since the passage of the *Oceans Act* in 1997, DFO's mandate has been expanded to address Canada's economic, social, and environmental objectives for our oceans. The Act commits the Government of Canada to a new management approach for the oceans based on the principles of sustainable development, integrated management, and the use of precautionary, collaborative, and ecosystem approaches. The new collaborative, integrated approach to ocean management is encouraging partnerships among various organizations and jurisdictions with interests in the oceans.

Globally, a greater concern for conserving marine biodiversity has spurred international treaties and programs to promote sustainable ocean use and conservation. In 1994, the World Conservation Union (IUCN) recommended that countries bordering on the world's oceans create systems of marine protected areas through legislation. The *Convention on Biological Diversity* was opened for signature in 1992 and by 2001 had been ratified by more than 180 countries, making it one of the most widely adopted environmental treaties. Canada was an early signatory and the sixth country to ratify the agreement, committing itself to:

[1] The authors would like to thank Scott Coffen-Smout, Gareth Harding, Glen Herbert, and Ian McLaren for their comments on earlier versions of this chapter.

(a) Develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, *inter alia*, the measures set out in this Convention relevant to the Contracting Party concerned; and

(b) Integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies. (Article 6, 1992)

Planning for sustainable ocean use requires the integration of available ecological information, such as information on oceanographic features and marine life. It requires knowledge of the interactions within and between marine geographical regions. For planning to be effective, important gaps in that knowledge must also be recognized.

This report has direct application for a range of DFO initiatives under the *Oceans Act*. It will be a reference for the continued development of ecosystem objectives and precautionary measures for ocean management. This overview is an integral component of the Eastern Scotian Shelf Integrated Management (ESSIM) initiative, a collaborative planning process that will lead to a comprehensive oceans management plan for the area. It will be used in developing management measures, including area and use zoning schemes and the application of marine environmental quality standards. The ESSIM initiative will use the overview in conjunction with other planning reports. These include a regulatory overview to identify policy and management gaps, and an issues-identification report to define and set priorities for ocean management challenges, and suggest various approaches for addressing them.

This document will also serve as an important source of information in the identification of areas on the Scotian Shelf that may require higher levels of protection through regulatory or voluntary measures. In particular, this overview helps support the ongoing efforts to develop a system of Marine Protected Areas (MPAs), as defined under the *Oceans Act*. Similarly, the overview will support DFO's efforts to identify indicators and reference points for evaluating and monitoring ecosystem health. This will include the development of appropriate standards and measures for marine environmental quality.

Although this document was developed primarily in support of DFO's oceans and coastal management initiatives, it provides timely and useful information for the broader oceans community. Other government departments, non-governmental organizations, and the general public have expressed the need for a document that highlights the major ecological components of the Scotian Shelf. For example, those involved in environmental assessments of proposed offshore activities have requested general information on the ecology of the Scotian Shelf from government, as well as specific information on sensitive areas.

The scientific literature on the Scotian Shelf is extensive. DFO has maintained a long-term scientific research and monitoring program aimed at assessing commercial species and changes in Canada's marine environment. In addition to research by Canadian government departments and agencies, the Scotian Shelf has been studied by university researchers, industry (such as fishing and hydrocarbon companies), and foreign researchers, including government scientists from the United States and the former USSR. More than 1000 scientific publications have examined the marine life or physical characteristics of the Scotian Shelf. However, most of the literature has focused on individual species or

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We would like to thank the following people from Fisheries and Oceans Canada who provided graphics, data, or other information for the report: Jerry Black, Lesley Carter, Kirsten Clark, Cheryl Frail, Charles Hannah, Peter Koeller, John Loder, Kevin MacIsaac, Denise McCullough, Shawn Oakey, Douglas Pezzack, Sean Smith, and Igor Yashayaev. Nancy Shackell of Dalhousie University and Fisheries and Oceans Canada provided many graphics. Susanna Fuller of Dalhousie University and Falk Huettmann of Simon Fraser University contributed information from their recent research projects. Stan Johnston, Fisheries and Oceans Canada, created most of the maps found in the report and his efforts were invaluable in producing this document. Angelica Silva, Dalhousie University, contributed to the initial stages of this project. Her efforts to collect the vast quantity of scientific information on the Scotian Shelf, in conjunction with an advisory committee (Kenneth Frank, Gareth Harding, Glen Harrison, John Loder, Peter Smith, and John Tremblay), laid the groundwork for this ecological overview.

ABSTRACT

Breeze, H., D. Fenton, R.J. Rutherford, and M.A. Silva. 2002. The Scotian Shelf: An ecological overview for ocean planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393: x + 259 pp.

This report describes the major ecological components of the Scotian Shelf and neighbouring waters (Scotian Slope, rise and abyssal plain within Canada's 200 nautical mile EEZ). The report summarizes what is known about the physical environment and the marine life of this large geographic region, based on existing studies. Individual chapters focus on physiographic features and surficial geology, physical oceanography, plankton, invertebrates, fish, marine mammals, marine-associated birds, sea turtles, and endangered species. Because it was prepared to meet the needs of planners and managers, spatial aspects of the oceanographic environment have been emphasized to help in the identification of areas needing special management measures. A concluding chapter highlights the major features of the shelf and identifies important knowledge gaps.

RÉSUMÉ

Breeze, H., D. Fenton, R.J. Rutherford, and M.A. Silva. 2002. The Scotian Shelf: An ecological overview for ocean planning. Can. Tech. Rep. Fish. Aquat. Sci. 2393: x + 259 pp.

Le présent rapport décrit les principaux composants écologiques du plateau néo-écossais et des eaux environnantes (le talus continental, le seuil et la plaine abyssale à l'intérieur de la ZEE de 200 milles marins du Canada). Le rapport résume ce que l'on sait sur l'environnement physique et la vie marine dans cette grande région géographique, d'après des études existantes. Les divers chapitres portent sur les caractéristiques physiographiques de la région et sa géologie superficielle, son océanographie physique, ses planctons, ses invertébrés, ses poissons, ses mammifères marins, ses oiseaux de mer, ses tortues marines et les espèces en péril qui s'y trouvent. Parce que le rapport vise à répondre aux besoins des planificateurs et des gestionnaires, une attention particulière a été accordée aux aspects spatiaux de l'environnement océanographique pour faciliter l'identification des régions particulières nécessitant des mesures de gestion spéciales. Le dernier chapitre met en lumière les principales caractéristiques du plateau et souligne les importantes lacunes dans nos connaissances à ce sujet.

biophysical features. The sheer volume of material available about the Scotian Shelf underscores the need for a concise work highlighting its major ecological features.

This report provides a synthesis of existing works, based on existing studies and in a form accessible to non-specialists.[2] Gaps in the available information are highlighted. No attempt has been made to include all species or identify the interactions between all processes; however, references are made to other works where more detail can be found. Because of the needs of the primary audience, ocean planners, spatial aspects of the oceanographic environment have been emphasized to help in the identification of areas needing special management measures. Human activities that are or need to be managed are generally not included in this report. Chemical oceanography and contaminants are also not included here. The reader is referred to Stewart and White (2001) for a recent review of contaminants on the Scotian Shelf and in Nova Scotia's coastal waters.

Geographical Boundaries of the Overview

The Scotian Shelf is the part of the North American continental shelf lying off Nova Scotia. The distance from the coast of Nova Scotia to the edge of the shelf varies from 125 to 230 kilometres. The Laurentian Channel separates the Scotian Shelf from the continental shelf off Newfoundland, and the Northeast (Fundian) Channel separates it from Georges Bank. For the purposes of this report, the slope and rise of the Scotian Slope and the deep waters of the abyssal plain within Canada's 200 nautical mile Exclusive Economic Zone are included (see Figure 1-1). Most of the text deals with the Scotian Shelf itself, as there is much less information available on the deep waters of the slope and abyssal plain. The Bay of Fundy-Gulf of Maine, Georges Bank, and the southern Gulf of St. Lawrence are not considered here, except as they relate to the processes of the defined study area.

This overview emphasizes the biological and physical processes of the offshore, and little detail is provided on coastal and nearshore areas.

Process of Creating the Overview

This project began by identifying sources of information relevant to an ecological description of the Scotian Shelf. The available literature was reviewed and individual scientists within Fisheries and Oceans Canada and elsewhere were contacted and asked for information. DFO staff from several divisions provided information, data, and maps for the overview. As material was collected, it became obvious that much information deemed necessary for a complete overview was not readily available. Each chapter was reviewed by at least two people working in that field and reviewers were asked to identify the major information gaps in their field. Information gaps are identified within each chapter and summarized in the final chapter.

The Scotian Shelf in the Literature

Other overviews of the Scotian Shelf have been conducted in various forms and degrees of detail. Most of these works have been in response to proposals for resource extraction on the shelf. The Environmental Impact Statement of the Venture Development Project was

[2] Only a fraction of the studies related to the Scotian Shelf could be reviewed for this overview.

one of the first attempts to combine the physical and biological oceanographic data on the Scotian Shelf (Mobil Oil 1983). The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) assessed the impacts of seismic exploration activities and exploratory drilling on the Scotian Shelf (CNSOPB 1998, 1999). They also carried out strategic environmental assessments of some of the offshore parcels considered for petroleum exploration (CNSOPB 2000, 2001). The Sable Offshore Energy Project's Environmental Impact Statement (MacLaren Plansearch 1996) is another compilation intended for environmental assessment and decision-making.

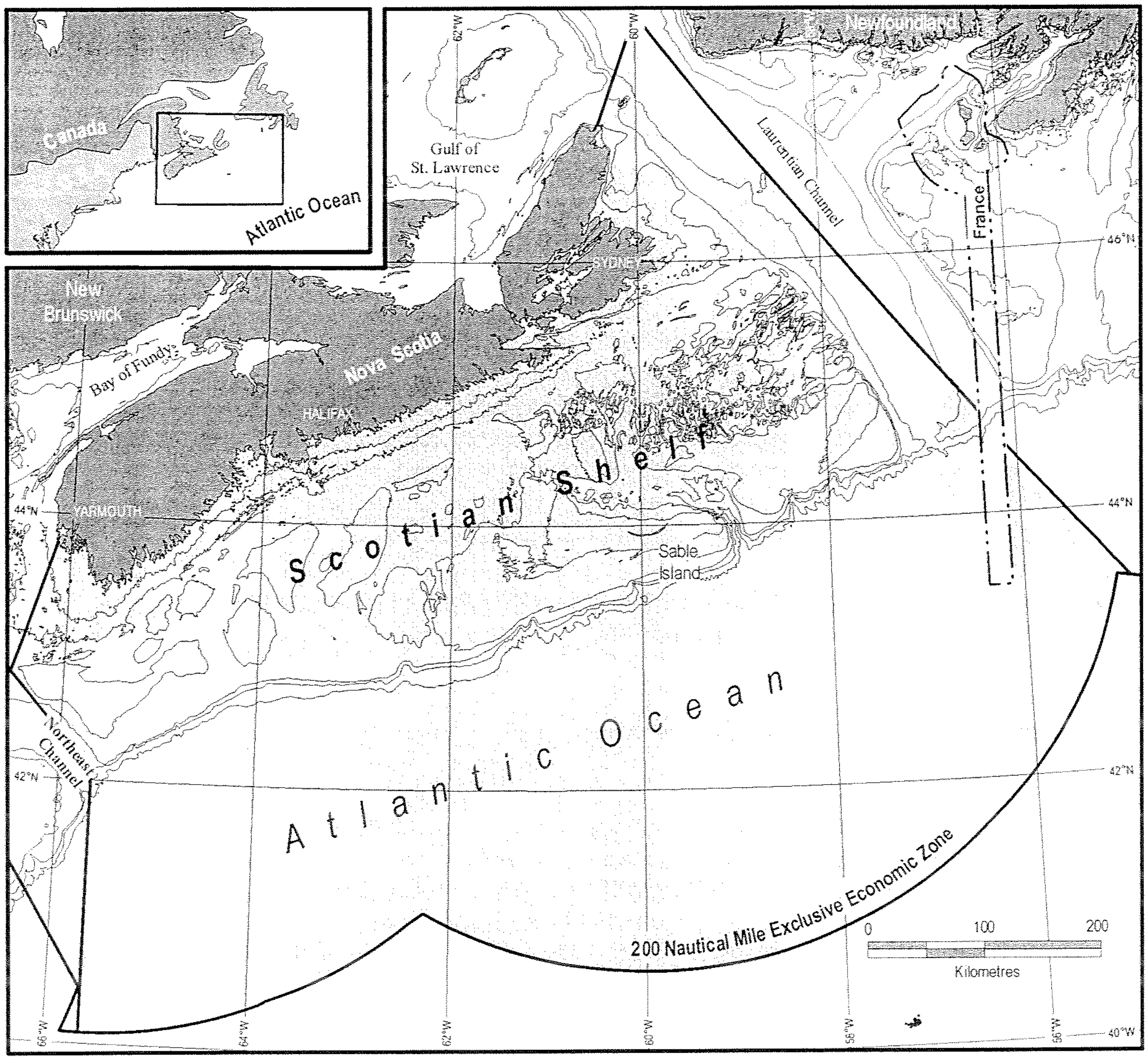

Figure 1-1. The Scotian Shelf and adjacent waters off Nova Scotia. Study area is shaded grey. The white corridor cut out of the study area is part of the Exclusive Economic Zone of St. Pierre et Miquelon, a French territory.

Parks Canada commissioned two reports that included the Scotian Shelf in their study areas. The first, *A Biological and Oceanographic Study of the Atlantic Southeast Coast Marine Region* (Steele et al. 1979), described the major features of the area from the western Grand Banks in the east to Georges Bank in the southwest. The report focused on mapping physical characteristics of the region and species distributions within it, and is a useful compilation of information available to that date. A later report (P. Lane and Associates 1992) provided a more detailed inventory and assessment of the Scotian Shelf, with the goal of identifying significant "marine natural areas" in the region. That report included information on the cultural history of the shelf as well as a detailed description of its physical and biological features for the purposes of marine park planning.

The Natural History of Nova Scotia (Davis and Browne 1996) took a theme region approach to Nova Scotia's ecological features. It discussed terrestrial and marine regions in one volume and linked them with specific processes and habitats in the second volume. A report commissioned by the World Wildlife Fund Canada called for a representative system of marine protected areas (Day and Roff 2000). It attempted to classify the marine areas of the Scotian Shelf and the Bay of Fundy based on certain variables in the ocean environment, such as water temperature and bottom sediment.

Zwanenburg et al. (in press) recently presented an overview of changes in the Scotian Shelf marine ecosystem over a period of several decades. The authors examined aspects of the oceanographic environment, fish communities, fisheries, and marine mammal populations, and identified spatial and temporal changes in these. That work highlighted the importance of considering change over time in the marine environment, and demonstratated how changes can influence ecosystem functioning.

Other works on the Scotian Shelf as a whole tend to focus on specific processes or groups of organisms. For example, the *Scotian Shelf* in the East Coast Basin Atlas Series describes the geology of the shelf (Ross et al. 1991). The *Gazetteer of Marine Birds in Atlantic Canada* provides an overview of east coast seabirds and their susceptibility to oil pollution (Lock et al. 1994). Mahon and Smith (1989) as well as various other authors have looked at fish communities on the Scotian Shelf and east coast. Those works, as well as others summarizing findings in other fields, were important sources of information for this overview.

Organization of the Report

The challenges of organizing and synthesizing such a huge volume of material are many. Other works that examined the biological and physical features of specific regions were examined for guidance. *Georges Bank* (Backus and Bourne 1987), a compilation about that area, is divided into four major sections: one that looks at physical oceanography of the bank, another that focuses on biological oceanography, a third that reviews fisheries, and a final section that looks at conflicts between users. The scientific review of The Gully, carried out under the auspices of DFO, was arranged in a similar manner to the Georges Bank work. Individual chapters address particular aspects of the canyon environment, such as geology, currents, marine birds, finfish, etc. (Harrison and Fenton 1998). Previous works reviewing the Scotian Shelf (mentioned earlier in this chapter) used a similar divide between physical features and processes and marine life.

This report adopts the organizing principle used in previous works. It is divided into two major sections, one on the marine environment and the other on marine life. The drawback to this organization is that interactions between the various elements – a holistic view of the shelf – may be obscured because of the separation between specific features. In recognition of this, the final chapter highlights the major characteristics of the shelf by geographic area.

The first section, **Marine Environment**, summarizes the oceanographic environment of the shelf. The first chapter of that section reviews the physiographic features and surficial geology. The next chapter looks at the physical oceanography, providing an overview of circulation patterns, temperature and salinity, and density stratification. The second section, **Marine Life**, examines the biological features of the shelf. The first chapter of that section discusses plankton, describing primary productivity at various times of the year, as well as the zooplankton of the shelf. The next chapter describes other marine invertebrates, with a focus on benthic invertebrates and their habitat. A chapter on fish follows with a brief overview of fish assemblages of the shelf and key areas and times of year for certain species at different life stages. The next three chapters look at the seabirds, marine mammals, and sea turtles of the Scotian Shelf. The final chapter of this section focuses on rare and endangered species. The concluding chapter of the report highlights the major processes and organisms of the shelf by geographic region, and summarizes the information gaps.

Although the central focus of this work is the Scotian Shelf, in some cases information from other regions has been provided to give a general description of certain features. The submarine canyons of the Scotian Shelf, for example, have not been thoroughly studied and information from nearby canyons on Georges Bank has been discussed in their place. In such cases where the information is not directly from research on the Scotian Shelf, the location of the studies are clearly identified. References and further reading can be found at the end of each chapter.

New research is constantly adding to our knowledge of the Scotian Shelf. This report should be considered an initial snapshot of the area. It is primarily intended to meet the general information needs of ocean planners and managers and will be updated as new information becomes available.

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Marine Environment

2 PHYSIOGRAPHIC FEATURES AND SURFICIAL GEOLOGY[1]

Introduction

More than 200 million years ago, Nova Scotia was part of Pangaea, the supercontinent made up of all the earth's landmasses. Over millions of years, the continents separated and oceans spread between them. Ice sheets formed, advanced, and retreated, scouring the land and depositing glacial till. Rivers carved valleys and canyons and the sea level fluctuated, causing regressions and transgressions over thousands of kilometres.[2] This geological legacy has shaped Nova Scotia and the adjacent continental shelf.

The geological history of Nova Scotia's offshore is long and complex and will not be examined in any detail here. Instead, this chapter focuses on the morphology of the Scotian Shelf and slope and the surficial sediments overlying them. These geological features are examined as they relate to the ecological character of the Scotian Shelf. The shape of the shelf influences the flow, mixing, and characteristics of water masses over the shelf and slope. In turn, water movement can influence the surficial geology by eroding and transporting sediments in some areas and depositing them in others. Surficial geology is an important component of benthic habitat, as the availability of particular surficial sediments, such as mud, sand, or boulders, influences the distribution of benthic species.

Physiographic Features

The continental shelf off Nova Scotia covers approximately 96,000 square kilometres from the coast to the 200 metre isobath at the edge of the shelf (Keen and Piper 1990). This expanse is almost twice the size of Nova Scotia, even without including the area of the continental slope with Canada's exclusive economic zone. Its varied topography was developed over millions of years. One hundred and fifty million years ago, much of the shelf was a vast coastal plain. The geology of the coastal plain developed over millions of years and more information on its formation and evolution can be found in Williams et al. (1972), Keppie (1989), and Atlantic Geoscience Society (2001). About 200 million years ago, during the late Triassic period (Table 2-1), the continents began to separate and the North Atlantic Ocean opened between what is now Europe and North America (Atlantic Geoscience Society 2001). The coastal plain began to submerge (King and Fader 1986). Nova Scotia's coastline and the features of the continental shelf began to take on their present shape.

Table 2-1 Geological time periods

Name	Millions of years before present
Precambrian	545 (and earlier)
Cambrian	545 to 495
Ordovician	495 to 443
Silurian	443 to 418
Devonian	418 to 362
Carboniferous	362 to 290
Permian	290 to 248
Triassic	248 to 206
Jurassic	206 to 142
Cretaceous	142 to 65
Tertiary	65 to 1.8
Quaternary	1.8 to present

[1] The authors would like to thank Carl Amos and Gordon Fader for their comments on earlier versions of this chapter.

[2] A regression is a withdrawal of the sea from the land and the land area that results from such a withdrawal; a transgression is a change that creates deep water conditions in areas that were formerly shallow and submerges land that was previously above the water.

Today, there are deep valleys and canyons, steep cliffs and gently sloping hills beneath the sea. Submarine canyons indent the shelf edge, perhaps showing the former path of rivers.

The offshore areas of Nova Scotia fall into two major geomorphic regions, the Appalachian Region and the Atlantic Coastal Plain Region (King and MacLean 1976). The evolution of these regions is discussed in Williams et al. (1972) and King and MacLean (1976). Most of the inner part of the shelf and much of the province of Nova Scotia falls within the Atlantic Uplands division of the Appalachian Region, while much of the Laurentian Channel and areas adjacent to Cape Breton fit with the Carboniferous-Triassic Lowlands Division, also within the Appalachian Region (Williams et al. 1972). The central and outer parts of the shelf, the Northeast Channel, and part of the Laurentian Channel are within the Atlantic Coastal Plain Region (Williams et al. 1972).

The basic morphology of the shelf has been largely determined by underlying bedrock structures affected by erosion. Glaciation had little effect on the basic morphology of the shelf (King 1980), but had considerable effect on the surficial geology by erosion, scouring, and deposition of sediments. The features of some areas, for example, the eastern shelf, show more evidence of glacial effects. King and MacLean (1976) and Fader (1991c) summarized the bedrock geology underlying the surficial sediments. Most of the bedrock of the middle and outer shelf is of Tertiary and Cretaceous age and consists of mudstone and sandstone. Bedrock of the inner shelf is largely hard material from the Cambrian-Devonian period. Most of Sydney Bight and part of the Laurentian Channel is of Upper Carboniferous age, while smaller areas off Cape Breton are of Upper Carboniferous-Jurassic, Lower Carboniferous, and Palaeozoic age.

The sediments overlying the bedrock have been highly influenced by the last glacial period, the Wisconsian glaciation. Surficial sediments were deposited on the Scotian Shelf and slope through erosion of bedrock underlying the seafloor and from erosion of adjacent coastal regions, with sediments carried by rivers and glaciers and deposited offshore. About 20,000 years ago, glacial ice covered most of the continental shelf. The ice retreated and advanced, eroding the shelf and leaving behind glacial till. Boulders and sediments dropped by retreating glaciers and furrows dug by icebergs can be found across the shelf. The last ice sheet retreated from the shelf between about 20,000 and 13,000 years ago. After the ice sheet melted, sea levels slowly rose, covering formerly exposed parts of the shelf. Sediments between the old shoreline and the current shoreline were reworked during this transgression, leaving large areas of well-sorted sand and gravel on the formerly exposed outer banks (King and Fader 1986). The reworking of sediments has filled in many of the depressions of the central and outer shelf.

The Scotian Shelf can be divided into three areas based on bottom characteristics: inner, middle, and outer shelf (King and MacLean 1976, King and Fader 1986). The Laurentian Channel and the Northeast Channel, and the continental slope and submarine canyons form separate deep water regions. The physiography of these areas is discussed below.

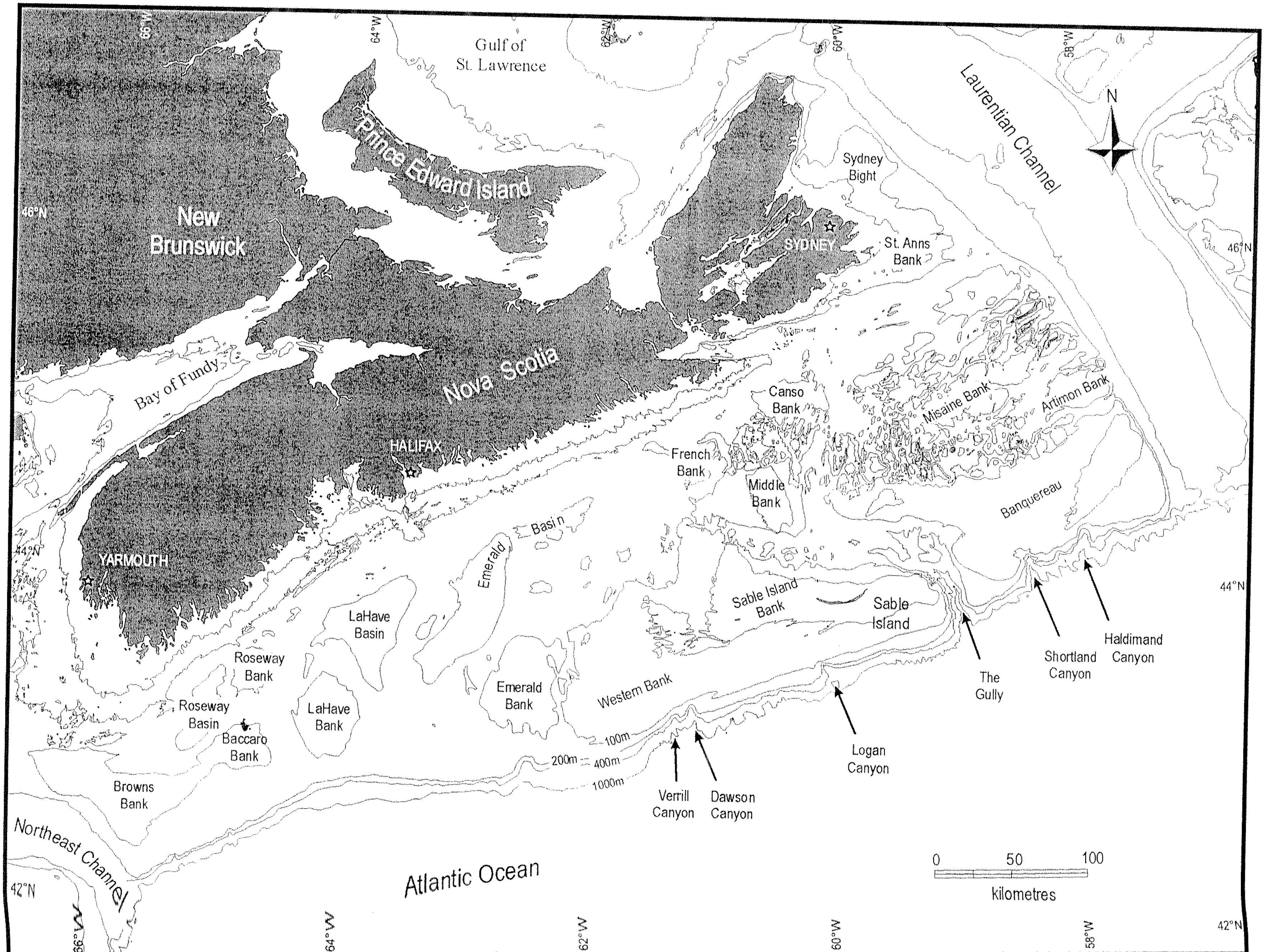

Figure 2-1. Physiographic features of the Scotian Shelf (some smaller features are not included on the map).

Inner shelf

The well-defined inner shelf along Nova Scotia's Atlantic coast has rough topography with bedrock outcrops scoured by glaciation (Fader 1991d). While the rest of the Scotian Shelf was free of ice, the inner shelf remained covered by glaciers. Sydney Bight, adjacent to Cape Breton (Figure 2-1), and an area of southwest Nova Scotia are flat, wide portions of the inner shelf.

Middle shelf

The middle shelf can be divided into eastern and western regions. The most prominent physiographic features of the western half of the middle shelf are three deep basins, Emerald, LaHave, and Roseway. Small shallow banks are also found in some areas of the middle shelf. About 30 to 40 kilometres from the coast and parallel to it, an end moraine system formed (King and Fader 1986). This feature marks stationary periods in the general retreat of ice from the shelf, or perhaps local re-advancement of the glaciers.

In contrast, the eastern section of the middle shelf has no large basins but is an area of highly varied topography, with deep narrow channels dissecting small banks north of Banquereau. Misaine Bank is the largest bank in this discontinuous area. This complex morphology was likely the result of multiple glaciations and shelf-centred ice, with ice advancing and retreating many times (Sankerelli and Fader 1999).

Outer shelf

The outer shelf is characterized by a series of large, shallow, flat banks. They were originally cuestas, bedrock formations formed when the shelf was emergent. These banks generally have moderate topography and slope gently to saddles lying between them. Some of the saddles between the banks may represent former drainage channels for both fluvial systems and ice streams. Sable Island Bank and Banquereau are shallower than the banks of the western Scotian Shelf, LaHave and Browns Banks.

Sable Island is a distinctive feature of the outer shelf, the only exposed portion of the outer continental shelf in the Northwest Atlantic (Beson 1998). The long, crescent-shaped island is an exposed sandbar and part of Sable Island Bank. The island has changed form over the years, especially after major storm events, and is perhaps slowly shrinking or moving eastward (Grey 1992, Cameron 1965). Because it is the only landfall for many miles, it is home to many marine-associated species that breed on land and is a refuge for terrestrial birds blown astray during migration. Large, shoreface-connected sand ridges link Sable Island to the adjacent shallow, sandy seabed and appear to be slowly moving to the east (Dalrymple and Hoogendoorn 1997).

Continental slope and submarine canyons

The continental slope descends from the edge of the shelf (about the 200-metre isobath) to a depth of about 2000 metres. At that point, it becomes less steep and is known as the "rise" from about 2000 metres down to the abyssal plain 5000 metres below the ocean surface.

The slope has steep to moderately sloping topography, with cliffs of exposed bedrock in some areas and sediments slumped off the upper parts of the slope in others.

Several narrow, deep, and steep submarine canyons indent the outer edge of the shelf and slope. These are believed to be former drainage channels for rivers and glaciers formed when the seabed was exposed, and now maintained through current action and sediment transport. The Gully, between Sable Island Bank and Banquereau, is the largest canyon and is more than 2000 metres deep. The V-shaped, steep-walled canyon is bordered by feeder canyons leading into the main canyon (Marlowe 1967, Amos 1989, Fader and Strang in press). Recent research programs have expanded the knowledge of the geology and morphology of The Gully (Fader and Strang in press). The nine major feeder canyons on the west side of The Gully have ledges, terraces, and smaller channels leading into them. The head of The Gully has numerous sand bedforms shaped by current action (Fader and Strang in press).

Smaller canyons indent the slope of the Scotian Shelf on either side of the Gully. From east to west, they are Haldimand, Shortland, Logan, Bonnecamps, Dawson, and Verrill. None of the smaller canyons have been thoroughly explored and inventoried. Small valleys also cross the slope and rise (Piper et al. 1985).

Laurentian and Northeast Channels

The channels on either side of the Scotian Shelf, the Laurentian Channel and the Northeast Channel, were carved and maintained by water, glaciers, and sediment transport. The Northeast Channel funnels the tidal currents of the Gulf of Maine and Bay of Fundy. The Laurentian Channel was formed by the outflow of the ancestor of the St. Lawrence River and deepened by glacial ice and meltwater. The Laurentian Fan is an area down the slope from the Laurentian Channel where sediments carried by the outflow from the St. Lawrence River were deposited.

Physiography and Oceanography

The seafloor in some areas continues to be shaped by currents, tides, storms, and, more rarely, earthquakes. In turn, its physiography affects current patterns, both on the large scale and in smaller tidal mixing along the shelf edge. The physiography of the shelf has important influences on temperature, bottom currents, nutrient mixing, and thus, biological productivity. The outer banks – Banquereau, Sable Island, Western, Emerald, LaHave, Baccaro, and Browns — function as a physical barrier between the Scotian Shelf and the deep ocean. Waters from the slope and deep ocean periodically leak onto the shelf in the saddles and channels between the banks. Water that settles in the bottom of deep basins is more highly stratified than the water masses that move over the banks (see chapter 3, Physical Oceanography, for more details). The interactions between the topography of the large, shallow banks and the tidal currents give rise to clockwise gyres. At the shelf break, the steep slope aids in mixing different water masses. Water from the offshore mixes with waters from the shelf, keeping nutrients near the surface. The interaction of the physiography with the physical oceanography determines habitat characteristics on the shelf.

Surficial Geology

The term sediment is used to refer to all unconsolidated particles transported and deposited by water, wind, glaciers, and gravity. Most sediments are deposited in the oceans along the margins of continents. The depth of the surficial sediment layer varies greatly over the Scotian Shelf, from areas of the inner shelf with exposed bedrock and no surficial sediments, to layers of silty sand only a few metres thick, and up to 100-metre thick deposits of silt and till at the bottom of basins (see e.g., King 1970, King and Fader 1986, Fader 1991d). The spatial distribution and character of modern marine sediments result from their geological history and from recent physical, biological, and chemical processes that modify and transport them (Amos and Judge 1991).

In eastern Canada, important physical processes include gravity, surface and sub-surface wave motion, currents caused by a variety of events, and scouring and transport by ice. Marine organisms are responsible for biological processes that transport sediments. Infauna move sediments on the seafloor, while free-swimming fauna and attached epifauna can affect the suspension of sediments. The chemical properties of the water column affect the properties of sediments, resulting in differing degrees of resistance to erosion, transport, or sedimentation. Although all these processes have ongoing effects, the current array of sediments on the Scotian Shelf seafloor has largely been controlled by the last glaciation and the rise in sea level during the last 10,000 years (Holocene period) (King and Fader 1986).

While the spatial distribution of sediments is influenced by the hydrological setting, the broad pattern of distribution is relatively stable and shifts in sediments are caused mainly by storms. The various infaunal and epifaunal benthic organisms have different sediment preferences, thriving in areas corresponding to their particular preferences for particle size and sediment sorting. Thus, knowledge of surficial geology provides information on the benthic communities likely to be found in that area.

Based on processes that affect sediments, the continental shelves of eastern Canada can be divided into two distinct groups, a northern group (north of 48°N) and a southern or temperate group (south of 48°N) (Amos 1990). The Scotian Shelf is part of the southern temperate group that is generally dominated by the effects of winds, waves, currents, and storms, and is much shallower than the northern group. The sands and gravels formed during the lower sea levels following the most recent glacial period are found on the shallow banks and the inner shelf. Deeper areas are covered in finer silt and clay interspersed with coarse glacial materials.

General characterization of Scotian Shelf surficial sediments

The spatial distribution and characteristics of sediments of the Scotian Shelf and other parts of the eastern Canadian continental shelf were systematically mapped during the 1960s, 1970s, and 1980s by the Geological Survey of Canada (King 1970, MacLean and King 1971, Drapeau and King 1972, Fader et al. 1977, Fader et al. 1982, King and Fader 1986, Fader et al. 1988, and Piper 1991). The mapping program broadly characterized the surficial sediments of the shelf, using the available acoustic technology combined with samples taken from the seafloor (see e.g., King 1970 for methods used). King (1970) produced the first map in the series, mapping the Halifax to Sable Island area of the central Scotian Shelf. Five sedimentary units of Quaternary origin were differentiated on the seafloor: Sable Island Sand and Gravel, LaHave Clay, Sambro Sand, Emerald Silt and Scotian Shelf Drift (see Table

2-2 for particle size and characteristics). These units were further sub-divided to reflect particular sediment characteristics that are more prominent in some areas. For example, Sable Island Sand and Gravel has both a sand phase and a gravel phase. Figure 2-2 is a schematic cross-section of the Scotian Shelf that shows the surficial sediments in Emerald Basin and on Emerald Bank.

Table 2-2. Characteristics of Scotian Shelf Quaternary Deposits*

Deposit	Characteristics
Sable Island Sand and Gravel	Fine to coarse, well-sorted sand grading to coarse angular to rounded gravels (pebble to cobble and boulder size).
LaHave Clay	Greyish brown, soft, silty clay grading to clayey silt (Holocene mud). Contains many foraminifera. Median grain size of 0.003 - 0.06 mm.
Sambro Sand	Silty sand grading locally to gravelly sand and well-sorted sand. Median grain size of 0.06 - 0.6 mm.
Emerald Silt	Poorly sorted clayey and sandy silt and silty and clayey sand, sometimes with gravel (glaciomarine sediments). Median grain size of 0.05 – 0.01 mm.
Scotian Shelf Drift	Undifferentiated, poorly sorted sediment, sandy with abundant silt and clay and fragments of pebble- to boulder-size gravel (glacial till).

*Adapted from MacLean and King (1971), King and Fader (1986), and Davis and Browne (1996).

King's initial classification and variants have been used to map the distribution of surficial sediments over the entire shelf and slope (see e.g., MacLean and King 1971, Drapeau and King 1972, Fader et al. 1977, Fader et al. 1982, King and Fader 1986, Fader et al. 1988, and Piper 1991). Fader (1991a) summarized this work with a compilation map of the surficial geology of the Scotian Shelf, not including the slope. Piper (1991) produced a surficial geology map based on research carried out on the slope. The following descriptions of the surficial geology of the shelf and slope draw largely from those summaries. Figure 2-3 is a composite map of the surficial geology of the Scotian Shelf and slope based on the reports and maps produced by the Geological Survey of Canada.

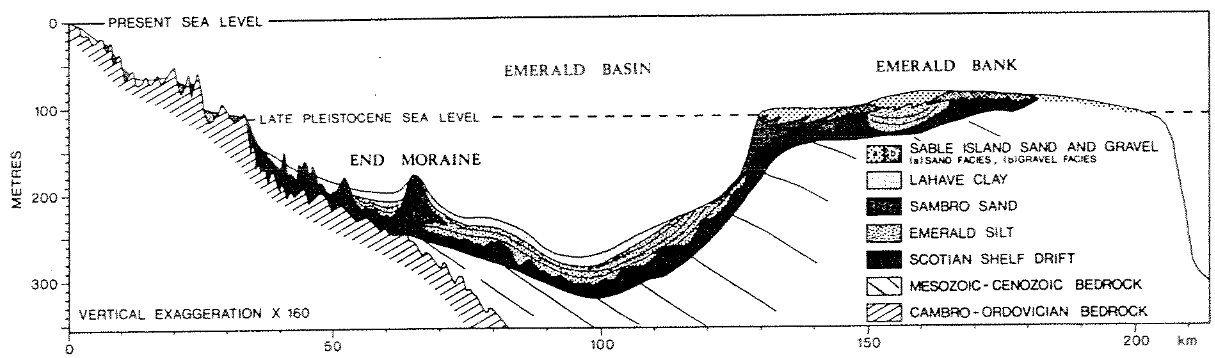

Figure 2-2. Cross section of the Scotian Shelf crossing Emerald Basin and Emerald Bank (King 1980).

Inner shelf

The surficial sediments of the inner shelf are mostly sand, gravel (granules to boulders), and exposed bedrock. In most areas, surficial sediments are thin, although glacial till has accumulated on bedrock in depressions. The rough topography and varied sediments available in inner shelf areas are particularly suited to some species of benthic invertebrates, such as lobster.

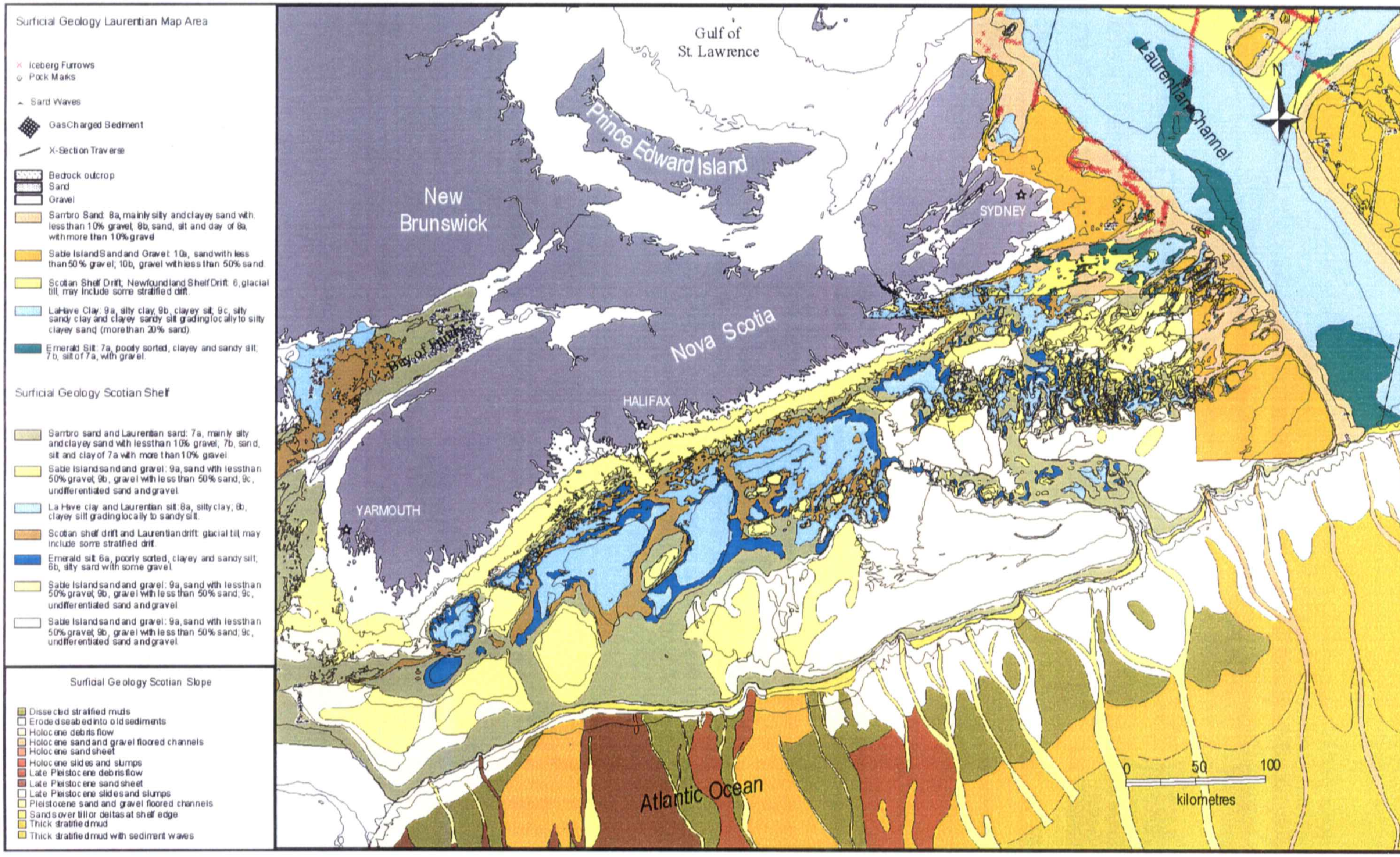

Figure 2-3. Surficial sediments of the Scotian Shelf (compiled from King 1970, MacLean and King 1971, Drapeau and King 1972, Fader et al. 1977, MacLean et al. 1977, Fader et al. 1982, and Piper 1991).

Middle shelf

The bottoms of the middle shelf basins are covered with clay overlying glaciomarine silty sediments. Bank areas are topped with sand and gravel, with edges overlain with muddy sand and occasional boulders. The flanks of basins have deposits of glacial till, especially on the shoreward side, as do some mid-basin areas. Glacial moraines are ridges of till, occasionally overlain by glaciomarine silty clay that has settled in depressions in the end moraine system (King 1970).

Outer shelf

The outer shelf banks are topped with a mix of sand and gravel of varying sizes known as Sable Island Sand and Gravel. The sand surface tends to be smooth and flat and the gravel is well-sorted and rounded from the passage of a former beach during marine transgression. A long sand-ridge system occurs on Banquereau and Sable Island Bank, including Sable Island, and is perhaps the remnants of a barrier-island system, now long-submerged (Amos and Knoll 1987). Much of Sable Island Bank consists of well-sorted sand, with sand waves occurring in some areas (King 1980, Amos and King 1984). These and other bedforms that occur on the outer banks can be generated and dispersed by storm events (see e.g. Amos et al. 1996), as well as non-storm related bottom current activity (Amos et al. 1988). The transport of sediments and the formation of bedforms on Sable Island Bank near Sable Island, have been studied in some detail (see e.g., Amos 1984, Amos and Nadeau 1988, Amos et al. 1996, Ingersoll and Ryan 1997, Li and Amos 1999). The large numbers of shell beds on Sable Island Bank are a prominent surface feature (Fader 1991d).

The grain size and the degree of sorting of surficial sediments on Sable Island Bank were assessed by James and Stanley (1968). This characterization of the sediments is useful in examining the distribution of benthic animals, many of whom have particular sediment preferences. For example, the distribution of the sand dollar *Echinarachnius parma* is strongly associated with grain size and sorting. It prefers medium and fine, moderately well-sorted sand (Stanley and James 1971). Amos and Nadeau (1988) characterized the grain size of the sandy sediments found on Banquereau, Middle, and Sable Island Banks. Sable Island Bank had the largest extent of areas with very fine and fine sands (less than 0.125 mm), while the sands overlying Banquereau were generally classified as medium to coarse in size (0.25 to 1.0 mm in size). The non-sand fraction of the bottom sediments was not included.

Gravelly areas, such as Emerald Bank, have occasional drifts of sand or long thin sand ribbons. These sand deposits can be moved by storms. Browns and Baccaro Banks have gravelly and sandy areas intermixed. The saddles between the outer banks and the edges of the channels are covered with a silty sand mixture known as Sambro Sand. Amos and Nadeau (1988) suggested that sandy sediments are generally trapped on top of the banks, while finer silt is able to move in suspension into the deeper waters of adjacent basins and the slope. Some sand does appear to move off Sable Island Bank into The Gully through feeder canyons (Marlowe 1967, Amos 1989, Fader and Strang in press).

Continental slope and submarine canyons

There are a variety of surficial sediments on the continental slope, with silty sediments carried down the slope through suspension, and sandy and gravelly sediments slumped over the shelf edge (Piper 1991). In general, the finer sediments are carried in a southwestward direction at the shelf break (Hill and Bowen 1983). Some areas of steep slope have exposed bedrock, as do the submarine canyons (Piper 1991). There are escarpments formed by slumping, perhaps caused by earthquakes (Piper et al. 1985). There is evidence that the 1929 Grand Banks earthquake (with an epicentre in the Laurentian Channel) caused slumping of sediments along the slope and resulted in turbidity currents. These deposited massive amounts of sediment on the slope, rise, and deep seafloor south of Nova Scotia and Newfoundland (Piper et al. 1992, Hughes Clarke et al. 1990).

The submarine canyons that indent the Scotian Shelf and slope have areas of exposed bedrock in cliffs, as well as areas where sediments have slumped from adjacent banks (Amos 1989, Piper 1991). Marlowe (1967) collected core samples and seismic profiles from The Gully. He sampled hard, compacted sediments along the west wall of The Gully. Softer sediments, largely sand and mud, were sampled from stations on the east wall of the main canyon and along the upper slope. Use of multibeam bathymetry has allowed a detailed description of the morphology and surficial sediments of The Gully (Fader and Strang in press). Images produced by multibeam show evidence of buried and infilled channels and continual sediment deposition in The Gully. Erosional processes exposed bedrock and there are cliffs and areas of very steep slopes. Glacial moraines occur on the eastern side of the Gully, at depths less than 800 metres. There is no evidence of direct glacial deposition below 800 metres. The floor of the Gully is mostly sand, likely transported and deposited from adjacent banks.

Laurentian and Northeast Channels

The sediments on the slopes of the Laurentian and Northeast Channels are classified as Sambro Sand. The floors of the two channels have different surficial sediments, reflecting the energy of the bottom currents. The Northeast Channel was highly affected by glaciation. Iceberg furrows and pits are widespread and ice-rafted boulders are found in many areas on the floor of the channel (Fader pers. communication). The seafloor of the Laurentian Channel is covered with finer sediments. Emerald Silt is found at the mouth of the channel and in smaller patches in other areas, and LaHave Clay makes up much of the middle portion of the channel (Fader 1991a).

Pockmarks, cone-shaped depressions up to 300 metres in diameter and 30 metres deep, are an unusual feature of the eastern Scotian Shelf, Scotian Slope, and Laurentian Channel (King and MacLean 1970, Fader 1991b). They are thought to indicate the release of hydrocarbon gases through muddy basins from beneath the surficial sediments and have been found near known areas of hydrocarbon resources (Fader 1991b). There are known hydrocarbon deposits in other areas of the shelf. Organic material buried millions of years ago in the basin around Sable Island was transformed over the centuries and is the source of gas reserves found in the area.

Recent detailed mapping of the Scotian Shelf

Although the mapping program of the 1960s to 1980s allowed the surficial geology of the Scotian Shelf to be regionally characterized, those maps do not provide sufficient detail or resolution to understand the coupling of benthic organisms with particular habitats (Fader in press). To relate benthic habitat with bottom-dwelling organisms, descriptions of the surficial sediments and morphology of small, discrete areas are needed, on a a scale that characterizes habitat details. For example, gravel bottoms in the Sable Island sand and gravel unit, as shown in Figure 2-3, may be flat or hummocky (King 1970). The category of "gravel" includes small, well-sorted pebbles, to rocks the size of boulders. Thus, a wide range of habitats could be found within a single category used in the mapping by the Geological Survey of Canada.

Since the regional mapping program was completed, new seabed mapping technology has been developed. It is now possible to portray the shape of the seafloor in detail using multibeam technology. This method also provides information on the attributes of sediment texture (Kostylev et al. 2001). Combining multibeam with existing surficial geology maps and other technology, such as sidescan sonar and photographs, would result in a detailed picture of the seafloor.

This approach has been taken on some parts of the shelf. Multibeam images are available for parts of Browns Bank, the Northeast Channel, Sable Island Bank, The Gully, Halifax Harbour and an adjacent coastal area (see e.g., Loncarevic et al. 1994), Scatarie Bank and a few smaller areas along the Atlantic coast (Atlantic Geoscience Centre 1999). Kostylev et al. (2001) used multibeam images, existing maps of surficial sediments, sidescan sonograms, and photographs of the seafloor to create a benthic habitat map for Browns Bank. They found that sediment type was strongly associated with particular benthic organisms and described the epifauna associated with particular sediments on Browns Bank. Prior to the use of multibeam data, it was possible to identify major benthic features, such as shell beds, from the data collected during the 1970s and 1980s (see e.g., Fader 1991d); however, the new technology allows much smaller features to be detected.

Fader and Strang (in press) reported on the multibeam bathymetry collected in The Gully during 2000. Their work provided a detailed morphology of the Gully and the sediments and processes overlying the bedrock. Such descriptions can be combined with photographic information and samples to gain a better understanding of benthic habitat. Kostylev (in press) used information on the physical environment of The Gully, including multibeam information, to describe benthic assemblages and habitat in the canyon.

Ecological Function of Sediments

The sediments covering the Scotian Shelf seafloor are an important structural and functional component of the marine ecosystem. Knowledge of linkages between sedimentary habitats, biodiversity, and ecosystem processes is somewhat limited but is gaining increasing attention by ecologists. Fader et al. (in press) described the recent emergence of marine geology in ecological studies of the Scotian Shelf. They listed the following geological seabed attributes as being of ecological importance: micro relief (roughness), macro relief (topography), grain size, lithology (rock composition), patchiness (local variability), sediment distribution, sediment sorting, porosity, grain shape, stratigraphy, dynamics/processes, bedforms, sediment transport pathways, sediment thickness, regional setting, geological history, and anthropogenic features (e.g., cables and features). These attributes influence the organisms living on and in the sediments.

Snelgrove et al. (1997) related the ecological role of organisms living in marine sediments with ecosystem functioning in general. Marine sediments support diverse communities of benthic organisms that contribute to the regulation of carbon, nitrogen and sulphur cycling, water column processes, pollutants distribution and fate, secondary production, and transport and stability of sediments (Snelgrove et al. 1997, Snelgrove 1999). Many of these organisms – and their role in the ecosystem – are not yet documented.

The stability of sediments and the communities living on and in them has repercussions throughout the ecosystem. Areas with a diversity of surficial sediments, such as a range in grain size, result in varied benthic habitat types and may support greater biodiversity than areas of a similar size with homogeneous characteristics. Areas with relatively stable surficial sediments may also support higher diversity or higher numbers of organisms. The heterogeneity of surficial sediments in The Gully, and perhaps in other submarine canyons, suggests that these areas could support enhanced biodiversity. There may be other areas of the shelf and slope with a diversity of surficial sediments. Detailed understanding of the Scotian Shelf's surficial geology will allow us to better understand the biological communities associated with the various sediments. The animals living on and in the sediments and the role they play in the Scotian Shelf ecosystem will be looked at in more detail in later chapters.

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3 PHYSICAL OCEANOGRAPHY[1]

Introduction

This chapter provides an overview of the physical oceanography of the Scotian Shelf: the physical characteristics and movements of the ocean that characterize this region. The spatial and temporal patterns of these features greatly influence the shelf's biological productivity at all depths and trophic levels. This information provided here is aimed at characterizing the shelf in a spatial manner and linking those characteristics with the spatial and temporal distribution of marine organisms.

An extensive database of oceanographic information has been collected and archived by the Oceans Sciences Division (OSD) of Fisheries and Oceans Canada at the Bedford Institute of Oceanography. The data have been used to describe ocean processes, monitor the oceanographic environment, and develop models to simulate and study patterns of circulation, temperature, and other variables in the physical environment (Tee et al. 1993, Cong et al. 1996, Han et al. 1997, Han et al. 1999, Shore et al. 2000, Hannah et al. 2000, Hannah et al. 2001). Resources available through OSD and elsewhere were reviewed with the aim of identifying relevant sources of information for this ecological overview. Particular emphasis was placed on finding synthesis works that depict seasonal variability over the entire continental shelf.

Variability in the Scotian Shelf marine environment is controlled by spatial and temporal changes in water masses brought on by various forcings, such as interactions between major currents and shelf topography, and seasonal changes driven by the atmosphere (Drinkwater et al. 1999, Han et al. 1997, Loder et al. 1997). Maps in this chapter are based on data for the years 1950 to 1990 and provide a reasonable estimate of average conditions for the entire period. Although strong annual and decadal environmental variability have been reported in this region (Petrie and Drinkwater 1993, Petrie et al. 1996, Loder et al. 2001), only average conditions, by season, were readily available for inclusion in this report. Strong short-term events can also have an important influence on the oceanographic environment. Nevertheless, seasonal variability and structures provide a broad and useful perspective of oceanographic events for the purpose of this section.

Factors affecting the biological productivity of benthic and pelagic habitats include solar radiation, water temperature, degree of physical retention, and degree of vertical mixing. These factors are not discrete: they are influenced by each other and by other factors, including surface temperature, topography, circulation (including tidal currents), and wind events. The high productivity of the Scotian Shelf marine ecosystem, in terms of biological components, implies that optimum conditions for growth, reproduction and survival of pelagic and planktonic species occur at various times across the shelf. However, these conditions vary seasonally. Similarly, the spatial distribution of marine organisms, their abundance, and their availability also appear to vary on seasonal timescales, although these interpretations are somewhat confounded by the effects of fishing. The oceanographic

[1]Staff from the Ocean Sciences Division, Fisheries and Oceans Canada, contributed to the writing and editing of this chapter. The authors would like to thank John Loder and Peter Smith for their comments on earlier versions of this chapter.

information provided here is intended to link physical variability in the ocean with biological variability.

Temperature and Salinity

Over 60 years of research have shown the ocean climate of the Scotian Shelf to be characterized by the occurrence of both short- and long-term variability, although a relatively consistent annual cycle has been described by Petrie et al. (1996) on the basis of seasonal average temperature, salinity and circulation. According to this work, a layered water mass structure is typically found on the Scotian Shelf; however, this structure varies geographically and seasonally.

As an example, the vertical water mass structure of the central Scotian Shelf can be described in general terms. During the winter, a two-layered structure prevails along the Halifax Section (crossing Emerald Bank and Emerald Basin). At this time, a cooler, fresher layer is found near the surface and overlays a warmer, saltier layer. During the summer, the same Halifax Section typically shows a distinct three-layered structure with warm, low salinity surface waters, a cold intermediate layer, and a warm, higher salinity bottom layer:

1) a surface layer (0-25 metres), typically of low salinity (less than 32 ppt) and seasonally variable temperatures;
2) an intermediate cold layer (25-50 metres) of less than 5 degrees Celsius and 32-33.5 ppt of salinity; and
3) a characteristically warm bottom layer with temperatures above 5 degrees Celsius and salinity that exceeds 33.5 ppt.

The bottom layer of Emerald Basin is the result of the intrusion of dense saltier and warmer water from the continental slope. Detailed data on temperature and salinity throughout the water column and over the whole Scotian Shelf can be found in Petrie et al. (1996).

Temperature

Temperature is an important environmental factor because many species have narrow temperature tolerances. Changes in temperature will affect their spatial distribution. Temperature influences metabolism, growth rate, and reproductive output.

Surface temperature is important for many migratory pelagic species, such as swordfish, mackerel and tuna, as well as jellyfish and the sea turtles that prey on them. Swordfish are concentrated in areas of the Scotian Slope and slope where surface temperatures climb above 15°C. Temperature influences the localized distribution of mackerel, as they much prefer to be in waters above 9°C.

The range of average bottom temperatures encountered by demersal and benthic organisms may be estimated from summer and winter bottom temperatures, based on historical data. The following maps represent the average seasonal temperature of all available years, from Oceans Sciences Division databases (Figures 3-1 to 3-4).[2]

[2] Charles Hannah, Oceans Sciences Division, Fisheries and Oceans Canada, provided the data for Figures 3-1 to 3-20.

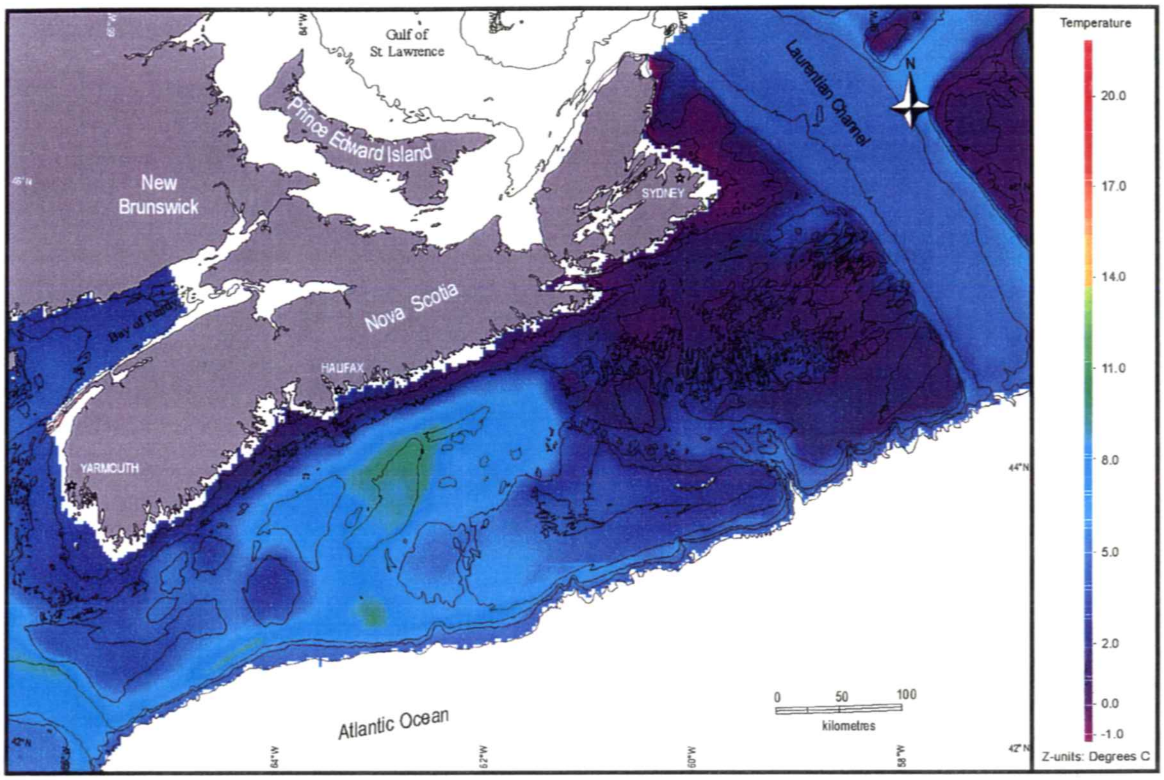

Figure 3-1. Spring bottom temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

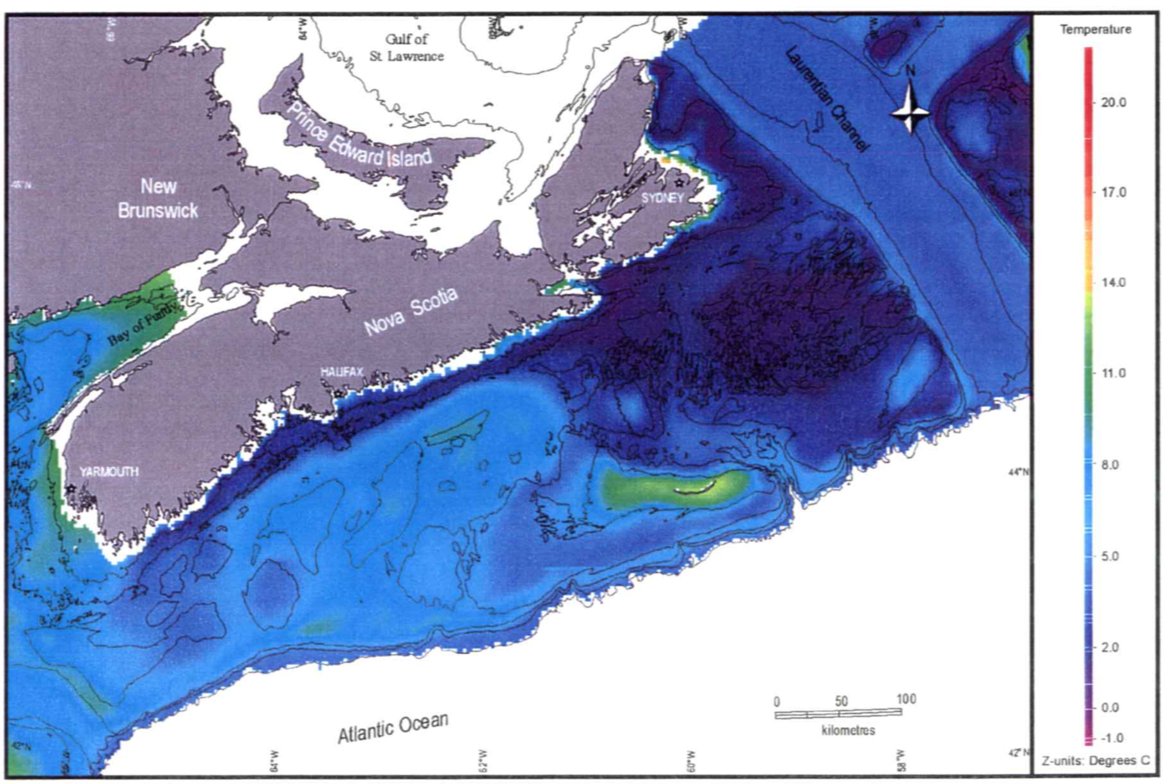

Figure 3-2. Summer bottom temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

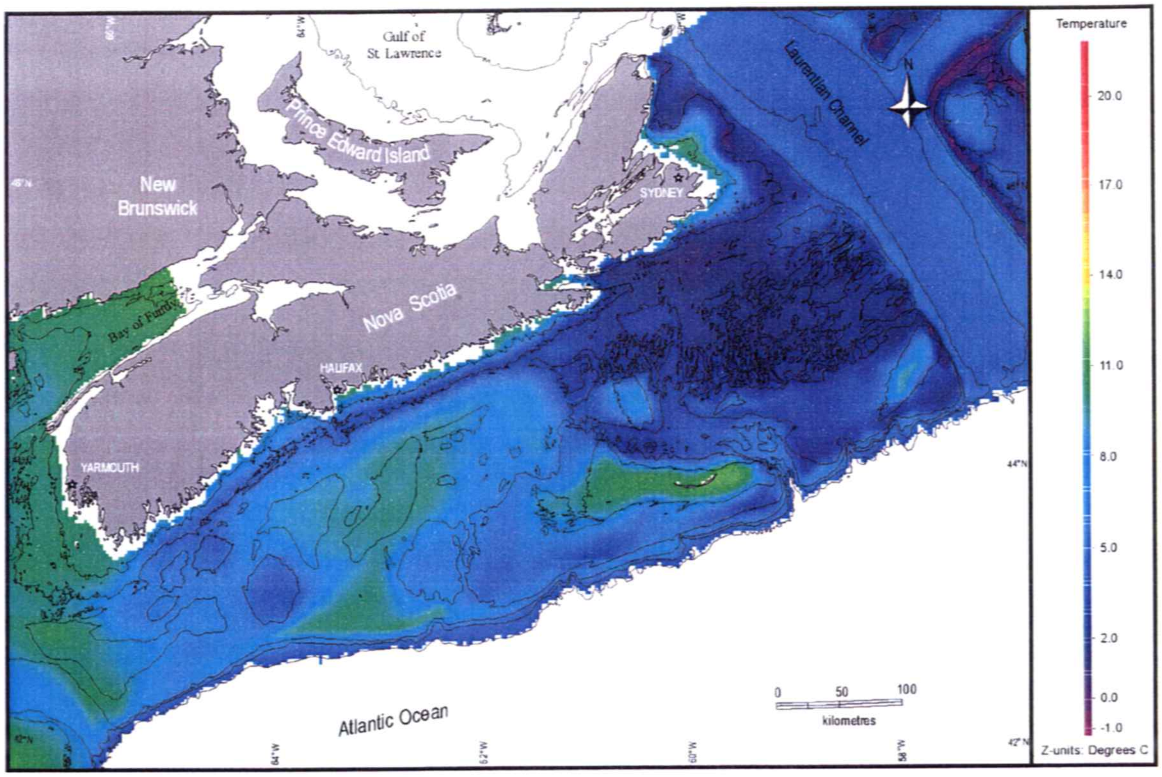

Figure 3-3. Fall bottom temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

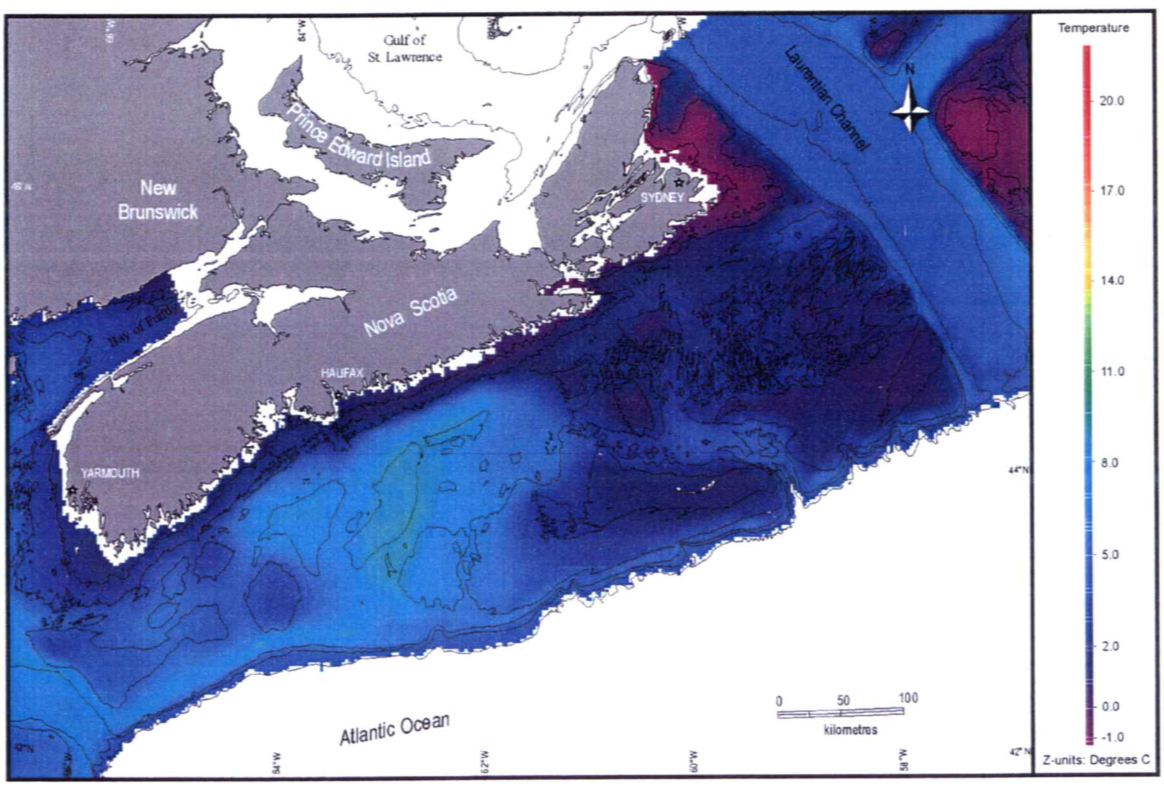

Figure 3-4. Winter bottom temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

For all seasons, bottom temperatures of less than 3°C are mostly confined to the eastern Scotian Shelf and to a thin intrusion westward along the coast where the bottom intercepts the cold intermediate layer. Bottom temperatures remain relatively unchanged during the winter in the area of the eastern Scotian Shelf, but the cold regime expands along the coast as well as on shallow Sable Island bank.

The western Scotian Shelf remains generally warmer than the eastern shelf. The temperature regime of the western shelf is also seasonally and spatially more dynamic, reflecting the greater influence of the slope waters and Gulf Stream and increased vertical mixing on the western Scotian Shelf.

Although bottom temperature is a useful indicator of areas where benthic animals with narrow temperature tolerances could be found, these portrayals of seasonal averages provide only a very broad indication of potential distribution. Through processes of mixing and stratification, midwater and surface temperatures also contribute regularly to bottom temperatures. Periods of deviation from the average annual or seasonal regime may have important consequences for the distributions of benthos on the shelf.

In some regions of the Scotian Shelf, bottom temperature has limited seasonal variability and this stability may be favourable for temperature-sensitive species (see Figure 3-5). In spite of seasonal to decadal changes throughout the water column, the bottom temperature regime appears to be relatively invariable on a seasonal scale, particularly over the eastern Scotian Shelf. There have been some decadal-scale variations in bottom temperature, which are discussed later in this section.

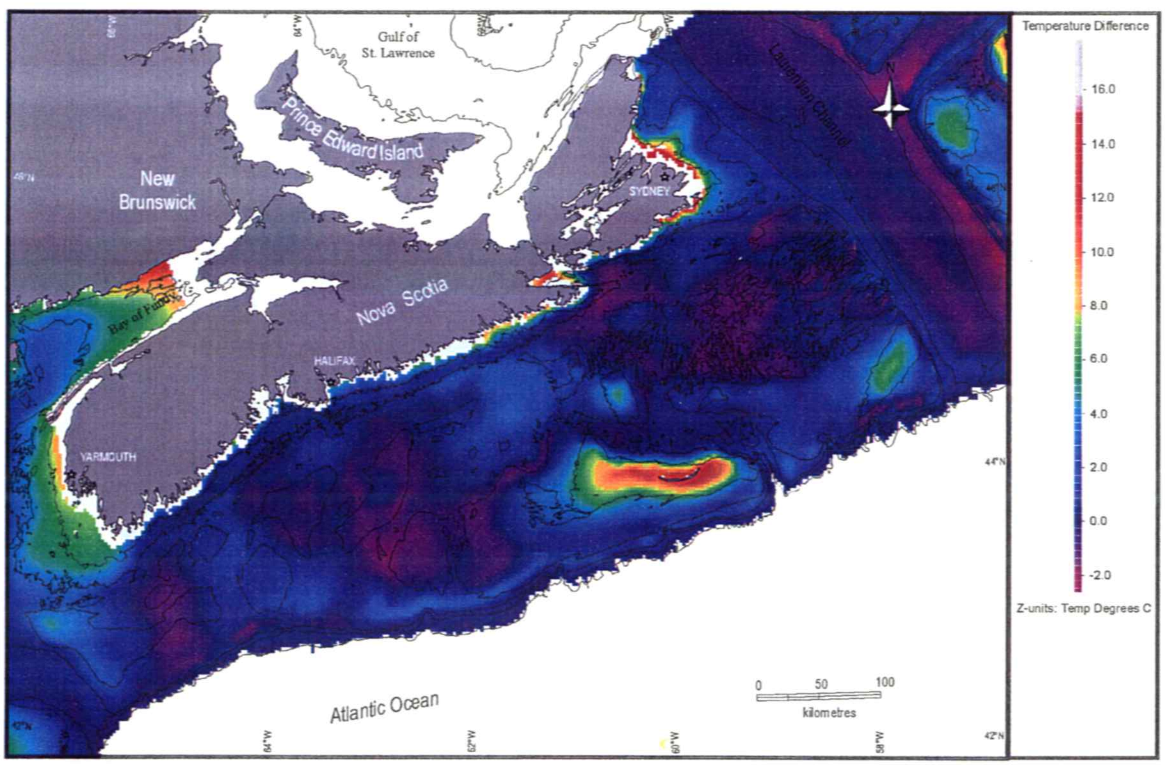

Figure 3-5. Difference between summer and winter bottom temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

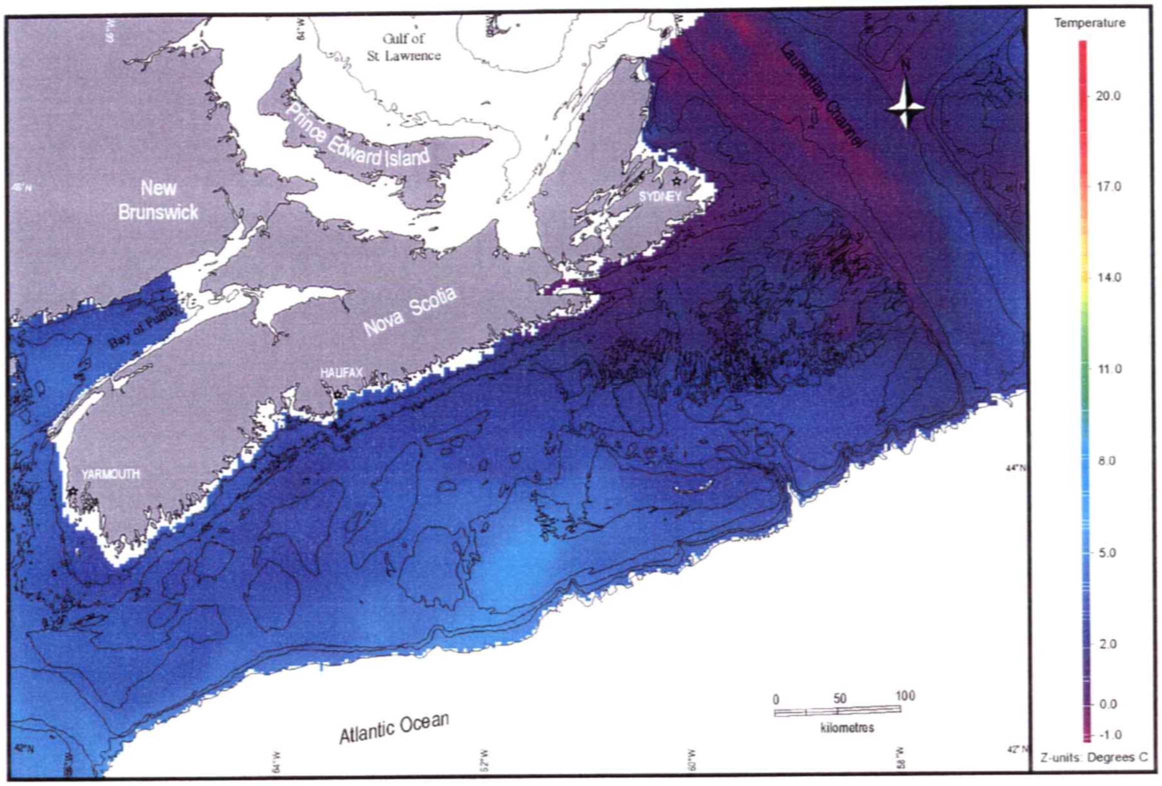

Figure 3-6. Spring surface temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

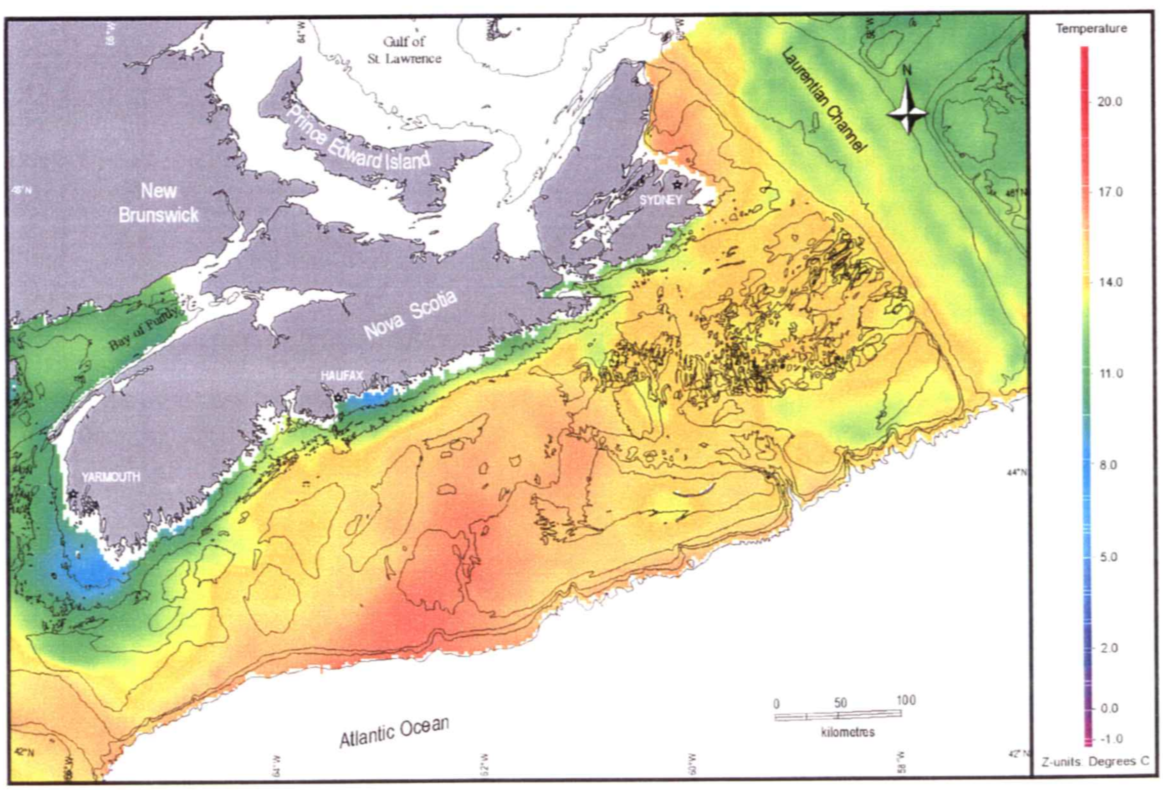

Figure 3-7. Summer surface temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

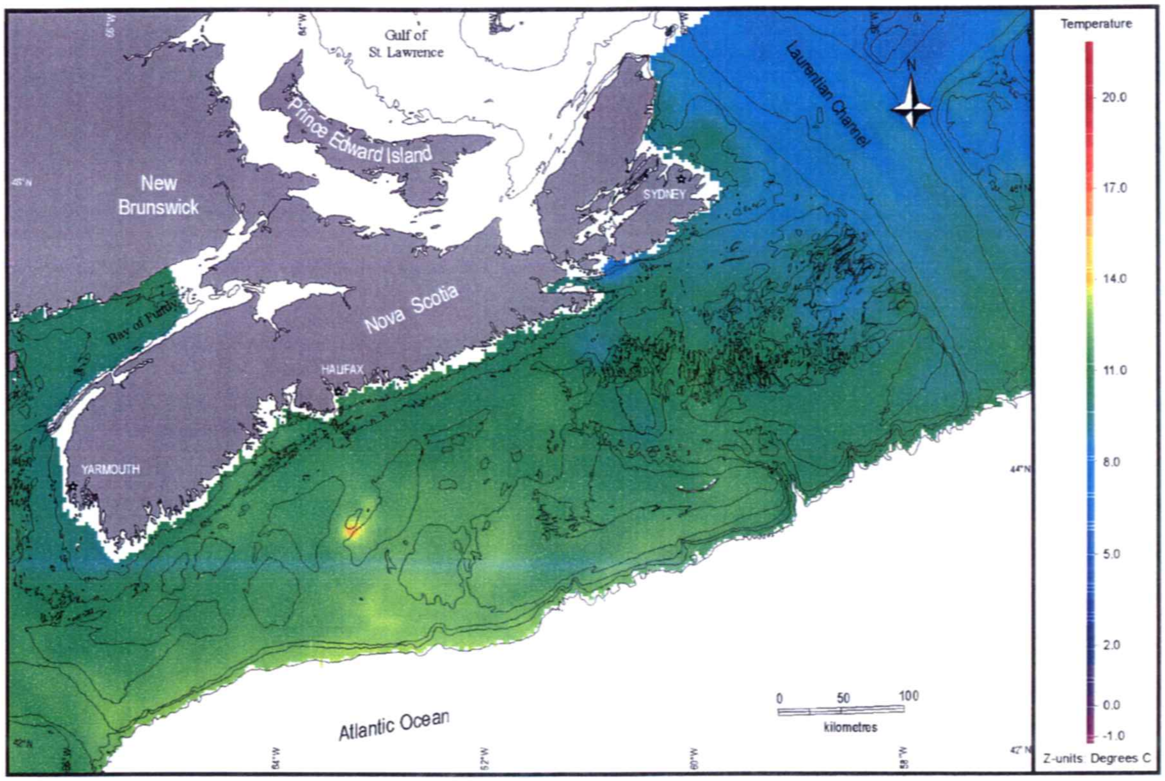

Figure 3-8. Fall surface temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

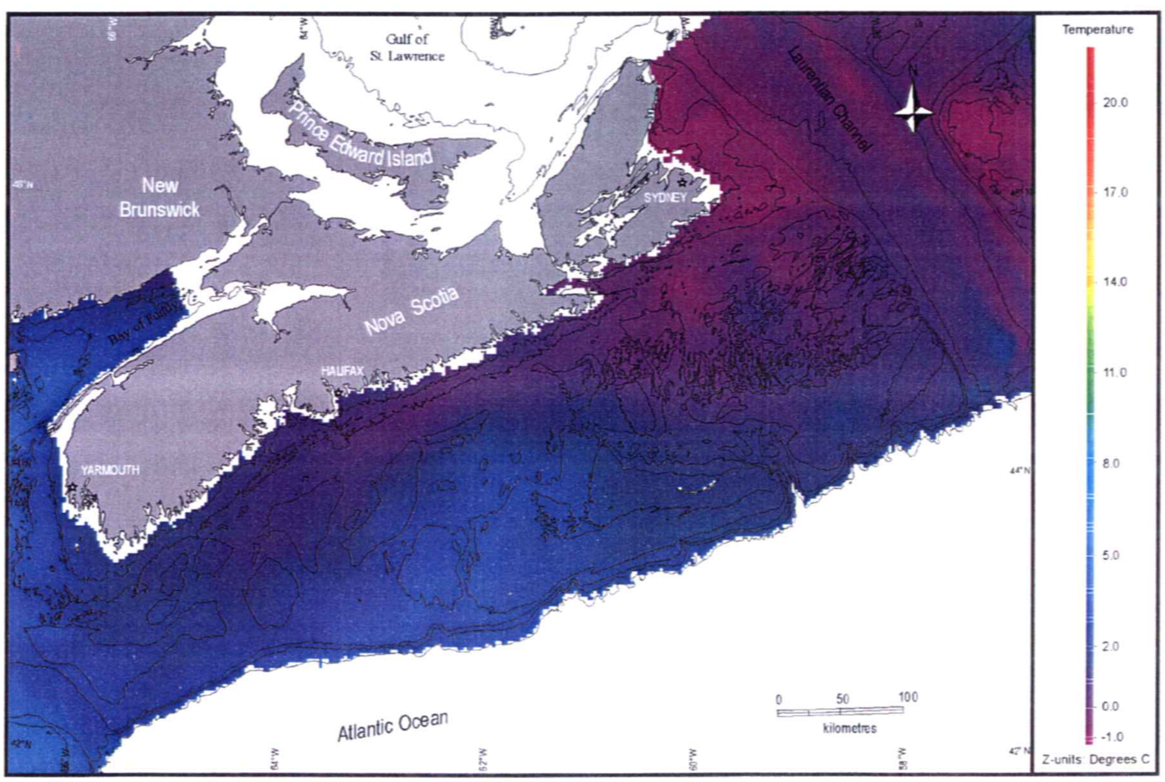

Figure 3-9. Winter surface temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

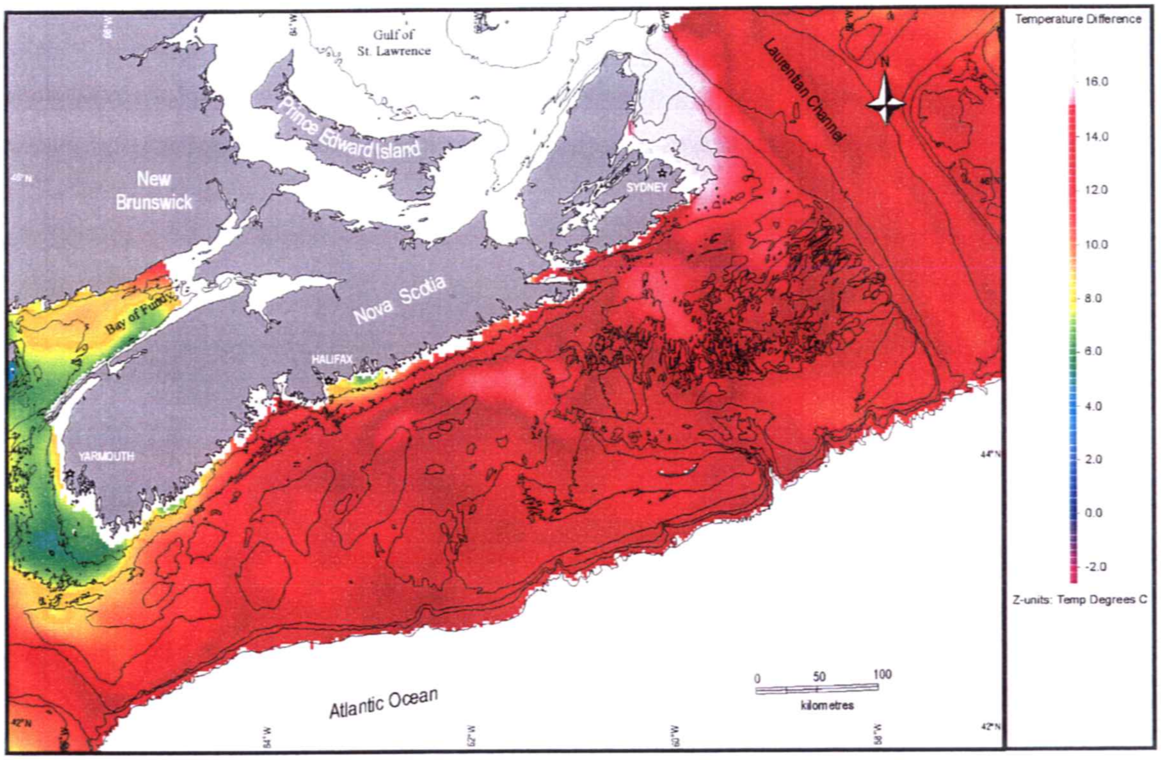

Figure 3-10. Difference between summer and winter surface temperatures on the Scotian Shelf and slope, to the 1000-metre isobath.

Surface temperatures show great seasonal variation over much of the Scotian Shelf (Figures 3-5 to 3-9). Sydney Bight shows a seasonal range in surface temperature of over 15°C from winter to summer (Figure 3-10). However, an area off southwest Nova Scotia shows a relatively stable surface temperature regime, with surface temperatures rarely rising above 11°C or falling below 5°C. This stability is due to the regular upwellling of cool bottom waters. Warm surface temperatures occur on the Scotian Shelf throughout the summer and fall and coincide with the highest abundance of whales, sea turtles, tuna, mackerel, and swordfish.

Ice coverage is rare in the offshore of the Scotian Shelf. However, pack ice occasionally extends into Sydney Bight during the winter and early spring and, more rarely, onto the eastern shelf south of Cape Breton. When pack ice breaks up, it can be carried southwestwards along the coast, to a limit of probably Halifax Harbour (Davis and Browne 1996). There are localized occurrences of sea ice along the coast, with a decreasing occurrence from Cape Breton to Yarmouth (Davis and Browne 1996).

Salinity

Salinity influences the presence of marine species both directly through salinity preferences of particular species and indirectly through its effects on stratification, water movements and hence, phytoplankton productivity. Both the Labrador Current and the Gulf Stream are saltier than Scotian Shelf waters, varying between 34-35 ppt and 35-36 ppt respectively. In general, it has been found that salinity does not vary systematically with temperature, although periods of low temperature are generally associated with lower salinities and vice versa, such that the water masses are roughly density-compensated (Petrie et al. 1996) (see below for discussion of density). The annual cycles of bottom and surface salinity are depicted by seasonal distributions (Figures 3-11 to 3-14 and 3-16 to 3-19). The bottom salinity of some areas of the Scotian Shelf, for example the mid-shelf basins, are relatively invariable over the whole year (Figure 3-15). Areas near the coast are generally less saline than areas of the slope and the basins. Surface salinity is somewhat more variable (Figure 3-20). Like temperature, the differences in surface and bottom salinities contribute to stratification in the water column.

Density stratification

Differences in the density of seawater throughout the water column (i.e. stratification) affect the aggregation of biological matter in the upper layers of the ocean. Density is a function of salinity, temperature, and pressure. In general, as water temperature decreases, it becomes more dense. Salinity moves in the opposite way – as salinity increases, water becomes more dense. Thus water masses of different properties overlay one another in the ocean, with warmer water overlying cooler water of the same salinity, and less saline water overlying saltier water of the same temperature.

Density stratification is represented here (Figures 3-21 to 3-24) by the difference in density between the water at 50 metres or the bottom (whichever is shallower) and the surface (0 metres).[3] Differences in density act both directly by providing restoring forces on buoyant, less dense particles, and indirectly by regulating vertical mixing rates. In the summer, regions of strongly stratified water lie inshore on the eastern Scotian Shelf and over the deeper basins and banks on the central shelf (Figure 3-22). On the western shelf, particularly near the coast, vertical mixing associated with strong tidal currents in the Gulf of Maine limits the density contrast in the water column. In the winter and spring seasons, enhanced surface forcing by strong winds and passing storms limits vertical density stratification in the upper 50 metres of the water column relative to the summer levels (Figures 3-21 and 3-24). During the fall, the density contrast is not as strong as the summer, nor are waters as well-mixed as the spring and winter seasons. Through its influence on physical aggregation and vertical mixing rates, density stratification may have important implications for the biological productivity of different geographic areas, as well as for the spatial distribution of species.

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[3] John Loder and Shawn Oakey, Oceans Sciences Division, Fisheries and Oceans Canada, provided the data for Figures 3-21 to 3-24.

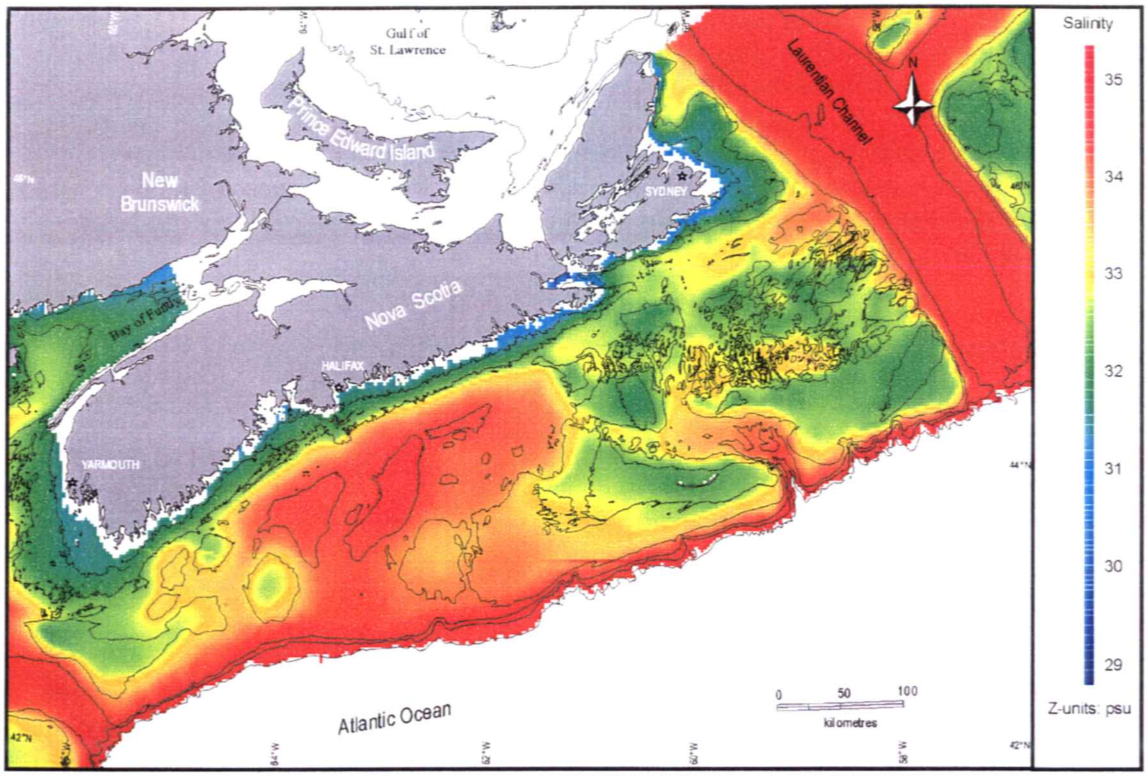

Figure 3-11. Spring bottom salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

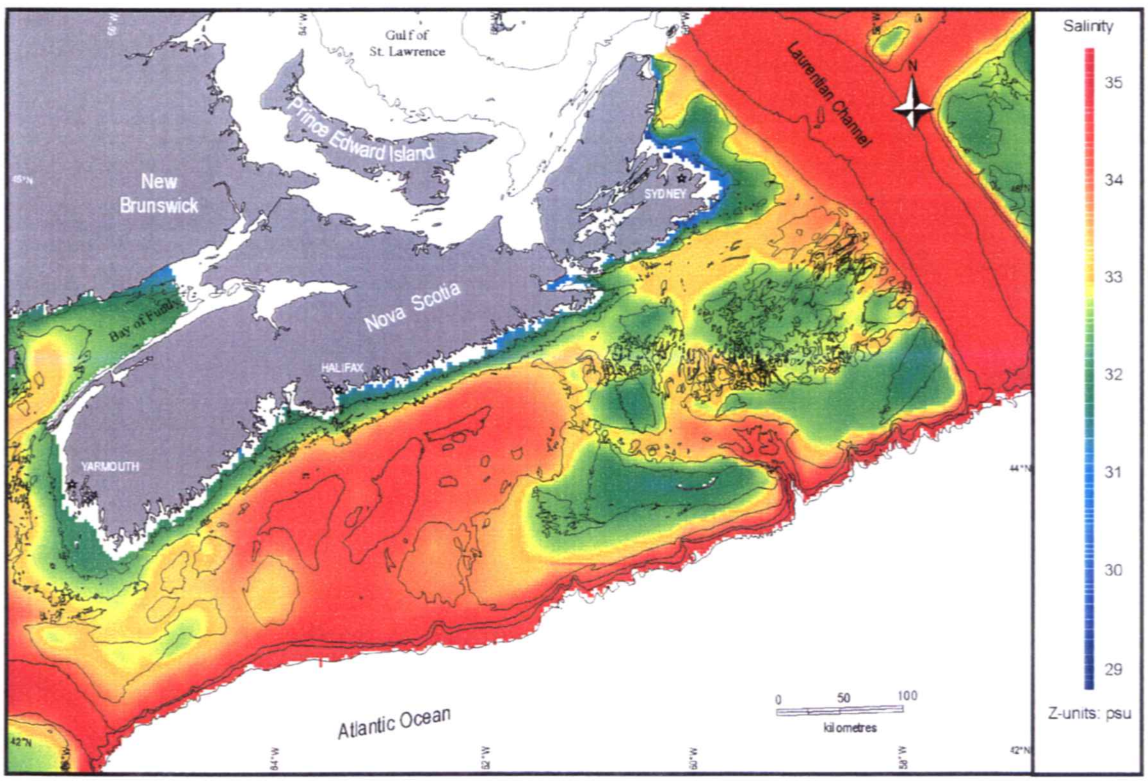

Figure 3-12. Summer bottom salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

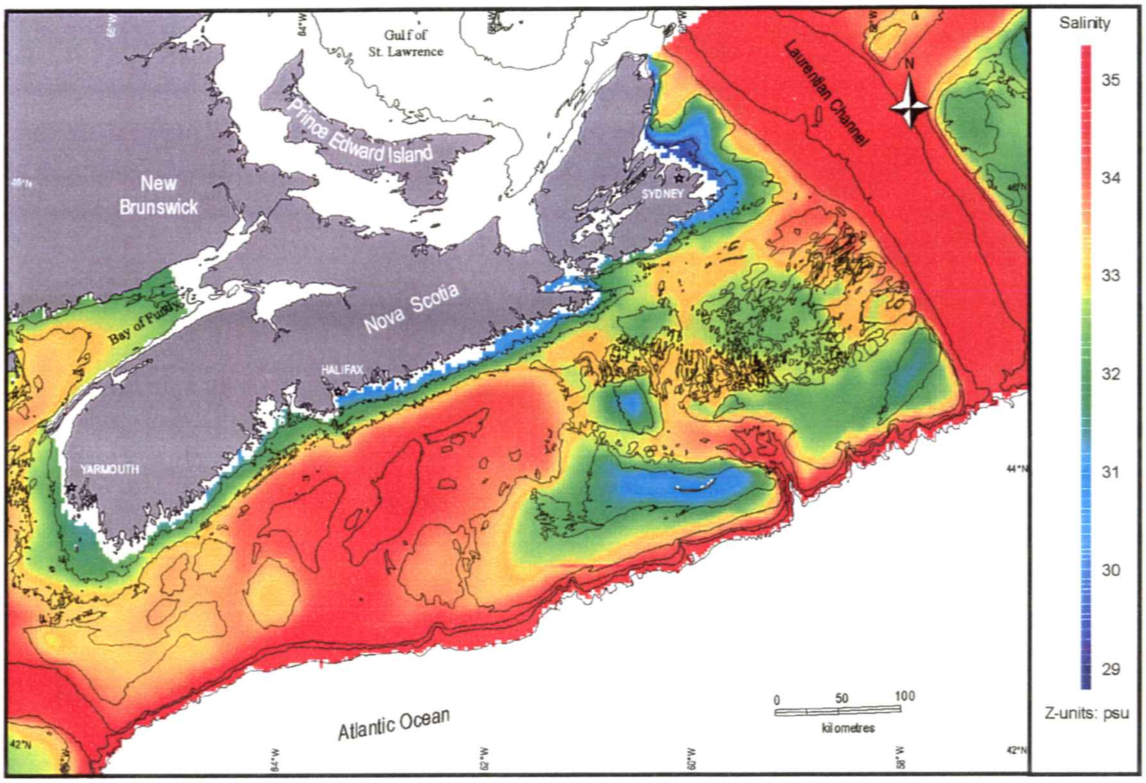

Figure 3-13. Fall bottom salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

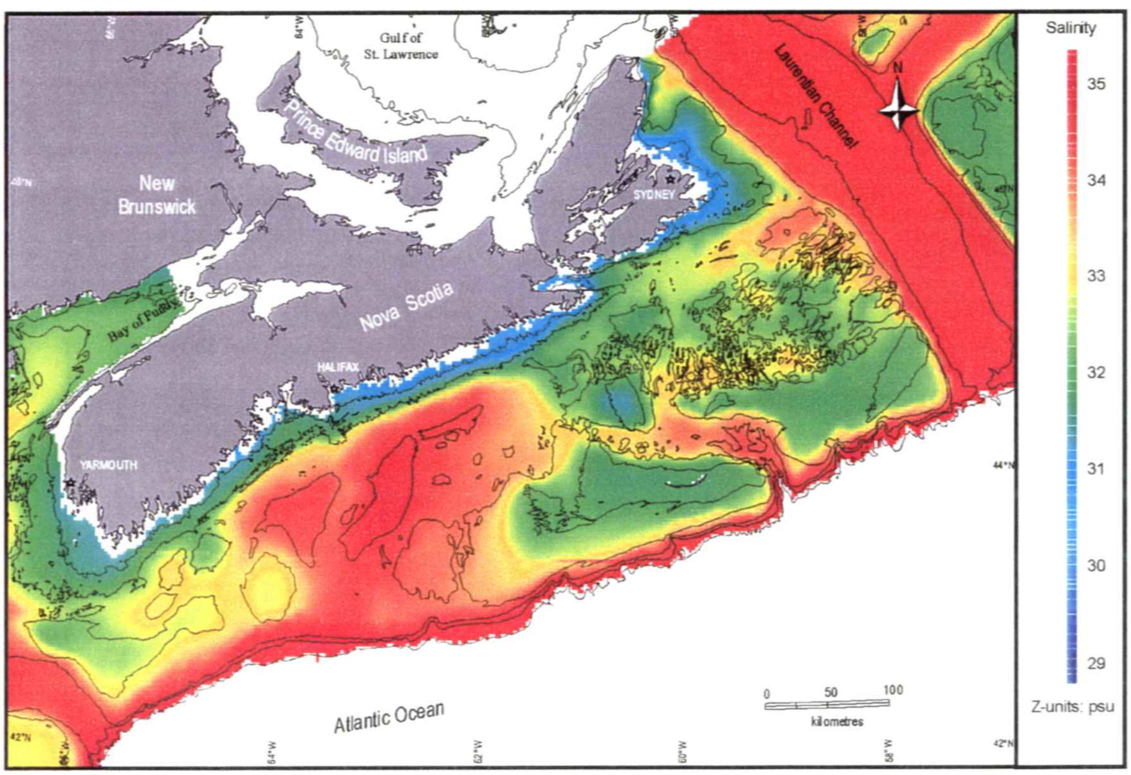

Figure 3-14. Winter bottom salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

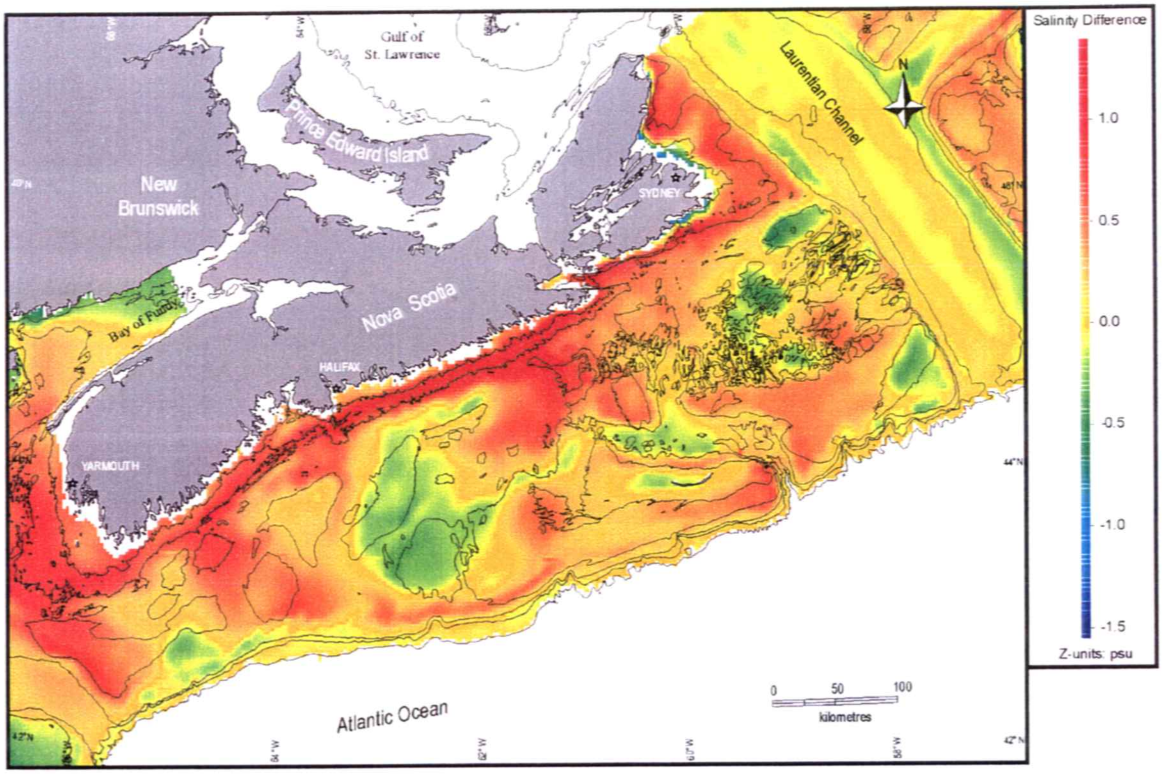

Figure 3-15. Difference between summer and winter bottom salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

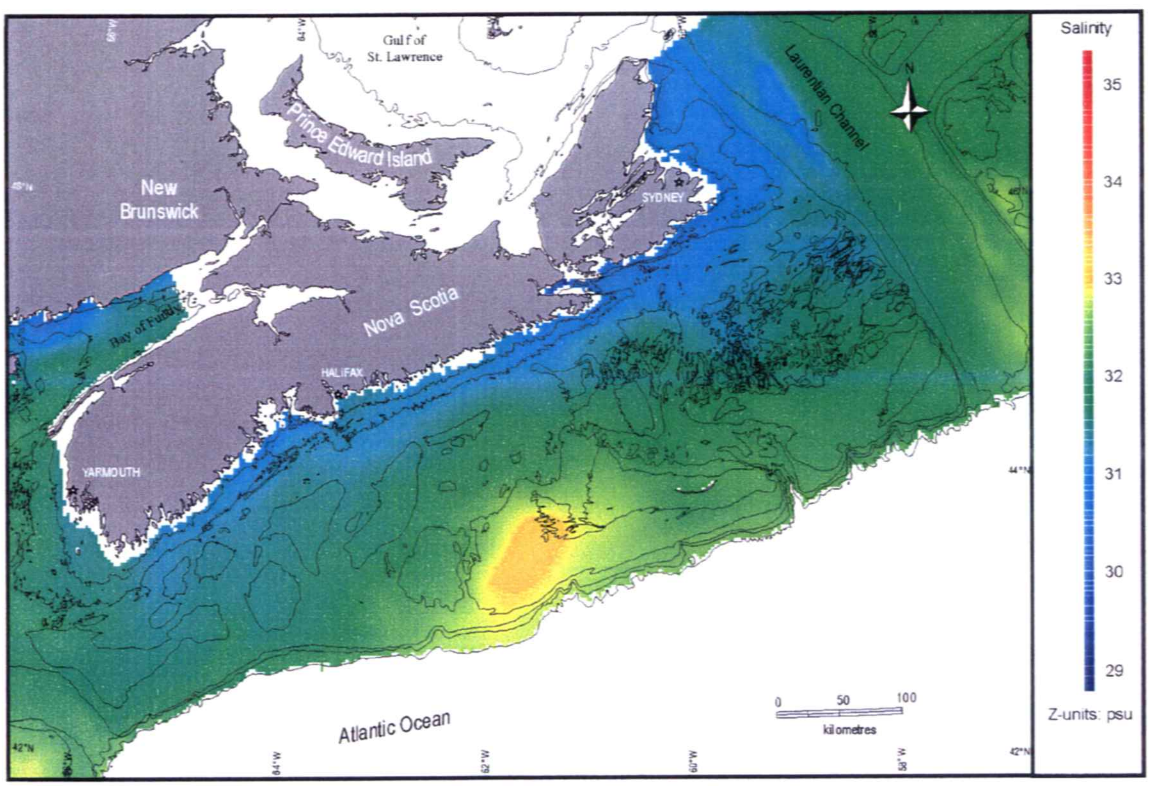

Figure 3-16. Spring surface salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

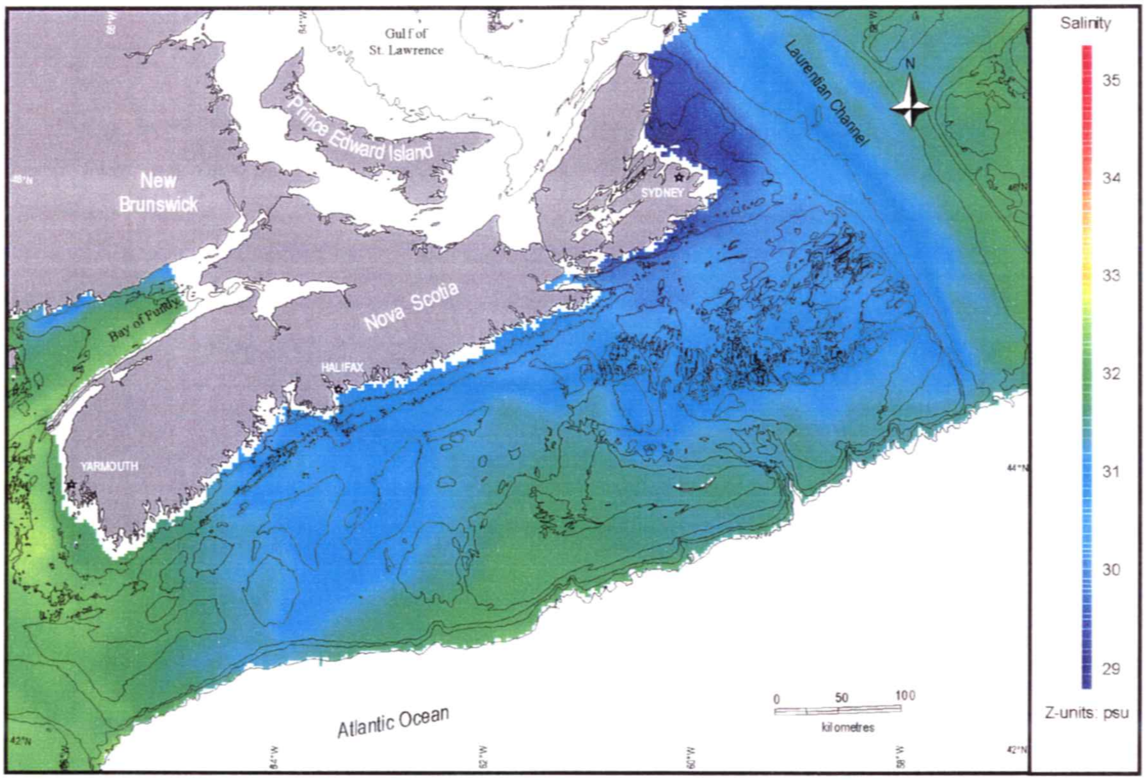

Figure 3-17. Summer surface salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

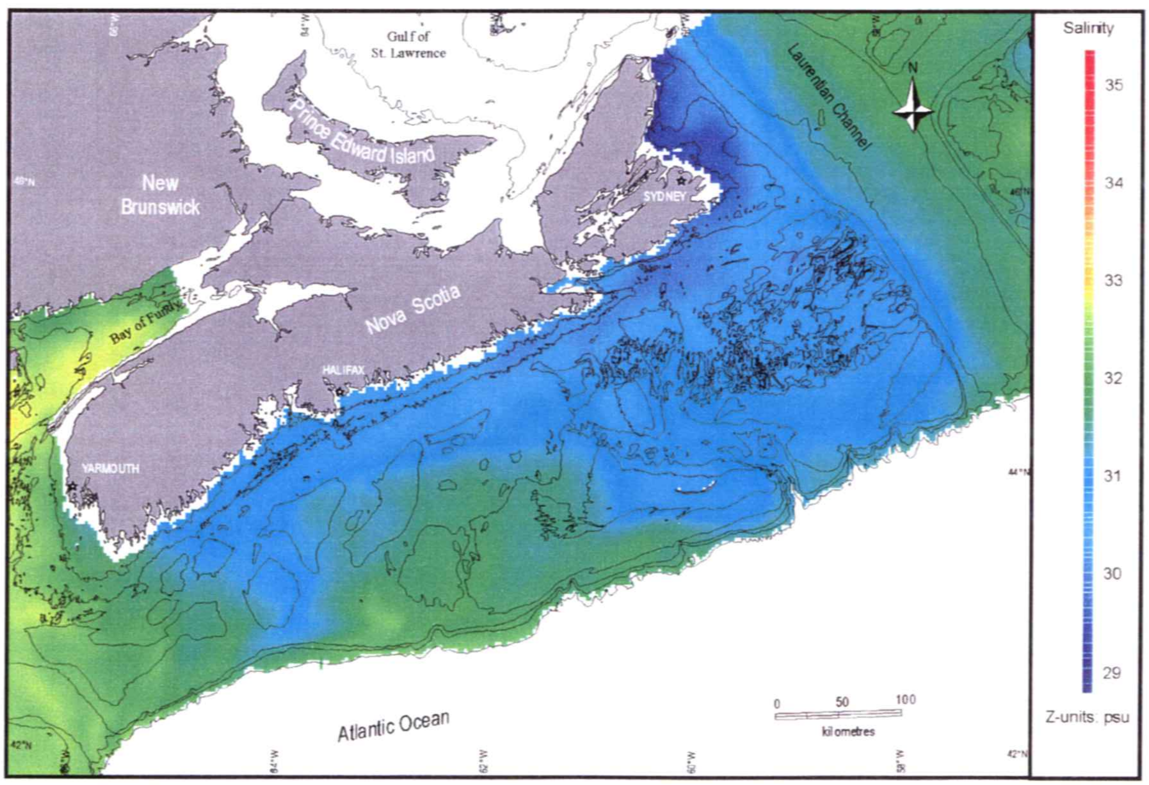

Figure 3-18. Fall surface salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

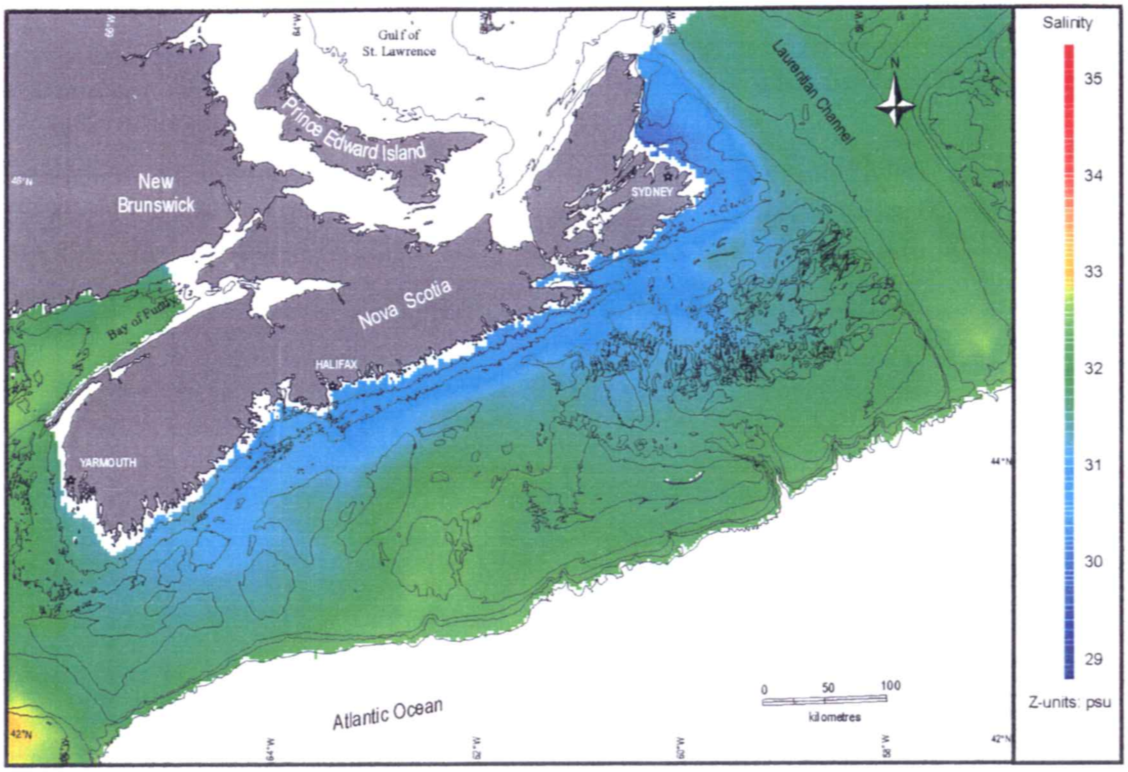

Figure 3-19. Winter surface salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

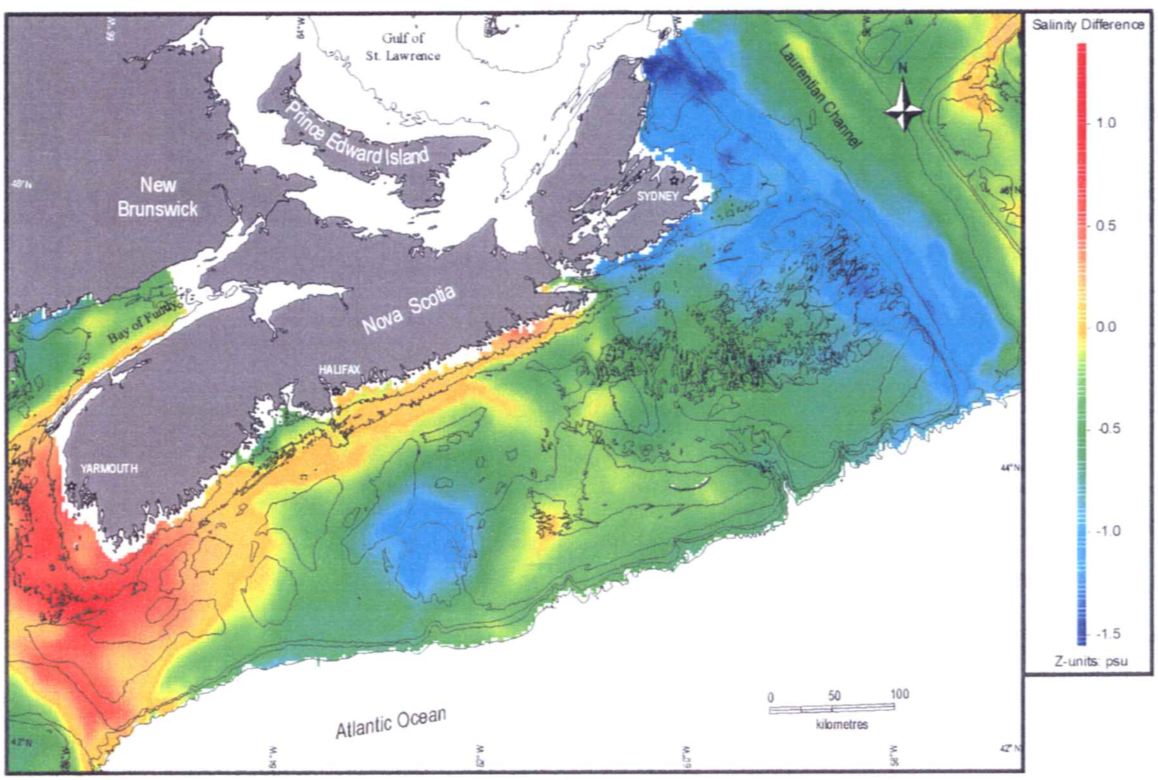

Figure 3-20. Difference between summer and winter surface salinity on the Scotian Shelf and slope, to the 1000-metre isobath.

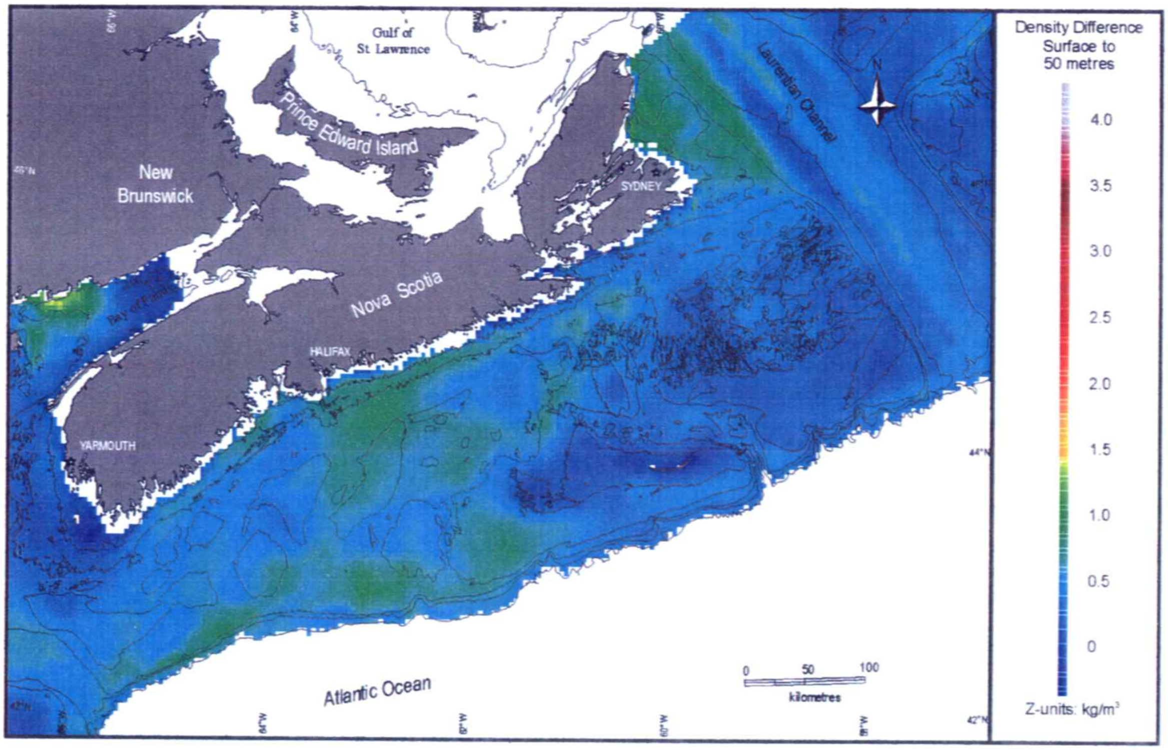

Figure 3-21. Spring density difference between 50 metres or the bottom (whichever is shallower) and the surface, measured in kilograms per cubic metre.

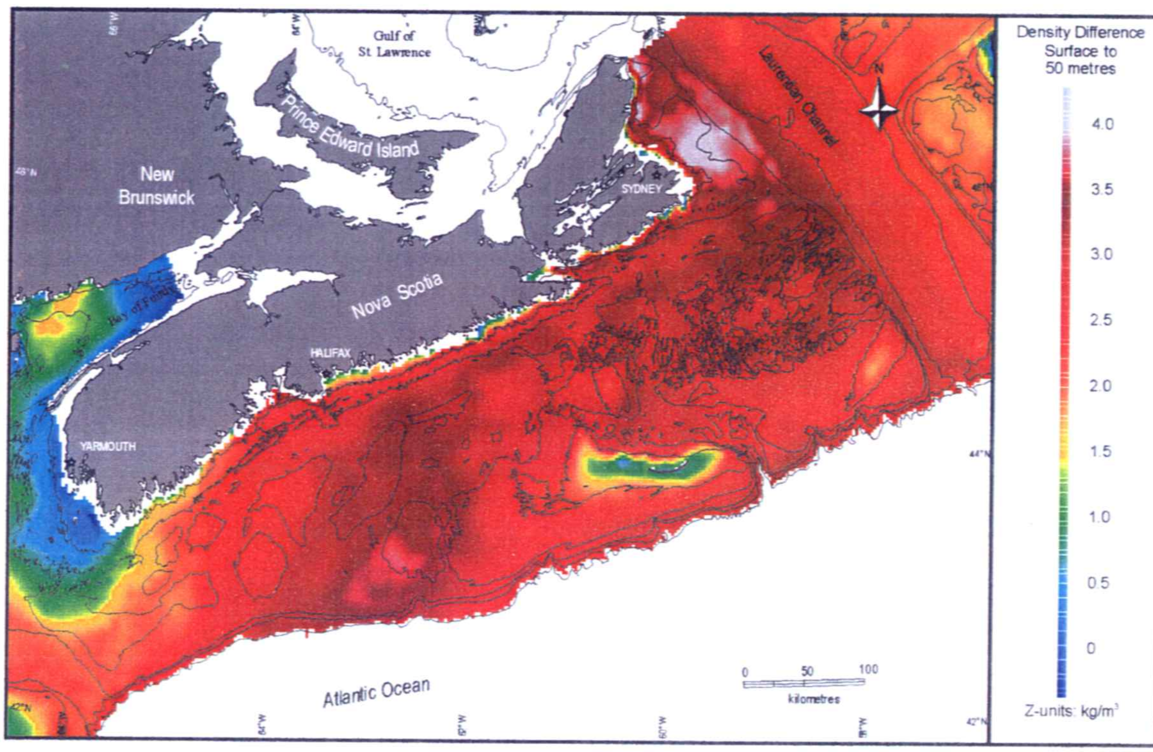

Figure 3-22. Summer density difference between 50 metres or the bottom (whichever is shallower) and the surface, measured in kilograms per cubic metre.

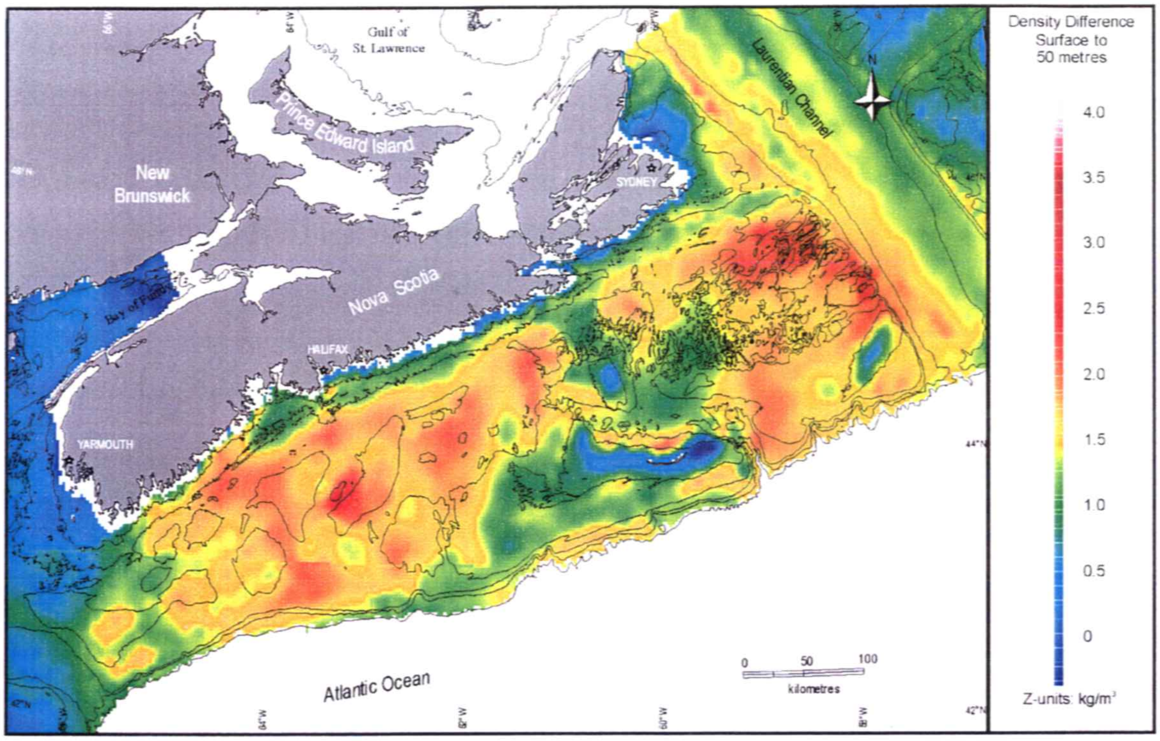

Figure 3-23. Fall density difference between 50 metres or the bottom (whichever is shallower) and the surface, measured in kilograms per cubic metre.

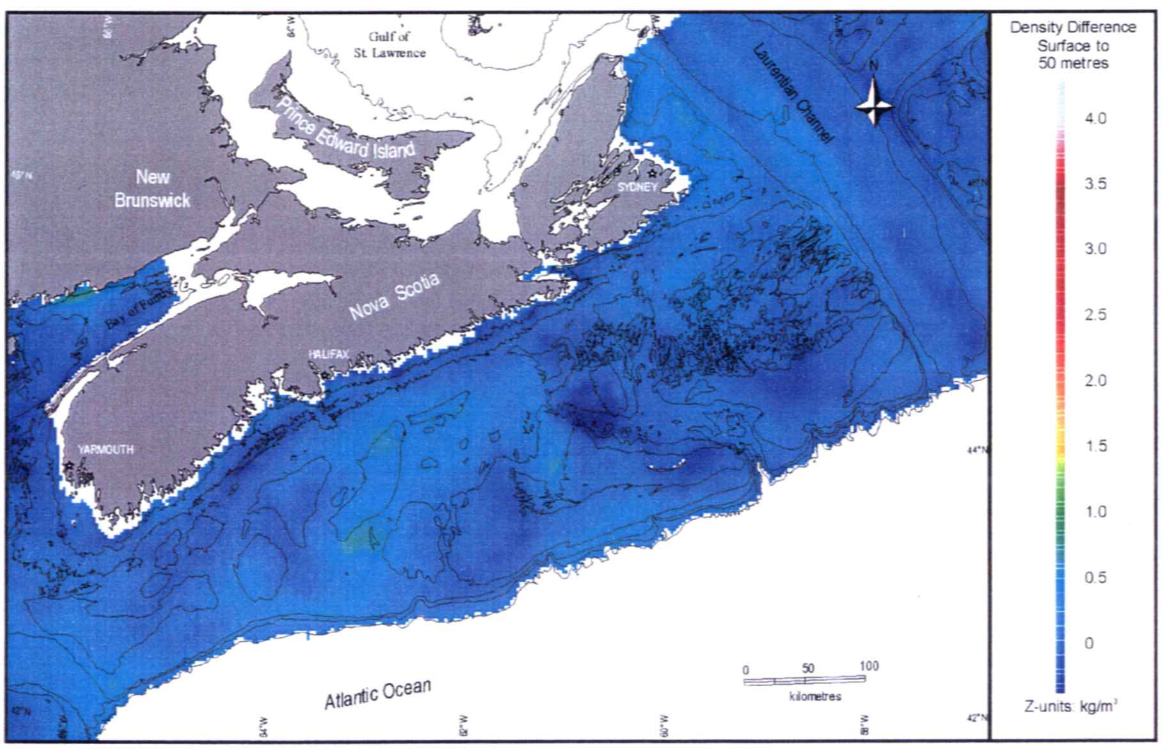

Figure 3-24. Winter density difference between 50 metres or the bottom (whichever is shallower) and the surface, measured in kilograms per cubic metre.

Long term variability of temperature and salinity

Petrie and Drinkwater (1993) reported that when over 50 years of data were analyzed to assess the variability of the vertical structure in Emerald Basin (Halifax line), temperatures were significantly colder during the 1960s than during later decades. Loder et al. (2001) examined the decadal variability in the hydrographic regime in the Scotian Shelf-Gulf of Maine region, with a focus on the cold period of the 1960s. They found that there was considerable interannual and decadal variability in temperature and salinity values. While the 1960s was a period of cold, fresh waters in the region, the 1970s was a warm, more saline period. The colder period appeared to be associated with increased influence of the Labrador Current on the Scotian Shelf (see Loder et al. 2001).

Recent measurements on the eastern Scotian Shelf have shown abnormally cold conditions since the early 1980s (DFO 2000). These cold waters began to slowly warm in the mid-1990s and have just reached average values (DFO 2000). The long period of cool waters may have increased the biological productivity of cold water species such as snow crab, shrimp, and capelin in the region and extended the southern limit of some species (Tremblay 1997, Drinkwater et al. 1999).

Circulation Patterns

The Scotian Shelf is a region of complex topography characterized by deep mid-shelf basins and a series of shallow offshore banks. While the topography influences circulation patterns on the shelf, the actual properties of Scotian Shelf waters result from the confluence of three major currents. The outflow from the Gulf of St. Lawrence through the Cabot Strait, the flow of shelf and offshore currents from the Labrador Sea and Shelf towards the equator, and the inflow of warm, salty Gulf Stream currents from the offshore to the southwest are the major currents affecting the Scotian Shelf and adjacent waters (Figures 3-25 and 3-26).

The relative influence of these three currents varies spatially and seasonally, but the dominant influence of the Labrador Current and the Gulf of St. Lawrence outflow produces a prominent and permanent feature of the circulation – the Nova Scotia Current. This cool, relatively fresh water mass flows southwestward along the coast over the eastern half of the shelf, then much of it abruptly branches offshore near Halifax to flow to the shelf break (200-metre isobath). There it joins with an existing current which lies just off the shelf (see Figure 3-25). This shelf edge current is another prominent and permanent feature of circulation on the Scotian Shelf and slope. A portion of the Nova Scotia Current continues along the southwestern coast of the province.

As the Gulf Stream moves northeast and away from the U.S. coast, it becomes unstable and begins to meander (see Figure 3-26). These oscillations in the Gulf Stream transport cool water to the north of the current southwards, and warmer Gulf Stream waters northwards. Some of the meanders separate into isolated rings, cut off from the originating water masses. Warm core rings spin off to the north of the Gulf Stream, surrounded by the cooler waters of the Labrador Current and Scotian Shelf. They bring warm water fish and invertebrates onto the Scotian Shelf. Cold core rings containing the cooler waters of the Labrador current are surrounded by the warmer waters found to the south of the Gulf Stream. The number and longevity of rings produced each year varies. Despite their unpredictability, these rings may be important for the productivity of deep water species.

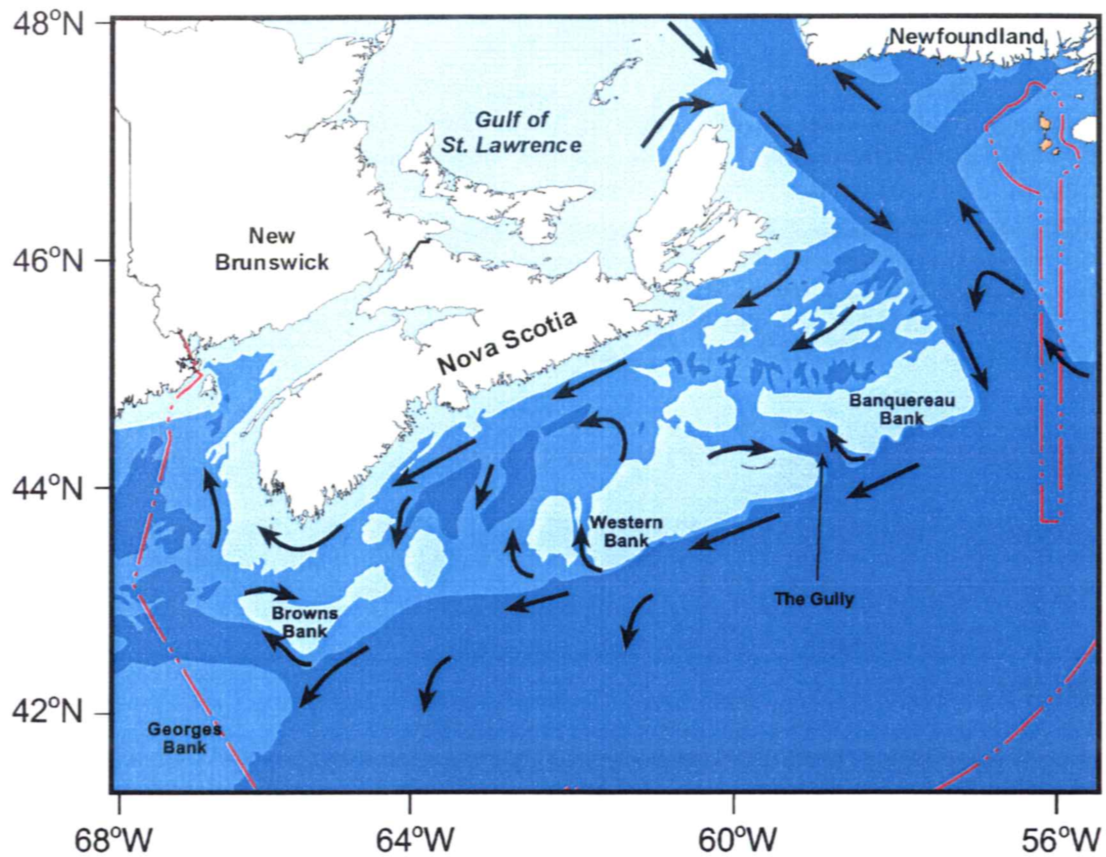

Figure 3-25. General surficial circulation on the Scotian Shelf (provided by C. Hannah).

On the shelf, the influence of the warmer Gulf Stream water is felt primarily in the deep channels and basins. Occasionally, these warmer waters penetrate the deep water layers of the shelf as a result of various physical mechanisms such as shelf break upwelling (see Petrie 1983). The depression between Emerald and LaHave Banks, known to physical oceanographers as the Scotian Gulf, is a well-known conduit to the inner shelf for warmer slope water. Warm slope water also enters the shelf via the Gully.

There are significant differences in circulation patterns between the western (i.e., Browns Bank area) and central (i.e., Sable Island Bank area) parts of the Scotian Shelf (Hannah et al. 2001). However, the water masses of the western and central areas are more similar to each other than they are to the eastern shelf. Warm slope water is conducted onto the central and western shelf through the Gully and Scotian Gulf (the area between Emerald and LaHave Banks). Slope water has less effect on the eastern shelf, which is more influenced by cool, low salinity water from the Gulf of St. Lawrence.

Hannah et al. (2001) found that there is significant seasonal variation in the circulation. They found the strength of the southwestward flow along the shelf edge (see Figure 3-25) to be greater in the summer than the winter. There is strong seasonal variability in the partial gyre in the Sable Island Bank region (discussed below) but not as much in the one on Browns Bank. Overall, the seasonal variation in circulation on the shelf was primarily influenced by the outflow from the Newfoundland Shelf and Gulf of St. Lawrence. On Browns Bank and nearby areas, the strength of the tides was a significant influence on circulation during all seasons.

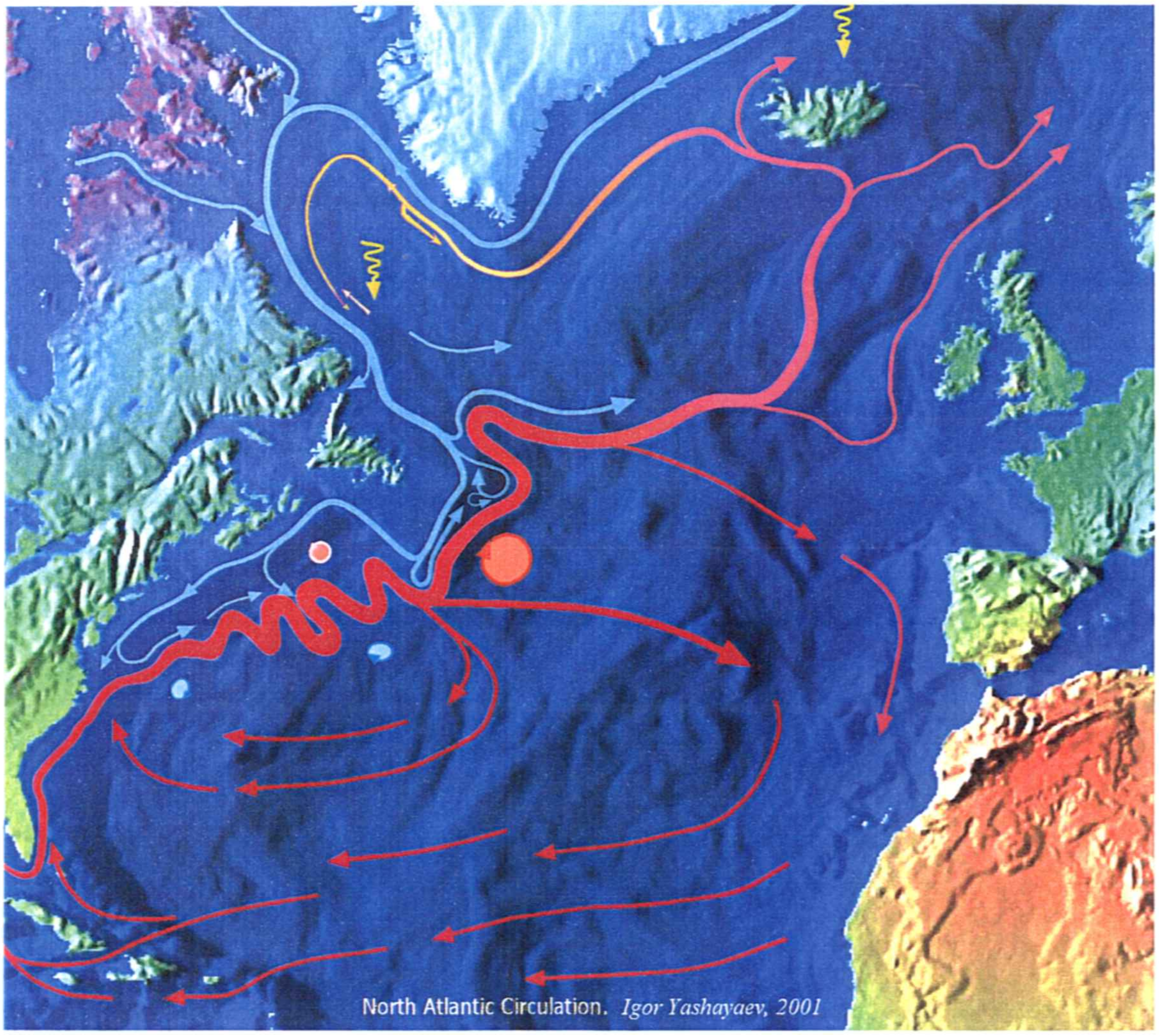

Figure 3-26. Surface circulation in the North Atlantic (prepared by I. Yashayaev). The red arrows indicate warmer, more saline waters and the blue arrows indicate cooler, less saline waters.

Retention

Retention, the amount of time that particles remain in a particular area, is thought to be important influence on biological processes. Differences in density throughout and across water masses on the shelf drive currents. This "density forcing" is believed to be the primary mechanism for retention on the Scotian Shelf (see e.g., Hannah et al. 1996, Han et al. 1997). The interaction of the currents with the rugged topography of the Scotian Shelf is largely responsible for the physical retention observed in the surface layers of some areas of the shelf. Density gradients are capable of supporting gyre-like circulation over banks. Other retention areas may be caused primarily by tidal processes, especially on the western part of the shelf. Tidal currents washing steadily back and forth can create gyre-like structures on the edges of banks and basins. These mechanisms produce clockwise gyres over the outer banks and counter-clockwise gyres over the deep basins or trenches, leading to relatively "dead" zones over the crests of banks or the deepest parts of basins.

Physical retention is most relevant for the passive drifters, such as buoyant plankton with no or poor swimming capabilities. As many fish and invertebrates are planktonic during their early life history, the degree of physical retention may play a key role in larval survival by keeping larvae near their prey or in areas of preferred habitat. Areas of retention may at the same time provide rich feeding grounds for animals that feed on larvae and other zooplankton.

Estimates of physical retention in the surface waters of the Scotian Shelf are based on the results of circulation models. Cong et al. (1996) used hindcasts (analyses that try to explain situations that occurred in the past) of surficial circulation, driven by historical wind fields, to identify regions of the Scotian Shelf in which passive drifting particles are retained for periods of 15 days or more. According to their model, regions of highest and most consistent retention during spring periods tend to occur over the shallow outer banks of the shelf, including Banquereau, Western Bank, and Emerald Bank, as well as the northernmost part of the Gully. Their study area did not include the eastern- and westernmost areas of the Scotian Shelf, including Misaine Bank, most of Banquereau, Browns Bank, and most of Roseway Basin, nor did they look at other times of the year.

Areas near the coast showed few indications of retention, likely due to the persistent influence of the Nova Scotia Current. It is interesting to note that even in periods where few areas of the shelf appeared to retain particles, such as March 1960 and March 1987, areas centred on Emerald Bank, Western Bank-Sable Island Bank, and the upper Gully still retained some particles over a 30-day period. For March 1965 and March 1974, an area centred over Emerald Bank was the only area with high indications of retention after 30 days. A very small part of Western Bank had lower indications of retention.

Hannah et al. (2001) used seasonal mean circulation fields to predict regions of low current speed that may be associated with retention. Some of the seasonal variations they observed in mean circulation on the shelf have been discussed earlier in this chapter. They found partial gyres providing some local recirculation around Browns Bank and in the area of Sable Island Bank. Unlike Cong et al. (1996), they did not find evidence of retention over Emerald Bank but instead, found persistent drift over that area. A partial gyre with a core of low-current speed over Western Bank was part of the seasonal variation in the Sable Island Bank gyre. It was present in the winter, and perhaps other seasons. Studies by Bowen et al. (1995) and Griffin and Thompson (1996) had suggested a partial gyre in that area during the spring and fall. A previous study by Hannah et al. (1996) had noted clockwise gyre-like tendencies over the major outer banks of the Scotian Shelf: Bauqereau, Sable Island, and Browns.

Other properties of circulation may limit or extend the influence of retention on biological productivity. Loder et al. (1988) described characteristic circulation of several outer banks of the northwest Atlantic continental shelf, including Browns Bank on the Scotian Shelf. The residence time of particles on Browns Bank– the time that passive particles remain on the bank – was relatively low compared to the other banks considered, but its vertical diffusion time was even shorter than the residence time. Thus passive particles would be distributed vertically through the water column before moving off the bank. This finding could have implications for primary productivity. Loder et al. (1988) suggested that banks with short vertical diffusion times may recycle nutrients or transfer energy to other trophic levels more quickly.

The location and strength of retention zones and vertical diffusion vary seasonally and annually. The outer banks, particularly Browns and Sable Island Banks, appear to be consistently retentive. These areas are used by haddock, cod, and other species of fish as spawning grounds. The coincidence of areas of physical retention and important biological events, such as spawning, warrants further study. Cong et al. (1996) concluded that the abundance of particular year classes of cod was somewhat related to retention indices on Western Bank. In other words, years with higher indications of retention on the bank were associated with stronger year classes of cod. Smaller areas of retention, as yet uncharted, may also be highly significant for biological productivity.

Oceanic fronts

An oceanic front is a sharp boundary where currents or water masses with different hydrographic properties meet. For example, fronts may occur where a mass of well-mixed water meets a mass of highly stratified water, or where a current travels through a water mass with different properties. At the boundary between the water masses, there is often intensified vertical and horizontal mixing due to the different properties of the water masses. For example, the water mass with a higher density sinks beneath the lower density water mass (downwelling), while less dense water rises (upwelling). As discussed earlier, the density differences contribute to circulation patterns on the shelf and slope.

Frontal areas are thought to be important ecologically. Floating organisms, such as jellyfish and small zooplankton, tend to collect in fronts, and these congregations are attractive to predators such as sea turtles, whales, and pelagic seabirds. Debris such as driftwood and garbage may also accumulate there (see e.g., Bowman 1978).

There have been relatively few studies of the dynamics and biological properties of fronts in the Scotian Shelf region. The fronts in the area of Georges Bank have had more attention (see e.g., Meise and O'Reilly 1996, Mavor and Bisagni 2001). Off Nova Scotia, shelf-break fronts are the best-known. Horne (1978) described the physical properties of the front at the Scotian Shelf break, where different water masses meet. The position of this front can vary greatly. Fournier (1978) estimated that in the area he studied, the front may vary by tens of kilometres over a few days, while Horne (1978) estimated that it may vary by at least 150 kilometres over several months. Fournier et al. (1977, 1979, see also Fournier 1978) observed enhanced phytoplankton production at the shelf-break front compared to adjacent shelf or slope waters. Herman and Denman (1979) studied vertical mixing at a shelf-break front off Nova Scotia and suggested that the mixing accounted for the high productivity in that area.

Sigaev (1996) studied preferred conditions for silver hake on the Scotian Shelf. He found that they were aggregated on the warm side of a shelf-slope front. Euphausiids were also found in aggregations on that side of the front. He suggested that this front provided optimal conditions for the development of silver hake.

Lochmann et al. (1997) described a convergent front on Western-Sable Island Bank where larval cod were more abundant than in adjacent water masses. They observed no difference in the condition of the larval cod in the frontal region compared to those found over the crest of Western Bank. However, McLaren et al. (1997) found that the cod larvae, although abundant, were less well-fed in that front than compared to nearby water masses. The best-fed larvae were over the crest of Western Bank, in an area of well-mixed water.

Griffin (1999) reported that sperm whales were sighted much more frequently on the eastern boundary of a warm core ring on the slope of the Scotian Shelf than in adjacent water masses. He suggested that these frontal regions were important sperm whale habitat. He speculated that zooplankton may be concentrated in warm core ring fronts, although he found little evidence for that hypothesis. Prey for sperm whales – primarily squid – would feed on the zooplankton, on the fish attracted to the high concentrations of zooplankton, and on other squid.

Wind-induced upwelling and tidal mixing

Areas of strong upwelling, in which cold, dense water from the bottom is forced to the surface, are often areas of enhanced biological productivity. The deep water carries nutrients to the surface, enabling phytoplankton to thrive. Upwelling occurs all over the Scotian Shelf because of strong wind events, but is enhanced by tidal currents and steep bottom topography. Along the coast, upwelling is caused by winds blowing along the shore combined with the Coriolis effect – a deflection of objects (e.g., water parcels) on the earth's surface caused by the rotation of the earth (Davis and Browne 1996, Petrie et al. 1987). Surface waters are deflected generally to the right of the wind (i.e., clockwise looking downward), so that on the Scotian Shelf, an alongshore breeze from the northeast to the southwest pushes surface waters onshore, where they are forced downward (downwelling). On the other hand, a wind from the southwest to the northeast pushes surface water offshore, causing upwelling. Upwelling frequently occurs along Nova Scotia's Atlantic coast during summer in response to the prevailing southwest winds (Petrie et al. 1987). At the shelf break, moderate winds lead to regular upwelling events from depths of 400 metres, or even deeper (Petrie 1983).

Another process affecting surface properties and stratification in the water column is tidal mixing. In the shallow approaches to the tidally-energetic Gulf of Maine, such as the region off Cape Sable Island, enhanced vertical mixing and tidally-driven upwelling produce a permanent area of weak stratification and cold surface temperatures, even during the summer and fall seasons (Tee et al. 1993). The upwelling is enhanced by bottom topography, which supports the vertical movements of the water. The regular occurrence of upwelling in this area results in high productivity (see Chapter 4 for details).

Internal Waves

In some areas of the shelf edge and slope, currents, tidal processes and bottom topography promote regular upwelling events and enhanced mixing of water masses. Although vertical mixing through upwelling caused by winds and the horizontal mixing of Gulf Stream waters with slope waters through eddies are important, the generation of internal waves at the shelf break may be the most important source of mixing along the shelf edge (Sandstrom 1991).

Interacting water masses at the shelf break front are mixed through tidal processes. When the water is stratified, internal waves are generated as the tidal currents flow back and forth across the shelf break. Their dissipation causes layers within the water column to be mixed (Sandstrom 1991). Topography enhances the effect. The steep bottom slope at the shelf break traps low frequency currents then refracts, reflects, and scatters them (Smith and Sandstrom 1988). The steep topography of the slope of the eastern Scotian Shelf is favourable to the generation of internal waves, but on the southwestern Scotian Shelf (Scotian Gulf), the tidal currents are stronger. Internal waves generated there propagate all the way across the shelf, causing widespread enhanced mixing. The semi-diurnal[4] tides regularly add energy to the system; however, the strength of the relationship of the semi-diurnal barotropic tide with the internal tides varies from strong to quite weak depending on the stratification of the water (Sandstrom 1991). The vertical mixing of the water column at the shelf break regularly brings nutrient-rich water from the depths into the euphotic zone.

Important Areas

The important processes for biological productivity on the Scotian Shelf and their spatial limits are still being determined. A few areas that are known to be important for biological productivity are highlighted here in relation to physical oceanographic processes. The locations described are fairly large and their boundaries are ill-defined. Smaller parts within them may have much greater importance for biological productivity than the area as a whole, and small areas outside the areas mentioned may be important on a seasonal basis. In fact, areas important for biological productivity may show large spatial and temporal variability compared to those processes on land.

Areas of physical retention are believed to be important for the survival of fish larvae. These areas also concentrate planktonic organisms – prey for marine mammals, many juvenile fish species, as well as adult fish. In turn, those animals that prey on plankton feeders will also be found in zones of physical retention. On the Scotian Shelf, modelling efforts indicate that areas of Western-Sable Island Bank and Browns Bank have partial gyres that encourage physical retention. Other areas show indications of retention on a less regular basis. The location of retention zones and their characteristics are still not well known. There may be many small, seasonal areas of retention that are unknown but are important for biological productivity on the shelf. Smaller areas may be particularly important if they are combined with other physical oceanographic features that encourage high productivity, such as enhanced vertical mixing.

Areas of upwelling and enhanced vertical mixing are important for biological productivity. By vertically mixing the water column and bringing nutrients to the surface, these areas tend to be productive areas for phytoplankton, which are then fed on by zooplankton. In turn, organisms that prey on zooplankton will be attracted to those areas. An area off Cape Sable Island consistently shows tidally-driven upwelling, associated with tidal mixing. P. Lane and Associates (1992) considered this area of persistent upwelling and related features to be important enough to be considered a candidate Parks Canada Marine Natural Area of Canadian Significance (NACS), one of only three NACS identified on the Scotian Shelf. Other areas along the Atlantic coast also show regular occurrences of upwelling, particularly in summer and fall. Areas with prominent headlands – for example, Chebucto Head and Chedabucto Bay – are known to have regular occurrences of upwelling throughout much of the year. The shelf break is another area of enhanced vertical mixing because of winds, offshore eddies, and tidal processes.

While mean circulation patterns on the Scotian Shelf are becoming better known, not as much research attention has focussed on the circulation on the slope and rise. The incursion

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[4] Semi-diurnal tides have two high waters and two low waters each tidal (lunar) day. A lunar day is slightly longer than twenty-four hours.

of slope waters is an important influence on the properties of Scotian Shelf waters and the movements of water masses on the slope warrants further investigation.

The interannual variability in the physical oceanographic environment is another area that warrrants more study. Research in the area of predictive models will help explain variability on the Scotian Shelf and slope and influences on the physical oceanography of the region. It may be useful to look at predictive models in small regions, rather than just over the whole shelf. Many of the studies of the Scotian Shelf have aimed to broadly characterize large ocean regions. Understanding the physical characteristics and seasonal, annual, and decadal variability of small areas within the shelf will provide a better understanding of the biological features of those areas and will give a greater appreciation for the variety of shelf habitats.

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Marine Life

4 PLANKTON[1]

Introduction

Plankton is a collective term for the animals and plants that drift in the water of oceans and lakes and are generally not able to swim against currents. This lack of strong swimming ability separates plankton from the nekton that move independently of wave and current action. Most planktonic organisms are tiny and can only be seen with the use of a microscope; others, such as the lion's mane jellyfish, can be more than a metre in diameter. Those plankton with the ability to photosynthesize are called phytoplankton. Zooplankton do not have photosynthetic capabilities. Instead, they feed on phytoplankton and other zooplankton and are in turn fed on by larger organisms. In this way, energy is transferred through the trophic levels.

Since primary productivity is responsible for the productivity of other groups of organisms, including commercial fish species, knowledge of the condition, abundance, and distribution of phytoplankton is key to knowing about productive areas of the Scotian Shelf in general. The primary consumers – the zooplankton – are important in passing energy from the primary producers to the rest of the ecosystem. In this section, the available scientific information on the distribution of phytoplankton and zooplankton is presented. Many fish and benthic invertebrates spend their larval stages of life in the plankton; however, this chapter will focus on the holoplankton, the animals that remain planktonic their whole lives.

Phytoplankton

The phytoplankton are the main primary producers of the ocean and the basis for all life in the open water of the Scotian Shelf. In near-shore environments, seaweeds and sea grasses make a major contribution to primary production. Phytoplankton are generally single-celled but sometimes assemble in long chains. They convert inorganic carbon into organic compounds through photosynthesis and constitute the basic source of energy in the marine ecosystem. It is difficult to sample and identify the tiniest species of plankton. Diatoms and dinoflagellates are the largest and most common phytoplankton groups sampled on the Scotian Shelf. Dinoflagellates are unusual phytoplankton in that many species both photosynthesize and feed on other plankton.

Growth and survival of primary producers are highly affected by environmental factors. Phytoplankton tend to appear where conditions are favourable. Photosynthesis can only occur in the euphotic zone – the part of the water column that sunlight is able to penetrate. The availability of sunlight varies seasonally. In winter, the low angle of the sun means that the euphotic zone is shallow while in late spring and summer, sunlight can penetrate to greater depths. Locations where waters are well-mixed and nutrients are continually available in the euphotic zone are highly favourable for phytoplankton. However, the presence of a seasonal thermocline[2] is another determining factor for productivity. In areas where there is a deep, well-

[1] The authors would like to thank Gareth Harding, Glen Harrison, and Ian McLaren for their comments on earlier versions of this chapter, and Brian Petrie for his comments on a portion of this chapter.

[2] A thermocline occurs where the temperature changes sharply in the water column. For example, in the summer, shallow surface waters warm up quickly. This warm, less dense water sits on top of a colder water mass. As this thermocline varies with seasonal conditions, it is called a "seasonal

mixed layer of water and lots of nutrients, phytoplankton may be mixed out of the euphotic zone and rates of photosynthesis will be low because of the limited light. However, in areas where waters are highly stratified, such as when there is a seasonal thermocline, nutrients in the top stratified layer will be used up quickly by the phytoplankton and productivity will be limited by the availability of the nutrients. The best conditions for phytoplankton growth and reproduction are alternate periods of stratification and mixing (Mann and Lazier 1996).

Nutrients and primary production

Inorganic nutrients are needed for the growth of organisms. They are incorporated into plant cells during photosynthesis. On the Scotian Shelf and in most marine ecosystems, the limiting factor controlling the growth and reproduction of phytoplankton is the availability of nitrogen (Riley 1967, Fournier et al. 1977)[3]. Nitrogen and other important nutrients, such as phosphorous, carbon, sulphur, and silicon, are dissolved in seawater as part of various compounds, for example, nitrate, ammonium, urea, silicate, and phosphate). More detail on how phytoplankton productivity is limited by nutrients in the world's oceans can be found in Falkowski et al. (1992). Mann and Lazier (1996) and papers in Falkowski and Woodhead (1992) discuss phytoplankton productivity and the physical and chemical cycles of the ocean.

Phytoplankton reproduce rapidly in areas rich in nutrients and periods of rapid population growth are referred to as blooms. The northwest Atlantic as a whole and its continental shelves in particular (including the Scotian Shelf) are considered relatively productive areas of the global oceans (see e.g., Fournier et al. 1977, Lenihan and Micheli 2001). This 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.

Fisheries and Oceans Canada collects observations on nutrient levels in seawater and compiles them in a database with observations from other organizations. The nutrients most commonly measured are nitrate, phosphate, and silicate (Petrie et al. 1999). Petrie et al. (1999) reviewed the data available for nitrate, phosphate, and silicate for the Scotian Shelf and Gulf of Maine. Most of the measurements were taken in the first 60 metres of the water column, where photosynthesis occurs. Of that group, most were taken in the first 10 metres of the water column. There were more observations for the western half than for the eastern half of the Scotian Shelf. Over the entire shelf, more observations were taken during the spring and summer than the fall and winter.

Petrie and Yeats (2000) analyzed these observations in a subsequent publication. They found that the Gulf of St. Lawrence was the primary source of nitrate on the Scotian Shelf during the winter. During spring and summer, they found the most significant external source of nitrate and silicate on the shelf came from the Gulf of St. Lawrence and transport of nutrients from slope waters onto the shelf in the area of Western Bank. However, during spring and summer, vertical diffusive fluxes of nutrients – processes that diffuse nutrients vertically through the water column, such as vertical mixing and upwelling processes -- were as large as processes that moved nutrients horizontally across the shelf (horizontal advective processes) (Petrie and Yeats 2000). In surface layers, the highest values for nitrates and silicates on the Scotian Shelf were observed in

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thermocline." During the fall and winter, surface waters cool, increasing their density, and they sink. The seasonal thermocline deepens or disappears completely.

3 The availability of iron is a determining factor in some marine ecosystems with low levels of productivity (see e.g., Faklowski et al. 1992, Falkowski 1995).

the winter. The authors found that there was significant annual variability in nutrient levels on the Scotian Shelf. In deeper parts of the water column (greater than 50 metres), the annual cycle was not as pronounced and highest concentrations were observed in summer (Petrie and Yeats 2000).

Recycled sources of nitrates and silicates (from the excretion and respiration of organisms and decomposing organisms) may be important in the euphotic zone at particular times of year (see e.g., Fournier et al. 1977). Petrie and Yeats (2000) observed that nitrate and silicate levels increased by about 40 percent between February and August in the 75 to 135 m depth layer. They suggested that the increase could be due to the sinking and decomposition of the spring phytoplankton bloom.

Research on phytoplankton and primary productivity

Mills (1989) traced the history of research on biological oceanography and the major findings in the field from 1870 to 1960. One of the early studies of the northwest Atlantic was undertaken by Bigelow (1924), who described plankton distributions in the Gulf of Maine, including the southwestern part of the Scotian Shelf. Other than this early study, based out of the Woods Hole Oceanographic Institute, observations of phytoplankton levels on the Scotian Shelf stretch back to the 1930s (Harrison et al. 2000).

Data on Scotian Shelf phytoplankton and the rate of primary productivity have been collected by filling bottles with sea water, straining samples of sea water through very fine mesh or silk, towing devices that measure fluorescent radiation emitted by phytoplankton, and using satellite images that depict ocean colour. An early method to calculate the rate of photosynthesis was to measure the difference in carbon dioxide and oxygen levels in bottled seawater. Since phytoplankton consume carbon dioxide and release oxygen, the difference in values gives a measurement of net primary productivity. The most commonly used method of the last 30 years involves incubating the phytoplankton in bottles with radioactive carbon and measuring the carbon uptake. Another method used levels of chlorophyll and chlorophyll fluoresence as a proxy for the presence of phytoplankton and the rate of photosynthesis.

Using these methods, researchers have attempted to quantify the primary productivity of the Scotian Shelf in units of carbon produced per square metre per year (see e.g., Fournier et al. 1977, Mills and Fournier 1979). Most of this research averaged productivity over the whole shelf, based on a transect from the coast across Emerald Basin and Emerald Bank to the slope. From this work it is possible to compare the productivity of the Scotian Shelf with other ocean regions. However, to understand distribution and abundance of phytoplankton within the shelf itself, the following section focuses on research with a broader geographic coverage. Records of phytoplankton from several sources are included in this section:

1) Seasonal depiction of surface chlorophyll derived from satellite images captured by the Coastal Zone Color Scanner (CZCS) between 1978 and 1986,
2) Observations of surface chlorophyll by the SeaWiFS program,
3) Records from the Continuous Plankton Recorder (CPR) survey, and
4) Surface chlorophyll measurements collected by other programs not listed above .

In recent years, there has been increasing interest in collecting observations through remote sensing by satellite and airplane. Satellites can provide data for large areas of the ocean over long time periods. Because phytoplankton influence the colour and the degree that light penetrates the ocean surface, images of surface ocean colour can show areas where phytoplankton are concentrated in surface waters. However, care must be taken in relating sea colour in satellite images with productivity. Colour sensors detect other substances suspended in the water column, such as sediments and dissolved organic matter. While this generally does not present a problem in open ocean areas, in coastal areas land-based run-off influences ocean colour. Several authors have addressed the problem of remotely sensing phytoplankton pigments along the coast (see e.g., Sathyendranath et al. 1989, Topliss 1989).

In the open ocean, pigment fields derived from the observed surface colour can be interpreted to estimate primary productivity but do not tell the whole story. Areas that do not have high surface concentrations of chlorophyll may be highly productive. Processes that mix surface and subsurface waters bring nutrients to the surface, allowing for higher productivity, but may also mix phytoplankton below the surface and out of range of satellite sensors. Phytoplankton exhaust surface nutrients and are found in numbers at the thermocline, particularly in summer. The euphotic zone – the part of the water column where light penetrates and photosynthesis can occur – varies seasonally and spatially. At the shelf break, productivity may occur significantly deeper than on the banks because of increased sub-surface mixing. There have been observations of high chlorophyll concentrations at 30 to 40 metres below the surface at the shelf break (Head and Harrison 1998). Thus phytoplankton may be plentiful in the water column yet not visible in satellite images of the sea surface. Phytoplankton may also be grazed down rapidly by copepods and other zooplankton in highly productive areas (Longhurst 1998). If the rate of grazing is high enough, these areas may not appear to have a high rate of primary productivity. Conversely, areas with high concentrations of surface chlorophyll or phytoplankton may not be highly productive if nutrients are not available. Chlorophyll measurements may be high after a bloom until phytoplankton settle out.

For these reasons, satellite images should be used with other measurements of primary productivity. Topliss et al. (1991) discussed some of the issues related to interpreting Coastal Zone Color Scanner data on the Scotian Shelf. The SeaWiFs website (http://seawifs.gsfc.nasa.gov/SEAWIFS.html) and the International Ocean Colour Coordinating Group website have detailed information on interpreting remotely sensed ocean data (http://www.ioccg.org). Models have been developed to calculate primary productivity using remotely sensed data while accounting for different variables, such as depth of the euphotic zone, length of day, and so on.

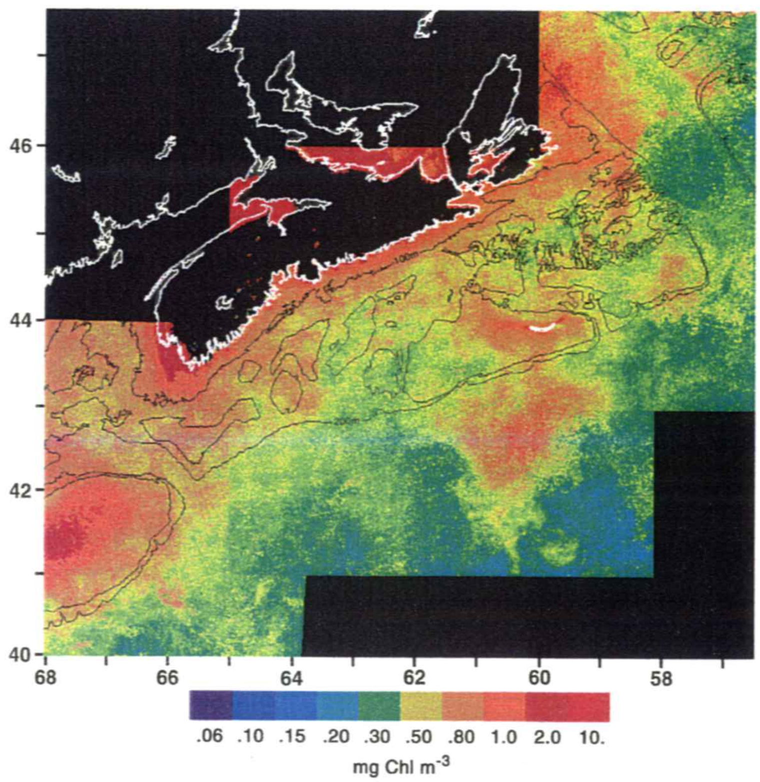

Figure 4-1. CZCS Surface Chlorophyll – Spring, 1979 – 1986.

Sathyendranath and Platt (1993) discuss some of the variables that are taken into account when models are developed. Behrenfeld and Falkowski (1997) provide a review of many of the models developed to that date.

Coastal Zone Color Scanner

The Coastal Zone Color Scanner provided satellite data on surface chlorophyll from late 1978 to 1986. This was the earliest satellite device to measure ocean colour and it sensed particulate matter suspended in the ocean, both organic and inorganic. The sensor stopped working in late 1986 (Farr 1996). For this report, data from 1979 to 1986 were compiled and grouped seasonally (Figures 4-1 to 4-4).[4] The data were compiled for an area roughly equivalent to the study area used for this report; they were not compiled for the areas shown in black. The grouping averages out all the data for each season and obscures short-term events. Thus the spring bloom, which may occur as a brief, intense peak in late March and early April, appears only as generally higher levels for the spring season. The images are also limited by the data available. Clouds and ice interfer with the colour sensor and few images are available for January, November, and December (Harrison et al. 2000). The colour index below each figure relates colour with chlorophyll concentrations.[5] The images do not represent the true colour as observed by the colour sensor, but an interpretation of the data with colours used to emphasize the different ranges in chlorophyll concentration.

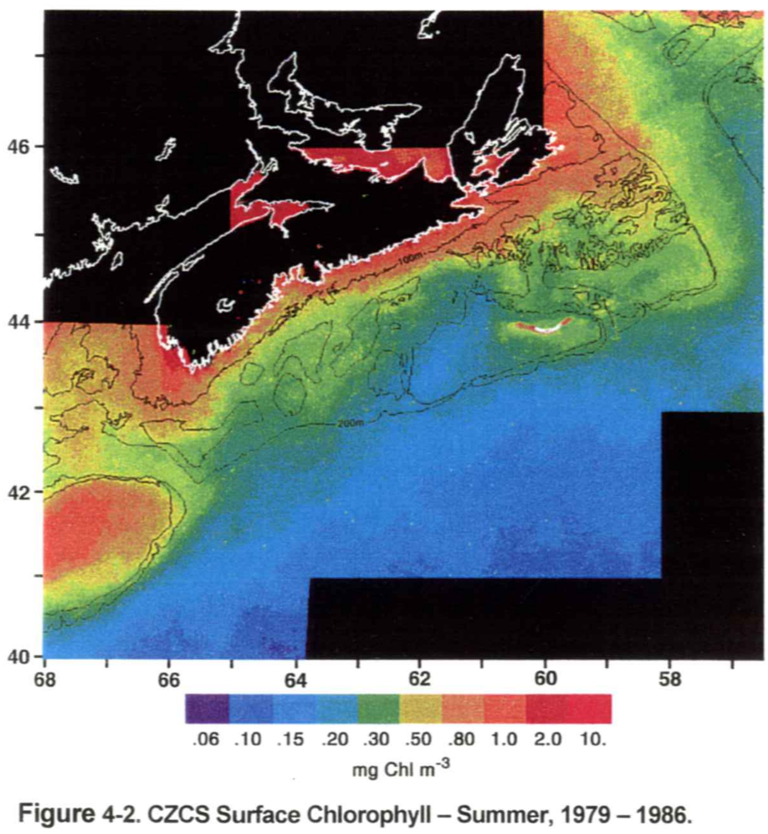

Figure 4-2. CZCS Surface Chlorophyll – Summer, 1979 – 1986.

Harrison et al. (2000) confirmed the strong seasonality of the CZCS images. They found the fall season showed the greatest surface chlorophyll intensity over the whole shelf for the period 1978 to 1986. The area off southwestern Nova Scotia, near the coast, maintained a high concentration over the whole year. The eastern shelf showed high surface concentrations of chlorophyll during spring, summer, and fall, while the central part of the shelf had relatively low concentrations for much of the year. The seasonal regime is described in more detail below.

During the spring, certain regions show particularly high chlorophyll concentrations compared to the rest of the shelf (Figure 4-1). An area off

[4] Glen Harrison of the Ocean Sciences Division, Fisheries and Oceans Canada, provided images from the CZCS for this document.
[5] Note that relating chlorophyll with ocean colour has limitations, as discussed earlier in this section. Despite these limitations, all figures are labelled "surface chlorophyll" as is standard practice.

Yarmouth, representing a zone of enhanced upwelling, shows high concentrations. High concentrations may also be observed in the area surrounding Sable Island, in patches on Banquereau and Misaine Banks, and in a large area south of Sable Island on the slope.

The summer period shows the lowest surface chlorophyll values for most of the Scotian Shelf with the exception of the Yarmouth upwelling area, where levels continue to be high, as well as an area off eastern Cape Breton (Figure 4-2). The area immediately around Sable Island shows colour indicative of higher chlorophyll values than the rest of the shelf; however, this colour may actually be caused by the sand in the shallow waters around the island. Similarly, the area along Nova Scotia's coast that registers high on the chlorophyll index likely indicates both concentrations of chlorophyll and suspended sediments.

The fall period shows the highest intensity of surface chlorophyll of all seasons, covering almost the entire surface of the Scotian Shelf with the striking exception of the central region from Western Bank to LaHave Bank (Figure 4-3). The winter period shows a scattered high concentration of chlorophyll over the central part of the shelf (Figure 4-4). High concentrations are found off southwestern Nova Scotia, with a thinner band extending eastward along the coast.

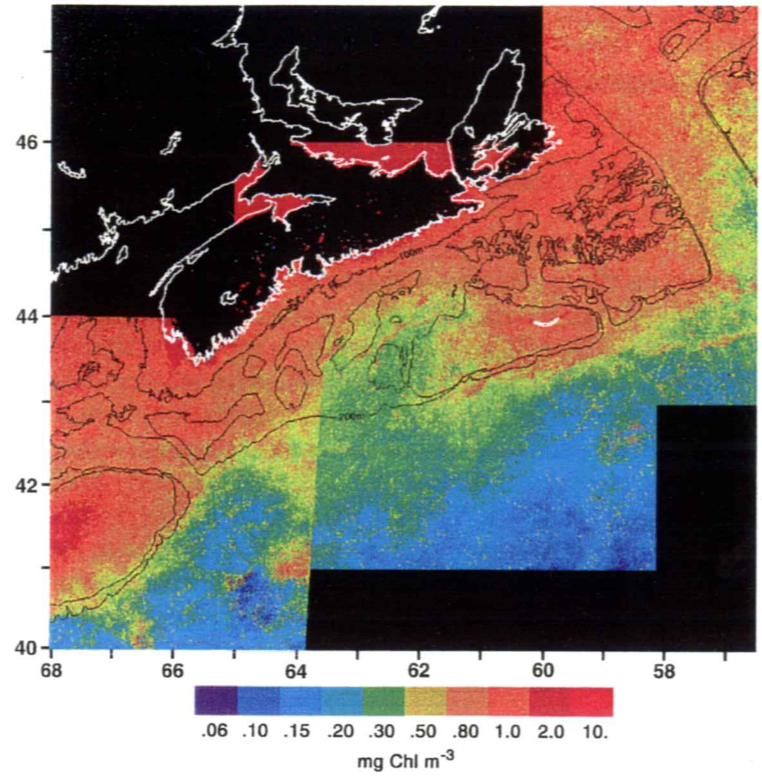

Figure 4-3. CZCS Surface Chlorophyll – Fall, 1979 – 1986.

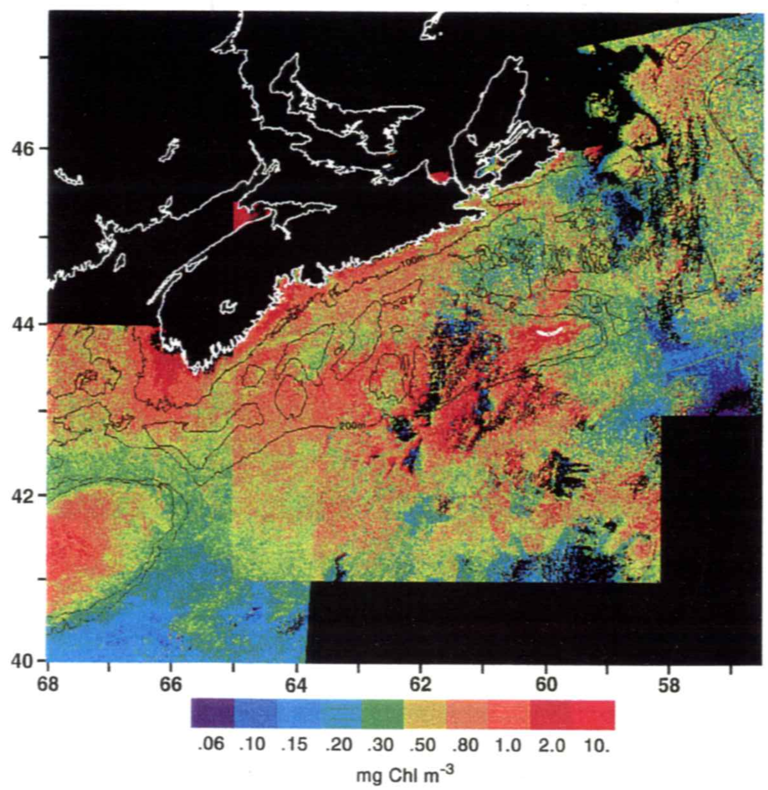

Figure 4-4. CZCS Surface Chlorophyll – Winter, 1979 – 1986.

Data were not available for the area in black on the eastern part of the Shelf due to ice or cloud cover. The winter period has the lowest number of observations due to poor weather conditions (Harrison, pers. communication).

SeaWiFS (Sea-viewing Wide Field-of-view Sensor)

The SeaWiFS project, led by NASA, uses a more refined sensor to measure changes in ocean colour. The satellite was launched in 1997 and information is available for the Scotian Shelf from September 1997 to the present. Data from the SeaWiFs website is a composite of half-month periods (e.g., January 1 –15, November 16-30, etc.), as well as single dates for particular geographic areas, such as the Scotian Shelf (DFO 2001). Because these data have not been grouped seasonally, as the CZCS data have, the two data sets are difficult to compare. An example of the type of images available through SeaWiFS is found in Appendix 1. Harrison et al. (2000) noted that to date, SeaWiFS images supported some of the patterns shown by the CZCS data. For example, SeaWiFS images show an absence of surface chlorophyll in the central shelf region and an increase in surface chlorophyll in the late summer/early fall on the eastern shelf (not shown). Composite figures by season, as done with CZCS data, would more readily indicate seasonal and annual trends and would allow comparison with the earlier data set. The most recent analyses of SeaWiFS show that the spring bloom is greater than the fall bloom, consistent with the chlorophyll data collected from ships over the last 30 years (Harrison, pers. communication).

Continuous Plankton Recorder

The Continuous Plankton Recorder (CPR) is the only long-term program that assesses plankton in the North Atlantic. Observations are collected by the Sir Alister Hardy Foundation using commercial and weather ships that travel standard routes and use the same methods to collect samples.[6] A silk filter is used to collect the phytoplankton. Samples are collected at an average depth of about 6.7 metres (Hays and Warner 1993). Only phytoplankton larger than about 260 micrometres are collected by the CPR and the bulk of phytoplankton biomass may be in smaller forms (see e.g., Mousseau et al. 1996).[7] The silk is divided into uniform sample sizes, which are assessed against a colour chart and identified as not green, very pale green, pale green, or green (SAHFOS 2001). Then the species in a portion of each sample are identified and counted (SAHFOS 2001). The degree of "greeness" is used in compiling the colour index, one indicator of phytoplankton abundance (Reid 1998).

For the Northwest Atlantic, samples were collected from 1959 to 1986 and again from 1991 to the present (Myers et al. 1994, AZMP 2001). Coverage is variable and does not include all months for all years. There was little sampling in the northwest Atlantic from the late 1970s to 1990 and no data were collected on the Scotian Shelf from 1976 to 1991 (Myers et al. 1994, Sameoto 2001).

Myers et al. (1994) examined the CPR data for the Northwest Atlantic from 1959 to 1992, grouping the information by NAFO (Northwest Atlantic Fisheries Organization) zone. On the basis of all years monitored by the CPR program, Myers et al. (1994) reported the largest annual peak in the phytoplankton colour index in the spring, with a smaller peak in the fall over much of the Northwest Atlantic, including parts of the Scotian Shelf. Off southwest Nova Scotia, a single

[6] The sampling routes were changed slightly on the Scotian Shelf in 1991 (Sameoto 2001); thus, the period 1961 to 1976 is not entirely comparable with the period from 1991 to the present.
[7] A micrometre (μm) is equal to one one-millionth of a metre or one one-thousandth of a millimetre.

broad peak was observed, with maximum abundance in the spring. The authors attributed that pattern to tidal mixing in the area.

The CPR data include over 300 different taxa and Myers et al. (1994) assembled abundance and distribution for 52 taxa, including 18 species of diatoms and 9 species of dinoflagellates (their observations on the zooplankton data are discussed later in this chapter). The phytoplankton colour index showed higher values and the abundance of diatoms was greater in the northernmost surveyed region, off Labrador and northern Newfoundland, and decreased toward the Scotian Shelf. Dinoflagellates had a much higher abundance over the Scotian Shelf than in the northern region. The spring bloom was nearly always dominated by diatoms and the fall peak was usually dominated by dinoflagellates. The most abundant diatoms were *Thalassiosira* spp., *Chaetoceros* (*Hyalochaete*) spp., and *Chaetoceros* (*Phaeoceros*) spp., and the most abundant dinoflagellates were from the genus *Ceratium*: *C. longpipes*, *C. fusus*, *C. tripos* and *C. arcticum* (Myers et al. 1994, Sameoto et al. 1996). No consistent long-term changes were found in any of the regions during the period examined (Myers et al. 1994).

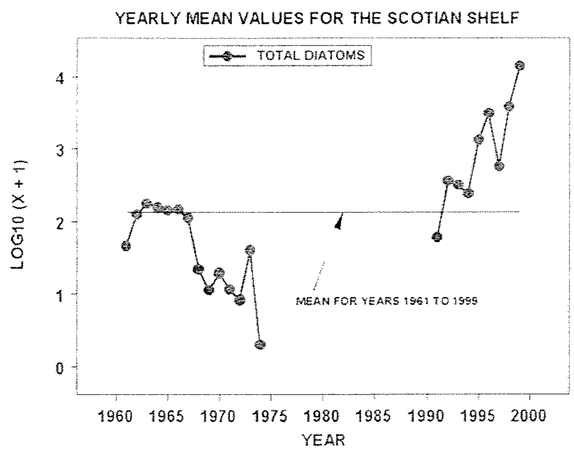

Figure 4-5. Abundance index, diatoms (from AZMP 2001).

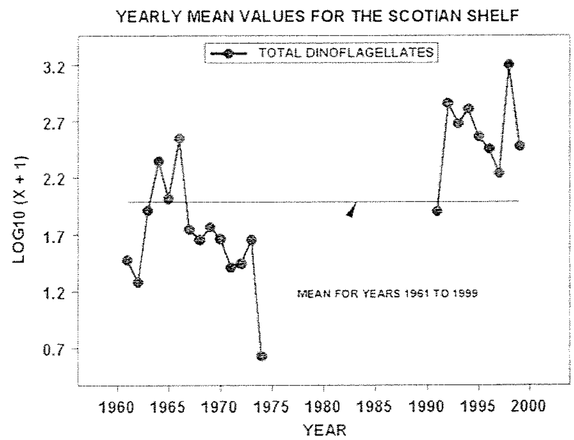

Figure 4-6. Abundance index, dinoflagellates (from AZMP 2001).

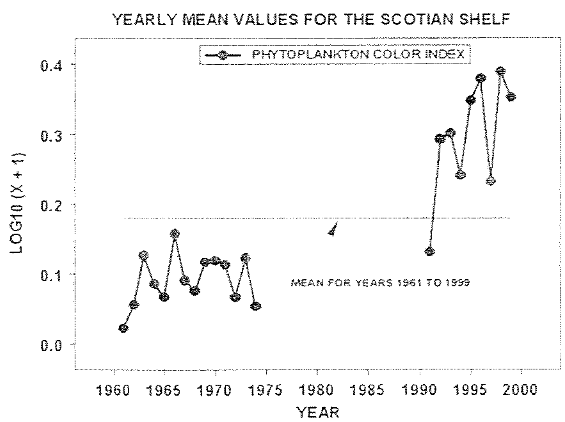

Figure 4-7. Abundance index, colour index (from AZMP 2001).

Although Myers et al. (1994) found little evidence of long-term trends in the phytoplankton colour index for the periods they examined, marked trends have been observed in recent years. More recent observations have shown increasing abundance of phytoplankton in the North Sea and some other areas of the North Atlantic, as well as decreases in the northernmost area of the North Atlantic (Sameoto et al. 1996, Reid et al. 1998, DFO 2000, Sameoto 2001). As part of the GLOBEC program, Sameoto (2001) examined the CPR data for the Scotian Shelf to 1998. He found that recent data showed a significant increase in phytoplankton biomass in the 1991 to 1998 period as compared with the 1961 to 1974 period. Abundance indices compiled from CPR data for diatoms, dinoflagellates, and the general colour index, with data to 1999, support the trend of increasing phytoplankton biomass (Figures 4-5 to 4-7). He also found that phytoplankton biomass was significantly higher in the earlier months of the year in the 1991-1998 period. The recent trends in the CPR data are matched by information from the SeaWiFS satellite (DFO 2000).

Reid et al. (1998) attributed the changes in phytoplankton abundance to changes in the climate of the North Atlantic. For example, colder surface water temperatures in the northernmost areas, caused by a variety of changes (including increased freshwater run-off from glaciers), have limited the productivity of the northernmost regions. In more southern regions, cooler waters did not limit productivity but instead led to increased productivity. A recent assessment by DFO (2000) attributed increased phytoplankton levels in the early 1990s to cooler water temperatures on the northeastern part of the shelf.
Zwanenburg et al. (in press) analyzed the CPR data for the period 1990 to 1994 and found that the phytoplankton colour index was significantly higher for all seasons for the entire Scotian Shelf than during previous periods. The authors suggested that the large increases in the CPR colour index were due to changes in weather patterns in the North Atlantic.

Other programs

Several other programs have examined primary productivity on the Scotian Shelf in the context of the productivity of other parts of the ecosystem. One such program carried out research on the Scotian Shelf in the mid-1970s. Papers produced from this research explored the relationship between nutrients, primary productivity, and fish production on the Scotian Shelf (Fournier et al. 1977, Mills and Fournier 1979). A major finding from this research was that primary productivity was highest in the area of the shelf-break (Fournier et al. 1977). This finding focussed attention on the dynamics of the shelf-break area in order to better understand the physical processes that supported high productivity (see e.g., Smith 1978).

The Scotian Shelf Ichthyoplankton Program (SSIP) was conducted between 1976 and 1982 (O'Boyle et al. 1984). Although designed to provide information on the spatial and temporal distribution of eggs and larvae of fish species, the SSIP also measured levels of nutrients, surface chlorophyll, and other species of zooplankton. In the early results of the program, O'Boyle et al. (1984) reported on two phytoplankton bloom periods observed on the eastern shelf: a major bloom in the spring (April) and another in the fall (observed only in October 1980). These observations reinforce the observations from satellite imagery and longer-term programs such as the CPR.

Mousseau et al. (1996) examined the population dynamics of the ultraplankton, the phytoplankton species less than 5 micrometres in size, as compared with larger phytoplankton such as the diatoms and dinoflagellates. They found that the spring bloom was dominated by the larger phytoplankton while the ultraplankton were the main primary producers for the rest of the year. Biomass of the smallest phytoplankton stayed relatively constant for the whole year, unlike the large phytoplankton that had peaks and lows (Dauchez et al. 1996). A later paper by Mousseau et al. (1998) examined the relationship between the smallest phytoplankton and the production of copepods and fish larvae on the Scotian Shelf . In the summer and fall, the small phytoplankton are found in greater numbers on the shelf than the large phytoplankton. The authors suggested that the small phytoplankton may be important food for the calnoiod copepods, who are abundant in the late spring and summer (after the height of the spring bloom).

Since copepods are important food for fish larvae, the small phytoplankton may be a more important component of fish production on the shelf than previously realized.

Data from other programs carried out on the shelf and slope are available from the Marine Environmental Science database (e.g., Irwin et al. 1977, Irwin and Platt 1978). Harrison et al. (2000) examined trends in the distribution of chlorophyll on the Scotian Shelf and adjacent areas using surface chlorophyll data from the CZCS program as well as data on chlorophyll sampled from the water column since the 1930s. They found that areas of coastal upwelling had generally high concentrations of chlorophyll, as did much of Georges Bank. The other banks did not show as high concentrations over extended periods; however, the eastern shelf (Sable Island Bank to the Laurentian Channel) had the highest observed chlorophyll concentrations, twice that observed in other regions. There were definite spring and fall blooms on the shelf, with the eastern and central shelf peaking most strongly in the spring, and the western shelf having the most pronounced fall bloom. The area between Emerald Bank and LaHave Bank, known as the Scotian Gulf, generally had very low concentrations of chlorophyll.

Harrison et al. (2000) found that measurements of chlorophyll at the surface were closely tied to measurements that accounted for chlorophyll throughout the water column. However, the degree to which these measurements matched varied seasonally and spatially across the shelf. Head and Harrison (1998) also related surface and integrated chlorophyll measurements for selected areas of the Scotian Shelf and found that the two measurements were generally well-correlated.

Human factors influencing primary productivity

By changing or increasing levels of nutrients in the water column through pollution and and by increasing sea-surface ultraviolet-B radiation through damage to the atmospheric ozone layer, humans have influenced phytoplankton productivity and species distribution (see e.g., Martin and Haya 1999, Monstajir et al. 1999). The artificial addition of nutrients to the ecosystem can cause excessive phytoplankton production, which may negatively affect productivity of other trophic levels. High levels of certain species of phytoplankton can be toxic, such as the well-known red tides that appear in coastal areas. Excessive phytoplankton production may also clog or damage the respiratory systems of higher life forms. Decreasing the productivity of phytoplankton also has negative consequences. In open ocean environments, ultraviolet radiation may limit the productivity of phytoplankton with repercussions for higher trophic levels. Specific effects of UV radiation on the Scotian Shelf are not well-known.

Zooplankton

Zooplankton are the link between the primary producers and the larger organisms of the Scotian Shelf. They are prey for many other creatures, from the large whales that filter them from huge mouthfuls of seawater, to small, attached anemones that catch them with waving tentacles. All species of fish feed on zooplankton during some stage of their life cycle. The availability of zooplankton is a limiting factor for the success of many other species on the shelf (DFO 2000).

Data on the abundance and distribution of zooplankton have been collected by various programs. Early research on zooplankton of the Scotian Shelf was carried out by Huntsman (1919) and Willey (1919) as part of the 1914-1915 fisheries expedition led by Johan Hjort. Bigelow (1924) examined the distribution of phyto- and zooplankton in the Gulf of Maine, including the southwestern portion of the Scotian Shelf. After these early studies, little research was carried out on Scotian Shelf zooplankton until the 1970s. Information in this section is from the following research:

1) the Scotian Shelf Ichthyoplankton Program,
2) the Continuous Plankton Recorder,
3) the Fisheries Ecology Program,
4) the GLOBEC program, and
5) other papers that discussed the distribution of zooplankton on the Scotian Shelf, from various research programs.

The copepods and the euphausiids make up a large proportion of the Scotian Shelf zooplankton biomass. These small crustaceans have been the focus of more research attention than the other zooplankton. The following discussion of zooplankton abundance and distribution is limited to those species groups.

Copepods are the most important component of the zooplankton of the shelf in terms of abundance, biomass, and secondary production. *Calanus finmarchicus* is the most abundant copepod of the Scotian Shelf in the spring and early summer and is prey for many species of fish larvae. This copepod species winters in deep waters. Several studies have attempted to determine the sources of *C. finmarchicus* on the Scotian Shelf. Some *Calanus* are believed to overwinter in deep basins of the shelf (Sameoto and Herman 1990) or in deep waters south of the slope (Head et al. 1999); others may be carried south from the Gulf of St. Lawrence outflow (Sameoto and Herman 1992); still others may originate in the Labrador Sea and be carried by the Labrador Current to the Scotian Shelf and slope (McLaren et al. 2001).

The euphausiids, commonly known as krill, are large zooplankton and important food for whales, birds, and many species of fish (for example, silver hake and redfish). The largest and most important krill species on the shelf is *Meganyctiphanes norvegica*, although *Thysanoessa inermis* and *Thysanoessa longicaudata* are also considered important (DFO 2000). *Thysanoessa* spp. feed mostly on phytoplankton while *M. norvegica* eat both copepods and phytoplankton (Sameoto and Cochrane 1996).

Scotian Shelf Ichthyoplankton Program (SSIP)

Tremblay and Roff (1983a) published a community analysis of the zooplankton of the Scotian Shelf using SSIP information from the central part of the shelf. They divided the zooplankton species into three groupings: a coastal group dominated by cold water species, a shelf group dominated by the copepod *Calanus finmarchicus*, and a shelf edge group consisting largely of warm water, southern species. Their findings have been found to be applicable for the entire shelf.

O'Boyle et al. (1984) estimated zooplankton abundance and biomass from SSIP stations on the Scotian Shelf. Using the results of 11 surveys carried out from 1978 to 1980, they found highest zooplankton biomasses on Emerald Bank, Western Bank, and the eastern end of Sable Island Bank, as well as high concentrations over Misaine Bank. Periods of peak abundance were in spring and early summer. Although the authors found high concentrations to be associated with bank areas, depth was found to be a statistically significant variable only in the fall. Most abundant species were *Calanus finmarchicus* and *Pseudocalanus* spp. In late summer, *Calanus* moved to deep waters of the basins and warm water species become more prominent on the banks, with *Centropages typicus* being the dominant copepod species. O'Boyle et al. (1984)

suggested that the abundance of zooplankton on banks may be related to circulation patterns on the bank.

Using the SSIP collections, Tremblay and Roff (1983b) estimated annual production by copepods on Emerald Bank. They ranked 10 copepod species using a ratio of production to biomass. They found *Calanus finmarchicus* to be the most productive of the copepod species. This species was also highly abundant in the zooplankton.

Other programs have used the SSIP data in combination with other data. Their results are discussed below. Findings from the SSIP on the abundance and distribution of ichthyoplankton are included in Chapter 6, Fish.

Continuous Plankton Recorder

Myers et al. (1994) used CPR data to examine the abundance and distribution of zooplankton in the northwest Atlantic. They divided this larger area into subregions and found that the most abundant group of zooplankton, the copepods, was most plentiful in the Scotian Shelf-Gulf of Maine area (NAFO zones 4W, 4x and 5Y). On the Scotian Shelf, they graphed a peak in *Calanus finmarchicus* abundance in May/June on the western and central shelf. The data showed a smaller May peak in the eastern shelf followed by a second higher peak in June. On the eastern shelf, there was a steep drop in abundance in the late summer and early fall, then a second, small peak in late fall. The western and central shelf showed a smaller drop in abundance in the summer, followed by a steep drop in the fall. A slight rise in *Calanus* abundance was charted in late fall in the central shelf region. The authors observed no statistically significant trends in abundance over time in the Gulf of Maine-Scotian Shelf area.

Sameoto et al. (1996) looked at zooplankton trends for the period from 1971 to 1993. They found that the period from 1991 to 1993 showed slightly higher zooplankton levels than average. Certain species were more abundant in the later period than they were in the earlier period, perhaps due to environmental change. Like Myers et al. (1994), they found no long-term trends in the zooplankton community.

An examination of more recent CPR data concluded that the seasonal abundance of several copepod species has changed. Sameoto (2001) reported that a shift in seasonal abundance occurred after 1991. Concentrations of *Calanus finmarchicus* and *Paracalanus-Pseudocalanus* spp. were higher in the first 3 months of the year during the 1991 to 1998 period as compared with 1961 to 1974. He suggested that the earlier abundance of zooplankton was due to a similar shift in phytoplankton abundance. The earlier bloom could in turn be explained by a change in oceanographic climate (discussed below).

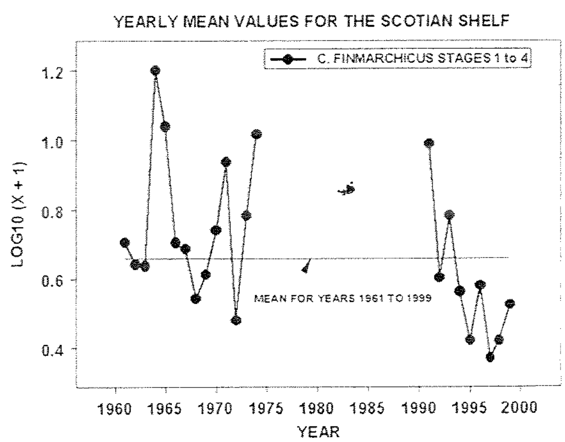

Figure 4-8. Abundance of *C. finmarchicus* stages 1 to 4 (from AZMP 2001).

Zwanenburg et al. (in press) analyzed the CPR data for the 1991 to 1994 period and found that copepod abundance was high in the spring over the entire Scotian Shelf region. Like Sameoto (2001), they suggested this was due to increased concentrations of phytoplankton, as shown by the phytoplankton colour index. However, the higher than average colour index was recorded during the 1995 to 2000 period as well as the 1990 to 1994 period (see previous section). In the latter period, the higher colour index corresponded with a marked decrease in the abundance of copepods and euphausiids on the shelf (DFO 2000, Figures 4-8 to 4-11). The increase in the colour index in the 1990s was due to an increase in the large phytoplankton (the diatoms and the dinoflagellates) (DFO 2000). However, the very small phytoplankton may play an important role as food for copepods (see Mousseau et al. 1998). Another possible explanation for the mismatch of trends is the low temperatures found in the late 1990s on the Scotian Shelf. McLaren et al. (1989) observed that development of copepods is strongly related to temperature. The early 1990s was a period of abnormally low temperatures on the eastern Scotian Shelf. Temperatures began to warm in the latter part of the decade and reached average values recently. Copepod and euphausiid numbers have increased slightly as temperatures returned to normal (DFO 2000). Sameoto (2001) pointed out that the negative relationship between copepods and phytoplankton may be a result of the predator-prey relationship. Periods of low phytoplankton abundance may be due to grazing by the zooplankton and conversely, the high indices of phytoplankton in the 1990s may be explained by a low abundance of *C. finmarchicus* during that period.

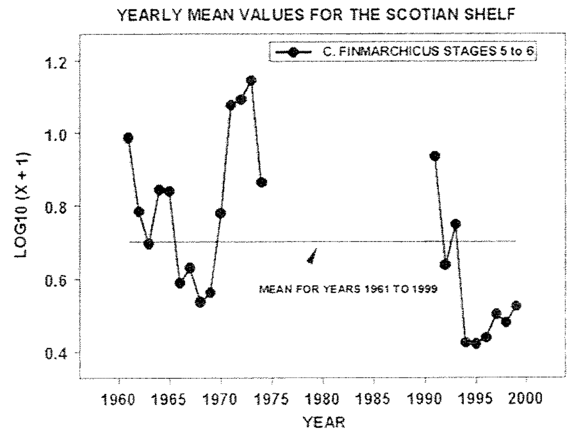

Figure 4-9. Abundance of *C. finmarchicus* stages 5 to 6 (from AZMP 2001).

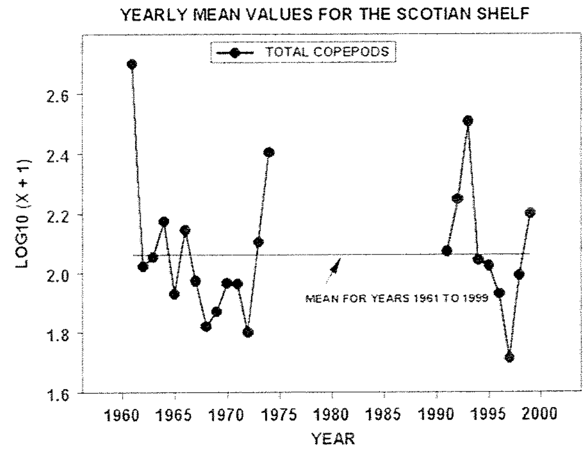

Figure 4-10. Abundance of all copepods (from AZMP 2001).

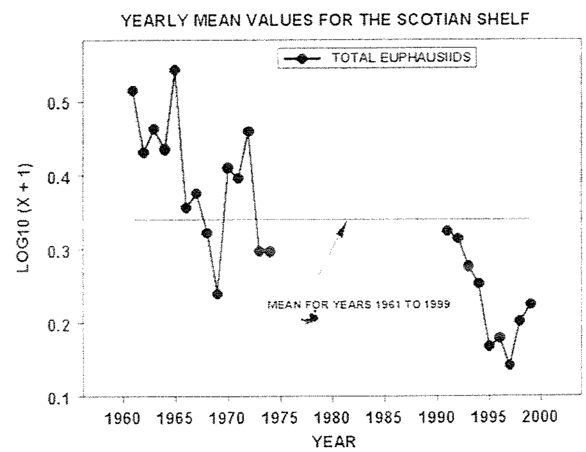

Figure 4-11. Abundance of all euphausiids (from AZMP 2001).

Fisheries Ecology Program (FEP)

The fisheries ecology program carried out by Fisheries and Oceans Canada analyzed plankton distribution off southwest Nova Scotia and related it to oceanographic conditions for the period 1981 to 1985 (Koslow et al. 1989). They observed the highest concentrations of zooplankton on the edge of Browns Bank, with low concentrations on the bank itself and in inshore regions. Data showed high inter-annual variability. The authors suggested that the distribution and abundance of copepods were related to the distribution of the phytoplankton bloom, and inversely related to the distribution of a ctenophore, *Pleurobrachia pileus*, that grazes heavily on copepods.

The FEP revisited data collected by previous programs. McLaren et al. (1989) looked at the lifecycle of copepods on Browns and Emerald Banks using FEP and SSIP data. They estimated the monthly and annual production of 10 copepod species found on Emerald Bank. They found two peaks in production, one in May and one in September. Like O'Boyle et al. (1984), McLaren et al. (1989) found that *Calanus* spp. dominated the May peak, while the September peak consisted of warm water species. The authors compared production with other areas and found copepod production on Emerald Bank to be considerably less than that on Georges Bank.

GLOBEC–Canada

The GLOBEC-Canada program examined the relationship between changes in the marine environment and marine orgranisms. As part of this program, McLaren et al. (2001) examined the life cycle of *Calanus finmarchicus* populations on Western Bank and adjacent areas. They found that the Western Bank population largely came from animals that overwintered and reproduced on the shelf. In some years, the overwintering Emerald Basin population received new recruits from the shelf break and the Western Bank population occasionally received new members from areas farther north and south. Their work indicates that the Emerald Bank population comes from further north and may be brought to the shelf by the Labrador Current. This program was followed by the Atlantic Zone Monitoring Program (AZMP). Further results from both these programs are forthcoming.

Other research

Several other researchers have looked at zooplankton abundance, distribution, and productivity on the Scotian Shelf. Mills and Fournier (1979) provided an estimate of zooplankton productivity as part of their study of the productivity of the Scotian Shelf ecosystem. Since their purpose was to look at the Scotian Shelf ecosystem in its entirety, they do not discuss the productivity of particular areas of the Scotian Shelf. However, the authors did point to the high catches of pelagic fish species off southwestern Nova Scotia as a potential indicator of high productivity.

Some researchers have tried to determine the areas where zooplankton are concentrated. Herman et al. (1981) have suggested that copepods gather in areas of convergence between water masses. Other zooplankton and free-floating species may also be concentrated in those areas. This concentration would make these areas attractive for zooplankton predators.

Zooplankton of the Scotian Shelf are regularly surveyed by research vessels. These observations are combined with findings from other programs such as CZCS and CPR to provide summary reports on the state of the plankton (see e.g., DFO 2000). Occasionally, special reports are written on a particular species or group of species. For example, Sameoto and Cochrane (1996) reviewed the information on krill of the continental shelf off eastern in response to a proposal for a krill fishery.[8] Krill are found in deep water during the day and migrate to surface waters at night, with *Meganyctiphanes norvegica* preferring depths below 200 metres during the day. Based on the depth preference of that species, Sameoto and Cochrane suggested that adult *M. norvegica* are concentrated in basins and along the shelf edge on the Scotian Shelf (Figure

[8] It was determined that not enough information was available to allow a fishery for this important forage species.

4-12). *Thysanoessa* spp. and juvenile *M. norvegica* are found in shallower waters over the whole shelf and the authors were not able to identify areas of concentration.

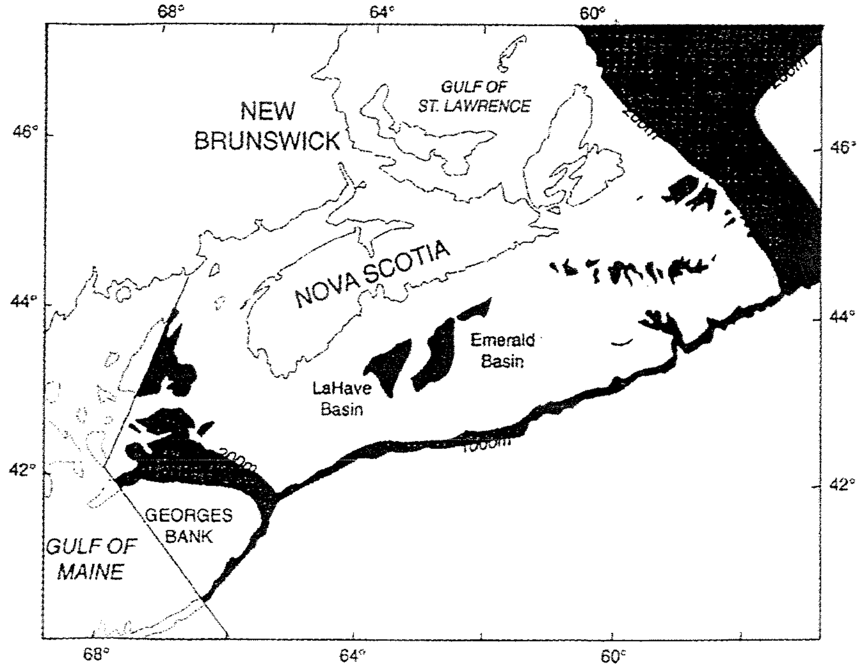

Figure 4-12. Areas (shaded) where the krill *Meganyctiphanes norvegica* are concentrated on the Scotian Shelf (from Sameoto and Cochrane 1996).

Important Areas

In general, the area along Nova Scotia's coast has high phytoplankton productivity. Areas of upwelling and tidal mixing off southwest Nova Scotia make this area productive year-round. Sydney Bight is also a productive area for much of the year. There are spring and fall blooms in offshore regions of the shelf, with the easternmost part of the Scotian Shelf showing an increasing concentration of chlorophyll through the late summer before peaking in the fall. This bloom covers Misaine, Banquereau, and Middle Banks and the eastern end of Sable Island Bank, with another bloom further west on Browns Bank. The area known as the Scotian Gulf, between Emerald Bank and LaHave Bank, generally had very low concentrations of chlorophyll and seems to be less important in terms of phytoplankton productivity.

Based on depth preferences, it is known that adult *M. norvegica* congregate in basins and along the shelf edge. The distribution of copepods is not as easily defined. Preliminary information from the SSIP showed high zooplankton biomass over Misaine, Western, and Emerald Banks and the eastern end of Sable Island Bank. It should be noted that these observations were collected from 1978 to 1982 and will reflect the oceanographic environment of that period. No other literature adequately indicates areas of high zooplankton biomass, although different authors have studied the zooplankton in specific areas. From their work, we know that spring and summer are the most important periods for early life stages of *Calanus finmarchicus*, while fall and winter have higher abundance of older stages and most of the smaller copepod species. Overwintering copepods stay in deep waters, some in basins of the shelf. Ocean currents seem to be important in determining where and when copepods will appear on the shelf in abundance. However, gaps in our knowledge of spatial distribution by season are significant.

The link between phytoplankton abundance and the abundance of copepods is not entirely clear and needs to be further explored. The timing of *Calanus* reproduction does not appear to be directly tied with spring phytoplankton blooms (Head 2001), although the productivity of that bloom may ultimately affect copepod abundance and distribution. Recent studies have suggested that certain species of diatoms, the main phytoplankton of the spring bloom, may actually have a negative impact on copepod egg production and hatching (see e.g., Starr et al. 1999, Miralto et al. 1999). There are still many questions about the links between the primary producers and primary consumers of the ocean. The present lack of information on the distribution of zooplankton, and the relationship of phytoplankton with zooplankton, limits our ability to identify important areas for zooplankton on the Scotian Shelf.

The spatial distribution of phyto- and zooplankton may provide information on the distribution of higher trophic levels, and vice-versa. Jacquet et al. (1996) related chlorophyll concentrations observed by satellite sensors with sperm whale distribution compiled from nineteenth century whaling records for the Pacific Ocean. They found that the two distributions were associated at the spatial scale they considered, with a few important exceptions. There may be potential to apply this kind of existing data to the Scotian Shelf to better understand the distribution of both plankton and their predators.

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5 BENTHIC AND PELAGIC INVERTEBRATES[1]

Introduction

This chapter discusses the diversity and distribution of the free-swimming and attached invertebrates of the Scotian Shelf. Many of the invertebrate species of the plankton have already been discussed in Chapter 4. They are not included here, nor are many of the pelagic and mesopelagic invertebrates, other than two commercial species, the short-finned squid and the northern shrimp. The pelagic invertebrates are not included because of a general lack of information on their occurrence and distribution on the Scotian Shelf. This chapter begins with a discussion of invertebrate diversity and distribution, with a focus on non-commercial benthic invertebrates. Because commercial invertebrates are much better known than non-commercial species, species descriptions of several important commercial invertebrates follow.

There has not been a comprehensive listing of marine invertebrates of Atlantic Canada since 1901, when J.F. Whiteaves produced the *Catalogue of Marine Invertebrata of Eastern Canada*. Since then, hundreds of additional species have been recorded in Atlantic Canada and a great number of changes have been made to taxonomic classifications. Despite the availability of more up-to-date information on many of the species found on the Scotian Shelf, there remains no comprehensive work along the lines produced for other groups of animals, such as the *Atlantic Fishes of Canada* (Scott and Scott 1988).

In 1998, a catalogue of marine invertebrates of the Gulf of St. Lawrence and the St. Lawrence estuary was produced (Brunel et al. 1998). This document lists thousands of species found in that area but provides few details on the natural history of these organisms. The Marine Invertebrate Diversity Initiative (MIDI) is compiling information by species in a web-based database (MIDI 2001). This ongoing initiative is focussed on the invertebrates of the Gulf of Maine, Scotian Shelf, and Bay of Fundy with the goal of updating Whiteaves' catalogue. Several guides to marine fauna exist. Most of these guides are aimed at a general readership and tend to focus on shallow-water, coastal species (see e.g., Gosner 1979, Martinez 1994, Harvey-Clark 1997). One of the few exceptions is Miner's 1950 work. Although entitled the *Field Book of Seashore Life*, it included deep-sea anthozoans and other species found beyond the intertidal zone. Gosner's 1971 key to marine invertebrates included many more species than do most field guides, including a few deep water species. More technical works focus on individual species or groups of species and are intended to aid marine biologists in identification (see e.g., Clark and Downey 1992, Pollock 1997).

Unfortunately, few of these works focus on the waters directly off Nova Scotia. They tend to cover well-defined geographic areas in a general way, such as Pollock's 1997 guide to northeastern North America that covers both fish and invertebrates, or they look at particular groups of species over very large geographic areas, such as Clark and Downey's *Starfishes of the Atlantic* (1992). Other works are limited to very particular fields and geographic areas, for example, the work by Bousfield that examines shallow-water amphipods of New England. Three of the most useful references for Nova Scotia marine invertebrates are a key to polychaetes of the Bay of Fundy (Appy et al. 1980), one outlining polychaete distribution in the northwest Atlantic (Pocklington 1985), and a comprehensive

[1] The authors would like to thank Derek Davis, Ellen Kenchington, Vladimir Kostylev, and John Tremblay for their comments on earlier versions of this chapter.

work on the decapod crustaceans of the Canadian Atlantic (Squires 1990). Unfortunately, detailed works for other taxonomic groupings do not exist. Those working in benthic ecology occasionally use works from other parts of the world to help identify unknown invertebrates to the family level, using, for example, works from the Northeast Atlantic (e.g., Ryland and Hayward 1977, Hayward and Ryland 1990) and even farther afield (MacIsaac, pers. communication).

Photos of the ocean bottom taken by the Geological Survey of Canada have been collected into a volume called *A Photographic Atlas of the Eastern Canadian Continental Shelf*. The atlas has both photos and descriptions of some of the benthos of the Scotian Shelf (Lawrence et al. n.d.) and is a useful resource to view Scotian Shelf species in their natural environment. Unfortunately, the photographic stations were concentrated in a few areas and photographs are not representative of all Scotian Shelf habitats.

The non-commercial invertebrates found in the deeper waters of the Scotian Shelf are not well-described. MacIsaac (pers. communication) has observed many species of invertebrates that he believes have not been previously recorded on the shelf, as well as new species not described in the literature. Recent research on sponges has expanded the distribution of many species to the waters off Nova Scotia and found species not recorded since the late 19th century (Fuller pers. communication). Yet despite the lack of knowledge on specific invertebrate species, there is increasing awareness that invertebrates play an important role in marine ecosystems as food, as habitat, and as cyclers of nutrients for other marine species.

Benthic Invertebrate Distribution and Diversity

The non-commercial invertebrate species found in Nova Scotia's waters represent many billions of animals, stretching from the shallow intertidal organisms to deep water abyssal species. Most of these species are not well-studied and some invertebrates have not yet been described in the literature (see e.g., Snelgrove 1999). This section focusses on bottom-dwelling species found in the sublittoral zone.[2] Benthic invertebrates provide food for groundfish, bottom-dwelling commercial invertebrates, and sea birds. They also create physical structures on the bottom, providing habitat for other species (Witman and Dayton 2001). Because the benthic communities of the Scotian Shelf are not well-described beyond the intertidal zone, this section will focus more on general description, with specific communities and habitats described where information is available.

There are many challenges to studying the fauna of the ocean bottom. Many of the studies collected data using grab, dredge, or core samples. This equipment is usually not suitable for hard, rocky bottoms, and fewer samples have been taken from those environments. This type of sampling means that the fauna is removed from its environment and makes it difficult to observe interactions with other species. More recently, studies have been carried out using photographs or video equipment. While allowing observation of organisms in their natural habitat, the use of videos and photos makes it more difficult to identify species and decreases taxonomic resolution.

Research into the non-commercial invertebrates on the Scotian Shelf began with the scientific collecting expeditions of the nineteenth and early twentieth-century and observations and collections carried out by fishermen. The U.S. Fish Commission collected many species from the

[2] The sublittoral zone is usually considered to be the area from the low tide mark seaward to the continental shelf break.

Scotian Shelf, Georges Bank, and Gulf of Maine in the late part of the nineteenth century. The leader of several of the voyages, A.E. Verrill, encouraged fishermen from Gloucester, Massachusetts to bring in invertebrates they collected while fishing on banks off Nova Scotia. These collections resulted in the descriptions of several animals new to science and provided basic information about the distribution of many other species. The Challenger expedition collected species from the deep waters of the Atlantic, including stations off Nova Scotia. The expedition presented several specimens of benthic fauna to Nova Scotia's provincial museum, some from Nova Scotia's offshore, others sampled from distant areas of the ocean (Davis 1973).

After the first eager efforts to classify the species of the ocean, interest in the benthic invertebrates of the Scotian Shelf waned. Although scientists from the former Soviet Union carried out some studies on benthic communities of the northwest Atlantic fishing banks (Nesis 1962, 1965), few other researchers did. Most studies of individual invertebrate species focussed on the accessible intertidal species and those with commercial potential. Studies of benthic communities also focussed on coastal areas. Along Nova Scotia's Atlantic coast, St. Margaret's Bay has been the focal point of most studies, with few other areas sampled (Mitchell 1999, see also Stewart et al. 2001).

Interest in understanding the dynamics of the marine ecosystem led to a new style of deep-water benthic studies, starting around the 1950s (Theroux and Wigley 1998). These new studies focussed on benthic productivity: the amount of living material generated by bottom-dwelling invertebrates. There was less interest in classifying the individual components of that productivity.

Benthic productivity

Theroux and Wigley (1998) reviewed the studies of macrobenthic invertebrates carried out off the northeastern United States. Some of these studies included areas in Canadian waters. Their overview discussed the trends in invertebrate studies, from early research aimed at cataloguing new marine invertebrates to later reports focussed on assessing environmental quality and monitoring impacts. Studies of the benthos in Canada have followed much the same pattern. Using data collected from the mid-1950s to the mid-1960s, the authors characterized the benthos of the northeastern United States. Each geographic area was characterized by number of specimens collected from the area and the biomass of specimens in grams per square metre. Specimens and biomass were divided into taxonomic groupings, with the distribution of those groupings also mapped. Browns Bank and the Northeast Channel fell within their study area. Their findings in that area will be discussed later in this chapter.

Stewart et al. (2001) compiled data from studies of the marine benthic macrofauna of eastern Canada, including previously unpublished data from scientific surveys. Most of these studies sought to estimate the productivity of benthic communities, in part by measuring benthic biomass. Some studies simply measured biomass without identifying the taxa that contributed to it. The authors compiled available data from the studies into a database (data were not available from all studies listed). From this database it is possible to map the biomass collected at various locations on the Scotian Shelf. In some cases, the proportion of various species groupings that make up the biomass of each station can be displayed (e.g., crustaceans, polychaetes, echinoderms, etc.). Data from individual studies, from individual data sets, as well as a combination of studies can be mapped. Figure 5-1 is an example of the type of map that can be created using this database. It shows macrofaunal biomass on the Scotian Shelf from all datasets that were available to Stewart et al.

Many early studies on marine ecosystem dynamics on the Scotian Shelf were undertaken with a view of better understanding groundfish population dynamics. Peer (1970) pointed out the need to know how energy is transferred through benthic food chains and the importance of quantitatively measuring productivity. He examined the productivity of the trumpet worm *Pectinaria hyperborea* found in St. Margaret's Bay. *Pectinaria* spp. are important prey for groundfish and the author estimated the production of the worms at each station of the study. Mills (1975) provided a fuller description of the importance of describing energy transfer from the benthos to other elements of the ecosystem and proposed that variations in the structure of benthic communities would affect levels of fish production. From there, Mills and Fournier (1979) sought to relate fish production with other aspects of the marine ecosystem, including the benthic environment. They suggested that differences in ecosystem structure may account for differences in productivity at different trophic levels. They found that sites sampled off Nova Scotia had higher primary productivity yet lower fish productivity than shown for areas of the North Sea, likely due to lower zooplankton and macrobenthic production at the Nova Scotia sites. The biggest observed difference in fish productivity in the two systems was in levels of pelagic fishes, with demersal fish catches in the two areas being almost identical.

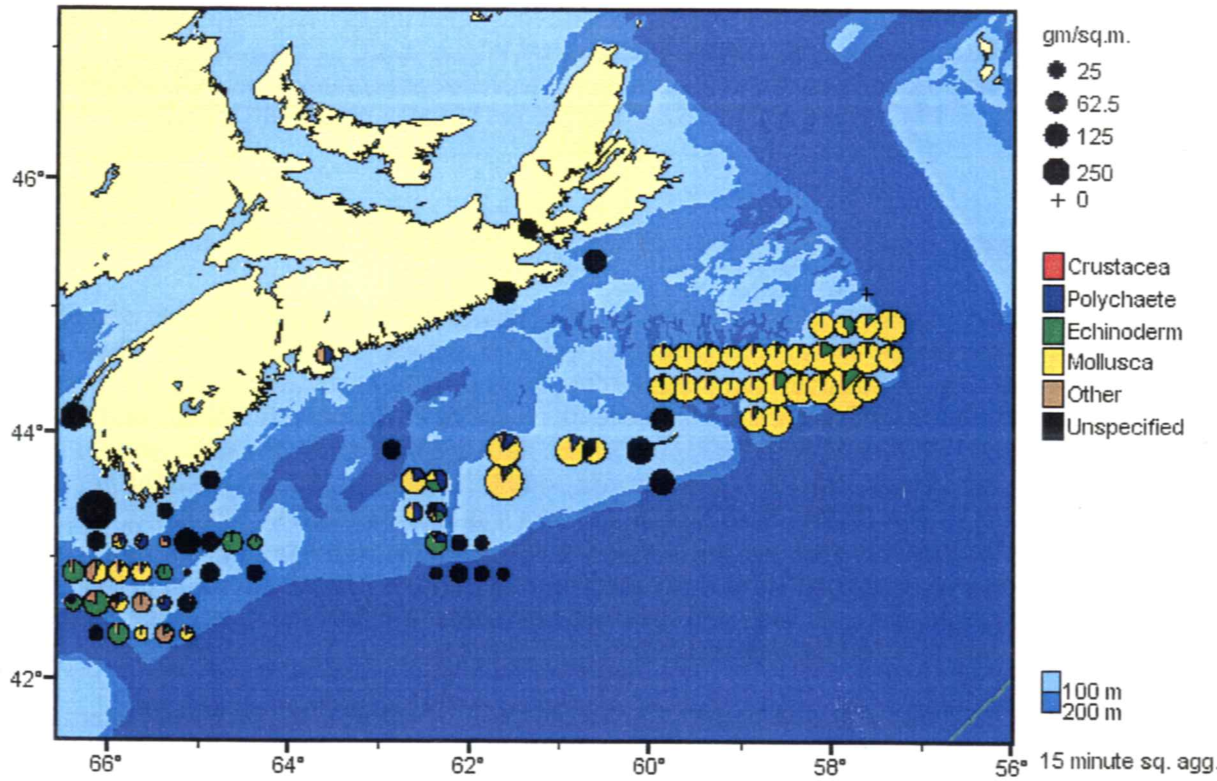


Figure 5-1. Macrofaunal biomass from data collected from studies of the Scotian Shelf, 1954-1999 (from data compiled by Stewart et al. 2001).

Other research aimed to trace productivity through the ecosystem. Mills et al. (1984) examined energy flow through the Scotian Shelf food-web. They found that food relationships on the shelf were quite complex. The authors had difficulty tracing energy flow through to the benthos, especially meiobenthic fauna. Wildish et al. (1989) examined benthic macrofauna production in a specific Scotian Shelf environment, Browns Bank, with the purpose of determining why it was suitable habitat for juvenile haddock. The researchers divided the macrofauna they sampled into deposit feeders and suspension feeders and mapped the distribution of the two groupings by biomass. They also compared the density of macrobenthic production on Browns Bank with that in the Bay of Fundy. The authors concluded that the deposit feeders – prey for juvenile haddock – were a much smaller component of Browns Bank benthic production than suspension feeders. However, they found that the area was important for juvenile haddock because the small size of the deposit feeders and their continual resuspension by tidal currents made it an attractive feeding area.

Wildish et al. (1992) later carried out research on the macrofauna species present on Browns Bank in the benthic boundary layer (BBL) – the first several metres of the water column above the ocean bottom, where water flow is influenced by bottom friction. That study sampled fauna in the BBL and measured its biomass. It also identified the specimens to the lowest possible level (species level for most) and associated the animals with particular sediments.

Desrosiers et al. (2000) investigated the trophic structure of benthic communities in the Gulf of St. Lawrence, Cabot Strait, in Emerald Basin on the Scotian Shelf, and on the slope of the Scotian Shelf. The authors measured the surface chlorophyll and bacteria and characterized the sediments at each station. They sampled the macrofauna using a core sample and measured the abundance of macrofaunal species as individuals per square metre. Abundance at various depths in the core at each station was compared. The authors characterized the species sampled as surface deposit feeders, subsurface deposit feeders, filter feeders, carnivores, or omnivores. The authors concluded that geomorphological characteristics and primary productivity influenced the composition of the benthos.

Studies relating benthic fauna as a whole with other components of the ecosystem have shed light on how ecosystems function. An understanding of productivity over the long term may provide information on the status of marine environments and may also determine the areas that are consistently highly productive. Knowledge of benthic biomass and components of that biomass can provide information on changes in benthic communities over time. However, identifying the individual components of that biomass has often been skipped over in studies of productivity on the Scotian Shelf. These studies have also been short-term and spatially scattered and are not able to present the complete picture of what is happening on the Scotian Shelf. It is important to look both at the productivity and the diversity of the benthos.

Benthic diversity and communities – early studies

The term "community" is often used to describe groups of organisms living near, on, or within one another and found in similar environments. Mills (1969) explained the difficulties of defining communities in the context of marine zoology. He proposed that community be defined as "a group of organisms occurring in a particular environment, presumably interacting with each other and with the environment, and separable by means of ecological survey from other groups." Various types of analysis have been used to group benthic fauna into communities. This section will discuss the major studies of Socitan Shelf communities.[3]

Nesis (1962, 1965) provided one of the earliest characterizations of deep water benthic communities of eastern Canada, based on research carried out in 1954 and 1958-60. He listed

[3] The associations between members of communities portrayed here are not universally accepted. Members of communities may share particular depth, temperature, or salinity preferences; however, the communities themselves may not be stable or predictable – characteristics that many biologists consider essential to the concept of "community" (Kenchington pers. communication).

twenty complexes (which he also called bioceonoses) of benthic animals off eastern Canada, whose distribution was associated with depth, grounds (geographic area), and water masses (Nesis 1962). The twenty complexes described in the 1965 paper had similar but not identical species and distribution to those described in the 1962 paper; both papers were based on the same research. The eastern Scotian Shelf and the slope were included in the characterizations. Some of the complexes described by Nesis were positioned in areas off Newfoundland as well as Nova Scotia, thus not all characteristic species are necessarily found in all areas. The stony bottom complex characterized by the sea urchin *Strongylocentrotus droebachiensis*, Icelandic scallop, chitons, and bryozoans was found on parts of Misaine Bank. The latter paper gave somewhat different species for a complex with a similar geographic distribution, *Thelepus cincinnatus* (a polychaete) – *Chlamys islandica* (Icelandic scallop) – *Ophiopholis aculeata* (daisy brittle star), and stated that this grouping was found at depths of 65 to 135 metres on stony bottoms.

In the same area, Misaine Bank, but on sandy bottoms, communities of *Echinarachnius parma* (sand dollar) predominated with a fish, *Ammodytes americanus* (sand lance) (Nesis 1965). This complex was also found on Banquereau. In deeper waters on the edge of the banks, from 95 to 220 metres, the complex *E. parma* – *Ophiura sarsi* (brittle star) was characteristic. Nesis added *Srongylocentrotus droebachiensis* (sea urchin) to the 1965 description of this complex. Nesis remarked on the cold waters found off the Atlantic Coast of Cape Breton, which influenced the species characteristic of the area. Cold water species typical of that area's complex included *Cardium ciliatum* (a cockle), *Sabinea septemcarinata* (a shrimp), *Solaster syrtensis* (sunstar), *Gorgonocephalus eucnemis* and *G. arcticus* (basket stars), and *Stegophiura nodosa* (brittle star). The brittle star *O. sarsi* and the sea urchin *S. droebachiensis* were also typical of the area.

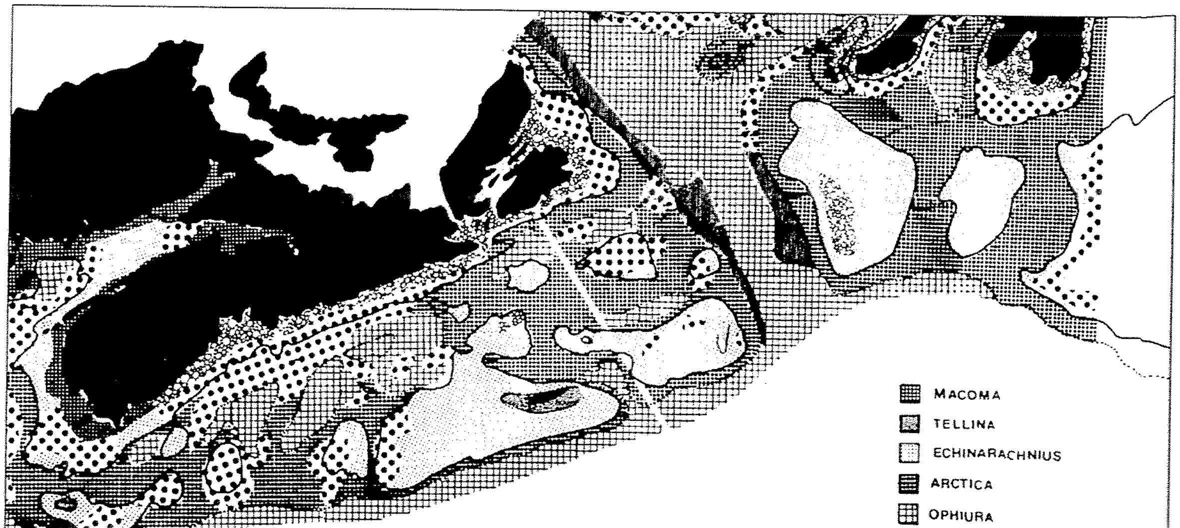
The complex *Brisaster fragilis* (heart urchin) -- *Ctenodiscus crispatus* (mud star) – *Yoldia thraciaeformis* (broad yoldia) – *Pennatularia* was considered characteristic of depths greater than 200 metres in the Laurentian Channel. The sea pens *Anthoptilum grandiflorum*, *Pennatula aculeata* and *P. grandis* were characteristic species. This complex was substantially different than that of the upper slope of the Scotian Shelf (250 to 500 metres): *Astropecten americanus* and *Porania insignis* (sea stars), *Cidaris cidaris* (sea urchin), and *Psolus valvatus* (sea cucumber). Fauna of shallower depths at the shelf edge was characterized by *Pseudarchaster parelii* and *Hippasteria phrygiana* (sea stars), *Echinarachnius parma* (sand dollar), *[Arctica] islandica* (ocean quahaug), *Placopecten magellanicus* (sea scallop), *Neptunea lyrata decemcostata* (whelk), and *Asterias vulgaris* (boreal sea star).

Nesis (1965) also grouped the species by feeding group affiliation – filter feeders attached to firm bottom, filter feeders attached to loose bottoms, species that ingest bottom soils, preying and omnivorous species, etc. From this, he divided eastern Canada into feeding zones. The area of the Scotian Shelf included in this study fell into one zone, while the Laurentian Channel fell into another zone. The categories used to group species are not entirely clear.

Theroux and Wigley (1998) used data from a similar period – 1956 to 1965 – to examine the distribution of macrobenthic invertebrates of the northeastern United States. Their work included a Nova Scotia sub-area that encompassed Browns Bank and parts of the Bay of Fundy and Gulf of Maine. The authors put species in taxonomic groupings, then mapped the distribution of those groupings. Like Nesis, the authors attempted to relate distributions to the physical environment, such as water depth, sediment type, temperature, and organic carbon content of sediment. Four taxonomic groupings made up more than 90 percent of the individuals sampled and 90 percent of the accumulated biomass: crustacea, annelida, mollusca, and echinodermata. Typical species of the Nova Scotia sub-area were the polychaete *Aphrodita* *hastata*, the bivalves *Astarte undata* (waved astarte), *Cerastoderma pinnulatum*, *Cyclocardia borealis* (northern cardita), and *Placopecten magellanicus* (sea scallop), the whelks *Buccinum* spp. and *Neptunea decemcostata*, the amphipod *Unciola irrorata*, the decapod crustaceans *Hyas coarctatus* and *Pagurus* spp. (hermit crabs), and the echinoderms *Asterias vulgaris* (boreal sea star), and *Strongylocentrotus droebachiensis* (green sea urchin). Relations to the physical environment were done by the larger taxonomic grouping, not by individual species or species assemblages.

Benthic diversity and communities – broad characterizations

Steele et al. (1979), Mobil Oil (1983), and the *Natural History of Nova Scotia* (Davis and Browne 1996) broadly characterized the benthic communities of the Scotian Shelf using existing studies. Many of the existing studies took place not on the Scotian Shelf itself, but in nearby areas such as the Grand Banks and the Gulf of Maine. Other studies included only a small part of the shelf.



Bottom communities of the Southeast Atlantic Region. The portion east of the white line is simplified from Nesis (1965). The western region is extrapolated from this on the basis of personal knowledge, the studies of Bigelow and Schroeder (1939), Brawn, Peer and Bentley (1968), Caddy (1970), Collins, J.W. (1884), Hughes, Peer and Mann (1972) Logan and Noble (1971), Nesis (1962) Peer (1963), Rowe, Polloni and Haedrich (1975) Stanley and James (1971), Wagner (1975) and Wigley (1961, 1968) and bottom photographs in Drapeau (1970), Emery, Merrill and Trumbull (1965), Fader, King, and MacKean (1977), James and Stanley (1968) Heezen and Hollister (1971), King (1970), MacLean and King (1971) and Stanley and James (1971).

Figure 5-2. Bottom communities of the Scotian Shelf and adjacent regions, from Steele et al. (1979).

Macoma (intertidal region, shallow depths on sandy mud and mud)
Baltic macoma *Macoma balthica*
soft-shell clam *Mya arenaria*
green crab *Carcinides (=Carcinus) maenas*
polycheate worm *Neanthes (=Nereis) virens*
polycheate worm *Sabellaria vulgaris*

Tellina (shallow water in wave washed sand)
dwarf tellin *Tellina agilis*
isopod *Chiridotea spp.*
amphipod *Amphiporeia lawrenciana*
amphipod *Psammonyx nobilis*

Echinarachnius (sandy bottom with less wave action)
sand dollar *Echinarachnius parma*
amphipod *Unciola irrorata*
amphipod *Leptocheirus pinguis*

Arctica (sandy bottom with some added fine sediments moderate depths)
ocean quahaug *Arctica islandica*
Atlantic surf clam *Spisula solidissima*
Arctic surf clam *Spisula (=Mactromeris) polynyma*

Ophiura (fine sediments in the deep basins and on the continental slope)
brittle star *Ophiura sarsi*
mud star *Ctenodiscus crispatus*
northern shrimp *Pandalus borealis*
crimson sea pen *Pennatula aculeata*
heart urchin *Brisaster fragilis*
snow crab *Chinoecetes opilio*
red crab *Geryon (=Chaecon) quinquedens*

Modiolus-Rhodophytes (shallow depths near shore, coarse substrate)
horse mussel *Modiolus modiolus*
coralline algae *Lithothamnium* spp.
red seaweed *Ptilota serrata*
sea cucumber *Cucumaria frondosa*
scarlet psolus *Psolus fabricii*
amphipod *Corophium bonelli*
amphipod *Ischyrocerus anguipes*
amphipod *Jassa falcata*

Modiolus-Rhodophytes cont.
amphipod *Caprella* spp.
sea star *Asterias vulgaris*
barnacle *Balanus crenatus*
barnacle *Balanus hameri*
Jonah crab *Cancer borealis*
rock crab *Cancer irroratus*
lobster *Homarus americanus*
northern lamp shell *Terebratula (=Terebratulina) septentrionalis* (western part of region)
sea urchin *Strongylocentrotus droebachiensis*

Modiolus-Ophiopholis (coarse sediments, moderate depths)
daisy brittle star *Ophiopholis aculeata*
sea scallop *Placopecten magellanicus*
lobster *Homarus americanus*
Arctic lyre crab *Hyas coarctatus*

Corals (deep water, coarse substrate)
basket star *Gorgonocephalus arcticus*

Steele et al. (1979) described the benthos of the western Grand Banks, Scotian Shelf, Bay of Fundy, and Georges Banks in a publication for Parks Canada. Their description of bottom communities was based largely on the characterization of the Grand Banks and eastern Scotian Shelf by Nesis (1965), extrapolated to the areas further west based on published data and bottom photographs from the Geological Survey of Canada (Figure 5-2). The authors stressed that their characterization was preliminary, based on fairly limited data. Species typical of each area are listed below the figure (from Steele et al. 1979).

The report by Mobil Oil was partially based on extensive field work carried out in the early 1980s; however, this field work was carried out on the Grand Banks (Hutcheson et al. 1981). No similar work was carried out on the Scotian Shelf. MacLaren Plansearch (1996) based their map of benthic invertebrates for the Sable Offshore Energy Project (SOEP) environmental assessment on the Mobil work and a few published Scotian Shelf studies. For example, Roddick and Lemon (1992) carried out exploratory surveys for Arctic surf clam (*Mactromeris polynyma*) on the Scotian Shelf and listed the species caught with them.

The MacLaren Plansearch (1996) characterization was based on depth, sediment, as well as characteristics of particular localities. It has been criticized as lacking in scientific rigour and it focusses on commercial invertebrates. However, with few other maps available, their characterization (Figure 5-3) is a useful visual aid for discussing the distribution of invertebrates on the shelf. Species considered to be characteristic of the various areas, as listed in the legend of Figure 5-3, are listed in Table 5-1 under "A". Species that may also be considered characteristic of each area are listed under B (from MacIsaac pers. communication).

The *Natural History of Nova Scotia* (Davis and Browne 1996) divided the offshore area of Nova Scotia into natural regions (see Figure 5-4). Bottom invertebrates typical of those regions are listed in Table 5-2. These species are typical of the broader areas but are not found in all areas. For example, lobster is rarely found on Banquereau but is found in other parts of the Outer Shelf Banks region. Snow crab is uncommon on the western part of the Scotian Shelf, but is a typical animal of deep, cold basins and holes of the eastern shelf.

Table 5-1. Characteristic Seabed Organisms (see Figure 5-3)		
Area	**A (from MacLaren Plansearch 1996)**	**B (from MacIsaac pers. communication)**
Shallow 1 (less than 100 metres)	sand dollar (*Echinarachnius parma*) ocean quahaug (*Arctica islandica*) surf clam (*Spisula solidissima*)* northern propeller clam (*Cyrtodaria siliqua*)	brittle star (*Ophiura sarsi*), polychaete (*Spiohanes bombyx*) amphipod crustaceans (*Ampelisac macrocephala* and *Priscillina armata*)
Shallow 2 (less than 100 metres)	dwarf tellin (*Tellina Agilis*)	very similar species to Shallow 1
Shallow 3 (less than 100 metres)	Arctic surf clam (*Mactromeris polynyma*) (see also Shallow 1)	very similar species to Shallow 1 may also see Arctic wedge clam (*Mesodesma arctatum*)
Shallow 4 (less than 100 metres)	sea scallop (*Placopecten magellanicus*)	see section on sea scallop for associated species
Shallow 5 (less than 100 metres)	horse mussel (*Modiolus modiolus*) brittlestar (*Ophiopholis aculeata*)	brittle star (*Ophiura robusta*) polychaetes: Sabellidae (*Chone duneri, Chone infundibuliformis, Jasminiera sp., Euchone sp.*), Terebellidae (*Thelepus cincinnatus, Polycirrus sp.*), and Maldanidae (*Praxillella praetermissa, Nicomache lumbroicalis, Nicomache* sp., *Petaloproctus tenuis*) amphipod crustaceans (*Erichthonius fasciatus, Unciola* sp.) encrusting coralline algae (species not identified)
Coastal, shallow	horse mussel (*Modiolus modiolus*) red algae (*Rhodophyta* sp.)	
Deep 1 (greater than 100 metres)	ocean quahaug (*Arctica islandica*)	likely similar to shallow 1
Deep 2 (greater than 100 metres, shelf edge)	Brittle star (*Ophiura sp.*)	polychaetes from the family Serpulidae in particular areas, there are likely to be dense concentrations of other invertebrates: cerianthid and other anemones, foraminifera, and pennatulaceans
Deep 3 (greater than 100 metres)	northern shrimp (*Pandalus borealis*)	
Deep 4 (greater than 100 metres, edge of Laurentian Channel/Stone Fence)	basket star (*Gorgonocephalus arcticus*)	northern propeller clam (*Cyrtodaria siliqua*) chalky macoma (*Macoma calcarea*) sand dollar (*Echinarachnius parma*) brittle star (*Ophiura sarsi*) polychaetes (*Prionospio steenstrupi, Spio filicornis, Praxillella praetermissa, Axiothella catenata*) amphipod crustacean (*Priscillina armata*)

*This species is likely an error. Arctic (Stimpson's) surf clam (*Mactromeris polynyma*) is more likely to be in this area. The Atlantic surf clam (*Spisula solidissima*) is commonly found in the intertidal zone.

The species listed with Figures 5-2, 5-3, and 5-4 are some of the more common species found in those areas at those depths. However, other invertebrates, less widely distributed, fill important roles in the ocean ecosystem. Erect sessile epifauna create relief on the ocean bottom. Their distribution may be limited to small patches with appropriate habitat characteristics, such as substrate and food availability. However, within these patches, they create habitat for other species (including refuges from predation) and alter patterns of of water movement, influencing food supply (Genin et al. 1986, Wildish and Kristmanson 1997). Finding the "special" habitats – where invertebrates with patchy distribution and very particular environmental preferences are found – is difficult to do without thorough surveys of the ocean bottom.

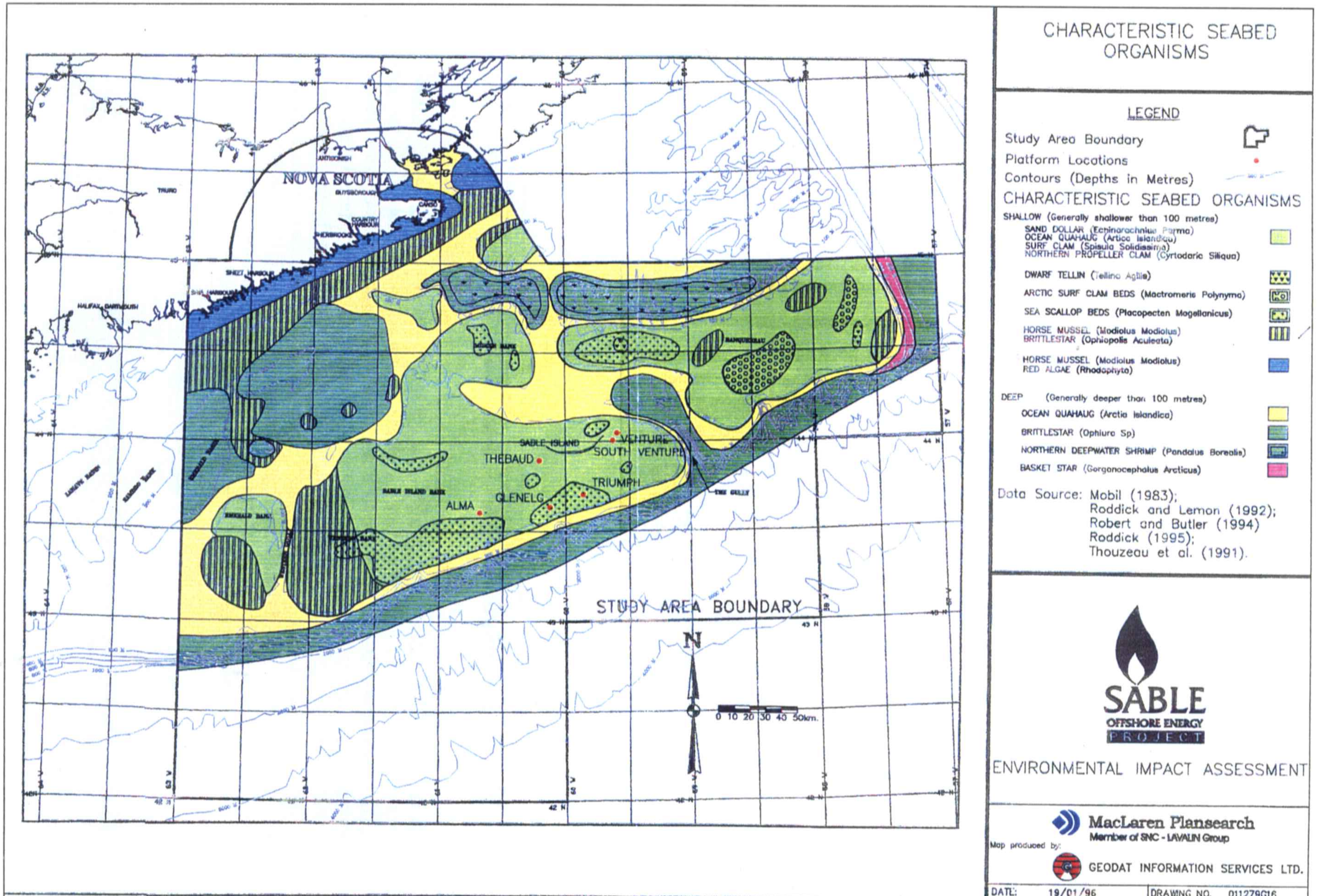


Figure 5-3. Map of characteristic seabed organisms from the Sable Offshore Energy Project Environmental Assessment (MacLaren Plansearch 1996).

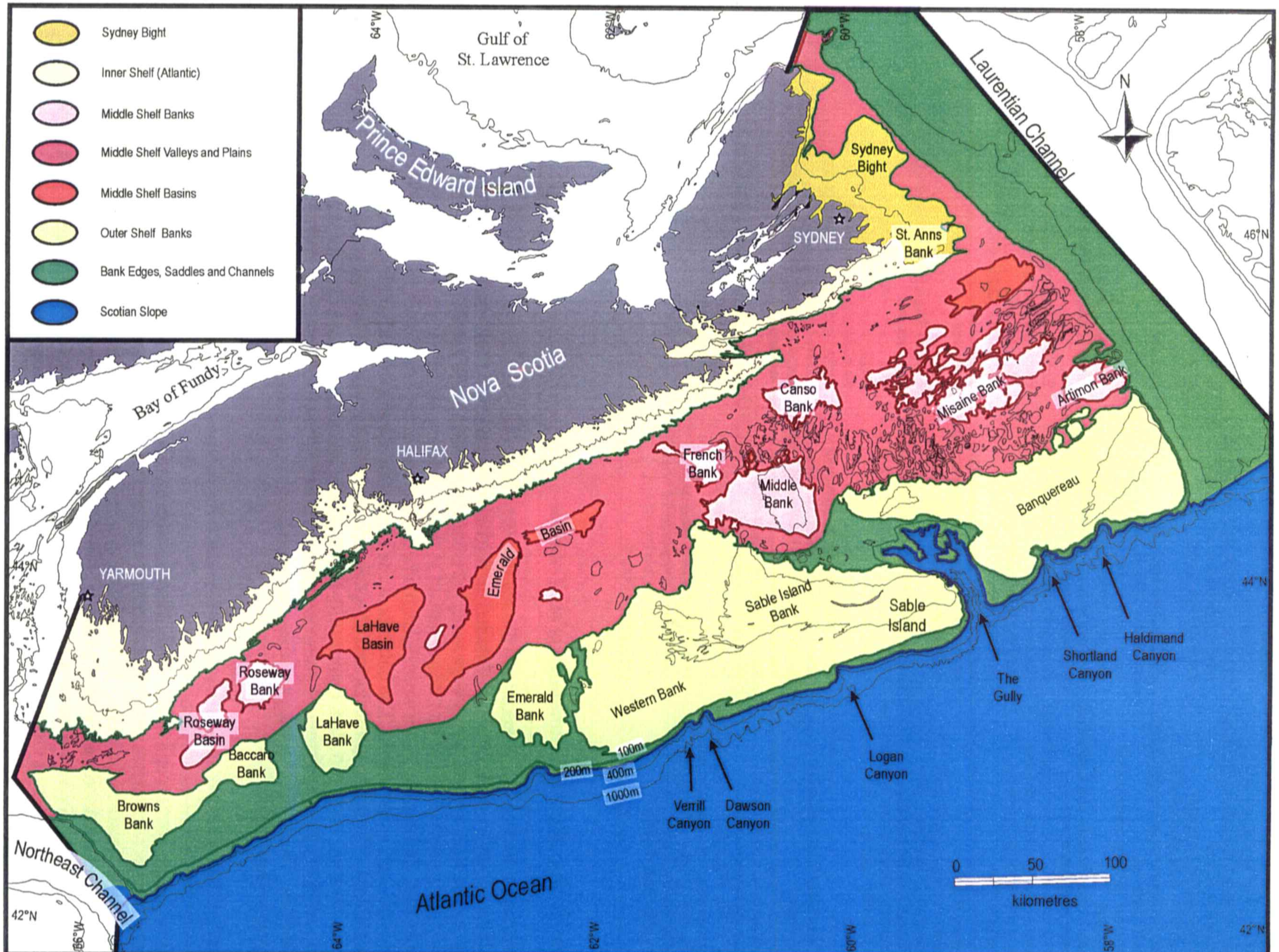


Figure 5-4. Offshore regions modified from the *Natural History of Nova Scotia* (Davis and Browne 1996). Regions in the Bay of Fundy and Gulf of St. Lawrence are not included.

Table 5-2. Typical bottom invertebrates (Figure 5-4, compiled from Davis and Browne 1996)

Inner Shelf Atlantic horse mussel *Modiolus modiolus* sea cucumbers *Cucumaria frondosa* and *Psolus fabricii* sea star *Asterias vulgaris* amphipods *Corophium bonelli, Ischyrocerus anguipes, Jassa falcata,* and *Caprella* spp. barnacles *Balanus crenatus* and *B. hameri* crabs *Cancer borealis* and *C. irroratus* lobster *Homarus americanus* sea scallop *Placopecten magellanicus* ocean quahaug *Arctica islandica* sea urchin *Strongylocentrotus droebachiensis* **Sydney Bight** lobster *Homarus americanus* snow crab *Chinoecetes opilio* rock crab *Cancer irroratus* sea scallop *Placopecten magellanicus* many similar species to Inner Shelf Atlantic **Middle Shelf Banks (coarser sediments):** ocean quahaug *Arctica islandica* Stimpson's (Arctic) surf clam *Mactromeris polynyma* sea scallop *Placopecten magellanicus* horse mussel *Modiolus modiolus* brittle star *Ophiopholis aculeata* lobster *Homarus americanus* toad crab Hyas araneus	**Middle Shelf Banks (finer sediments):** sand dollar *Echinarachnius parma* amphipods *Unciola irrorata* and *Leptocheirus pingus* **Middle Shelf Basins** brittle star *Ophiura sarsi* heart urchin *Brisaster fragilis* mud star *Ctenodiscus crispatus* northern shrimp *Pandalus borealis* sea pen *Pennatula aculeata* snow crab *Chinoecetes opilio* Jonah crab *Cancer borealis* tusk shell *Dentalium spp.* polycheate worms especially Serpulidae and Onuphidae (Arctic species in deep waters, warmer water species in shallow waters) **Middle Shelf Valleys and Plains** similar species to adjacent banks and basins **Outer Shelf Banks (in general):** ocean quahaug *Arctica islandica* (concentrations on Western and Sable Island Banks) Arctic (Stimpson's) surf clam *Mactromeris polynyma* (concentrations on Banquereau) **Outer Shelf Banks (fine sand):** sand dollar *Echinarachnius parma* amphipods *Unciola irrorata* and *Leptocheirus pingus*	**Outer Shelf Banks (coarser substrate):** sea scallop *Placopecten magellanicus* horse mussel *Modiolus modiolus* brittlestar *Ophiopholis aculeata* lobster *Homarus americanus* toad crab *Hyas araneus* **Bank edges, saddles and channels** red crab *Chaecon quinquedens* lobster *Homarus americanus* **Scotian Slope and deep water of channels and canyons (throughout):** brittle stars (Ophiuroids) crustaceans sea spiders **Scotian Slope (soft sediments):** Echinoderms tube worms (Pogonophora) bristle worms (Polychaeta), especially Serpulidae and Onuphidae cnidarians: sea pens, whip corals, solitary corals (*Flabellum spp.*) scaphopod, pelecypod, and gastropod molluscs **Scotian Slope (ice-rafted boulders):** sponges, cnidarians, bryozoa, and brachiopods

Benthic diversity and communities of shelf regions

A survey of Browns Bank examined the sea floor and its epifauna to better understand its role as habitat (Kostylev et al. 2001). A detailed geological survey using a multi-beam system was carried out and benthic invertebrates were sampled using a grab and photographs. The photographic and grab stations and the benthos observed at these stations were linked with the sediment type. From this, different habitats were distinguished, based on substrate, habitat complexity, current strength, and water depth. The habitats of the bank were described with their associated megafauna. The authors also looked at species diversity in the various habitats. They found that the lamp shell *Terebratulina* community that typically occurred on gravel substrates had the highest diversity of epifauna. A subtype of this community was dominated by sponges and tunicates. The surficial geology of this area was complex, with large boulders providing topographical relief.

The benthic species of two small areas of Western Bank have been sampled extensively as part of a study examining the impacts of trawling. Prena et al. (1996) listed the taxa sampled on and just below the seafloor by epibenthic sled. The two sites sampled are about 30 kilometres apart. More species of molluscs and echinoderms were sampled than any other invertebrate phylum; those phyla were also abundant by number and volume. At site A, the most abundant species of molluscs and echinoderms were *Colus* spp., *Pandora inornata* (inornate pandora), *Margarites* sp. (margarite), *Echinarachnius parma* (sand dollar) and *Ophiura sarsi* (brittle star). The same species of echnioderms were abundant at site B but the most abundant molluscs were *Astarte* *undata* (waved astarte), *A. crenata* (crenulate astarte), *Cyclocardia borealis* (northern cardita), *Antalis entale* (entale tusk shell), and *Nuculana pernula* (northern nutclam). The polycheate *Nothria conchylega* was fairly common at both sites. The authors sampled a smaller area of each site using the video grab, which sampled deeper into the sediment. From the video grab, they determined 10 species that were abundant at one site and 17 that were abundant at the other (Table 5-3).

Table 5-3 Abundant species sampled by video grab (modified from Prena et al. 1996)

Western Bank Site A	Western Bank Site B
Unciola irrorata (amphipod)	*Nothria conchylega* (polycheate worm)
Clymenura borealis (polycheate worm)	*Chone infundibuliformis* (polycheate worm)
Erichthonius rubricornis (amphipod)	*Erichthonius rubricornis* (amphipod)
Corophium insidiosum (amphipod)	*Bathyarca pectunculoides* (ark shell)
Nothria conchylega (polycheate worm)	Ascidiidae (sea squirts)
Trochidae (top shell)	*Phascolion strombi* (=*strombus*, peanut worm)
Aglaophamus circinata (polycheate worm)	*Eunice pennata* (scale worm, polycheate)
Arctica islandica (ocean quahaug)	*Ampelisca agassizi* (amphipod)
Travisia forbesi (polycheate worm)	*Unciola irrorata* (amphipod)
Nemertini (ribbon worms)	*Notomastus latericeus* (polycheate worm)
	Antalis entale (entale tusk)
	Arctica islandica (ocean quahaug)
	Cyclocardia borealis (northern cardita)
	Ophiura sarsi (brittle star)
	Astarte crenata (crenulate astarte)
	Nemertini (ribbon worms)
	Scalibregma inflatum (polycheate worm)

Nearby Georges Bank has been the focus of several studies of benthic invertebrates. Thouzeau et al. (1991) sampled the benthic megafauna of the Bank and grouped them in assemblages (see section on the sea scallop for more detail). These assemblages were related to sediment type and mapped. The authors found well-defined patterns of benthic megainvertebrates related to environmental conditions on the bank. In their study of Oceanographer canyon, a submarine canyon on the edge of Georges Bank, Valentine et al. (1980) found that the megafuna observed from a submersible could be divided into assemblages by depth. Using a submersible rather than a trawl survey allows the observation of species that are rarely brought up by trawls, including many attached forms. It also allows the observation of habitat use by mobile megafauna, providing information on relationships between species in the ecosystem.

The macro epifauna of the Scotian Shelf have received much more attention than the micro and meio infauna, which nonetheless are important to ecosystem functioning. Snelgrove et al. (1997) discussed the importance of maintaining biodiversity of benthic organisms living in the sediments. Many of these species are undocumented. Snelgrove (1999) suggested that less than 1 percent of marine benthic species are known. Many of these species inhabit deep water areas that have not been adequately sampled, while others are tiny animals living in the sediments or in other species such as sponges or corals.

Benthic invertebrates of canyons

Like Browns Bank, the bottom habitats of The Gully have been investigated with the objective of describing physical habitats and characterizing the fauna. Recent research carried out by DFO in The Gully has provided videos and photographs from areas of the canyon, although the deepest parts of the canyon remain unsampled (Kostylev in press). The Gully is the only canyon along the margin of the Scotian Shelf that has been studied in any detail (Harrison and Fenton 1998, Gordon and Fenton in press). Kostylev (in press) characterized the epibenthic communities of The Gully, according to depth. Seven groups of co-occurring species were distinguished. The author found that hard substrates supported the greatest number of megafauna and appeared to be important in supporting biodiversity; however, softer sediments may support a rich infauna which was not visible in the photographs. In particular, areas of hard glacial substrate along the edges of channels appeared to support a diverse epifauna. Figure 5-5 is a schematic showing the distinctive species found on the sea floor of The Gully at different depth intervals.

Hecker et al. (1980) examined the epifauna of three canyons found along the edge of the U.S. Atlantic continental shelf using an underwater towed camera sled. Two of the canyons, Oceanographer and Lydonia, are along the margin of Georges Bank. Baltimore Canyon is further south, off Cape May. The authors found that there was considerable variety in the sediments found within the canyons. Glacial erratics were frequently found in the two Georges Bank canyons, and were colonized by several species of anemones, and gorogonian corals, such as *Acanthogorgia armata* and *Parmuricea grandis*. The authors did not find any cohesive faunal assemblages in their investigations. Species appeared to be independently distributed, with overlapping ranges in some areas but not in others. The availability of suitable substrate was a key factor controlling the distribution of many species. They did find evidence of commensal relationships between some species.

The authors found that the dominant epifaunal species could be grouped by depth zones. Patterns of dominant fauna were different for each canyon, partially due to different substrate availability, but also partially because of faunal emergence at higher latitudes. Further north, the depth range of some species was shallower than in the canyon farther south. Common species for the two Georges Bank canyons are found in Table 5-4.

The two Georges Bank canyons were found to have a greater diversity and density of corals as compared to the third canyon and slope environments. The authors concluded that the determining factor was the availability of hard substrate, such as bedrock outcrops and glacial erratics, in parts of Lydonia and Oceanographer Canyons. Separate chapters were prepared on the scleractinian (hard) corals and octocorals (horny and soft corals) found in the canyons. For these chapters, the authors used historical data that included data on other canyons along the U.S. continental slope. One of the canyons, Corsair Canyon, indents the Canadian side of Georges Bank.

Benthic invertebrates of the slope and abyssal plain

The benthic invertebrates of the deep waters of the Scotian Slope and abyssal plain have received little attention, with the notable exception of one area, the HEBBLE site, which is discussed below. The slope has occasionally been sampled by research surveys (see e.g., Figure 5-1, Desrosiers et al. 2000), but the benthic invertebrates in that environment have received even less attention than those of the shelf. Work describing the megafauna of deep waters further south has been carried out by Grassle et al. (1974), Grassle and Maciolek (1992), Blake and Grassle (1994) and many others. Snelgrove and Grassle (1995) review the work carried out on benthic invertebrates in the deep waters along the U.S. Atlantic contintental slope. Sokolova (1997) discussed energy flow in the abyssal environment on an oceanic level. Gage and Tyler's (1991) book *Deep-Sea Biology* is the general reference on the deep sea environment and its benthic organisms.

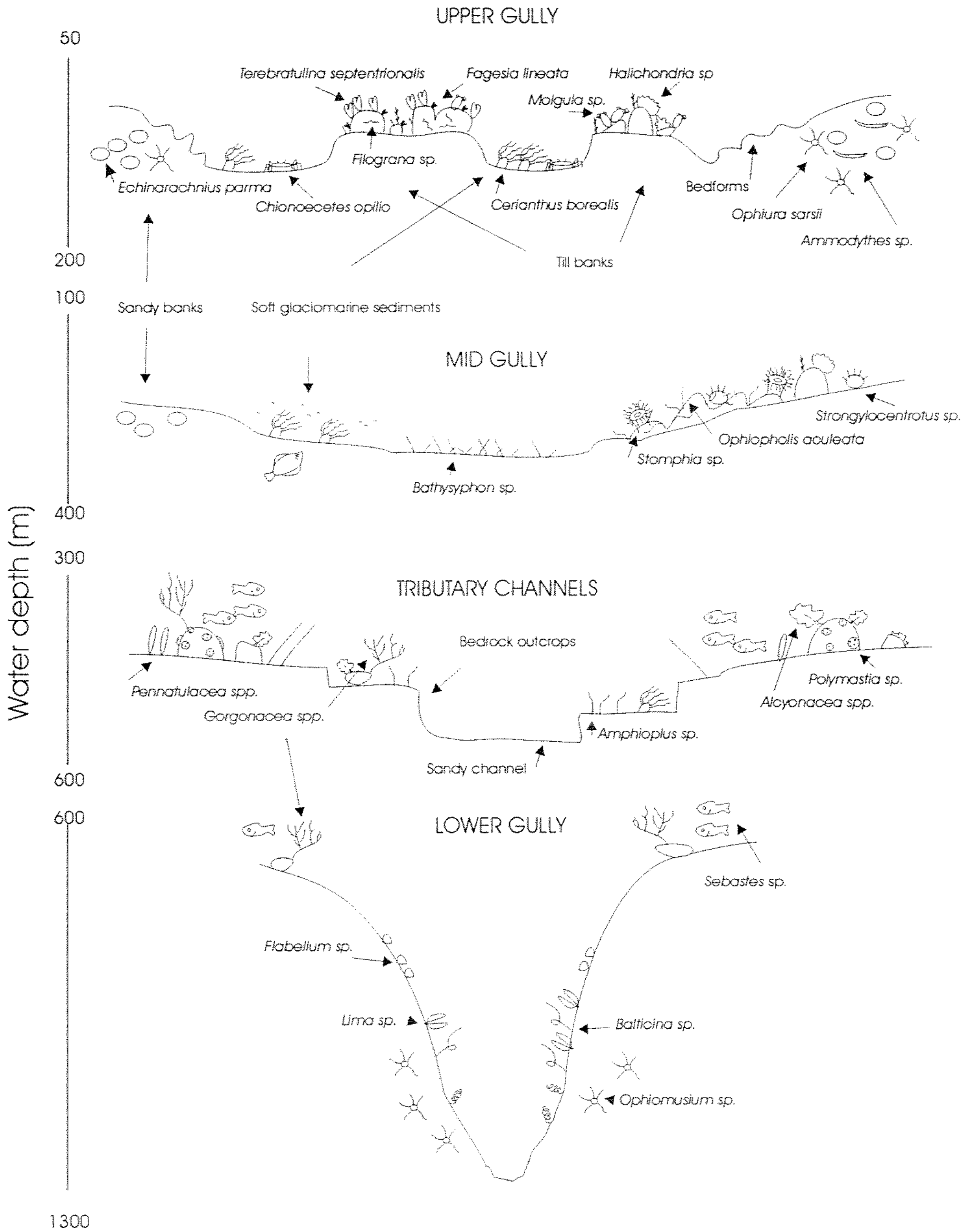


Figure 5-5. Schematic distribution of common species in The Gully. Bathymetric ranges are approximate (from Kostylev in press).

The HEBBLE (High Energy Benthic Boundary Layer Experiment) project examined sediments, sediment transport, and the impact of transport on benthic communities (McCave et al. 1978, Aller 1989). The purpose was to examine high energy events in the benthic boundary later in very deep waters. The site selected for study was on the Nova Scotian rise, 40°27' N, 62°20' W, just outside Canada's 200-mile EEZ and 4820 metres below the ocean surface. The site was studied in depth, with papers appearing on sediments in the general area, biological activity, relationship of the benthos with sediments, benthic communities, and responses of benthic communities to disturbance (Driscoll and Tucholke 1983, Aller and Aller 1986, Carman et al. 1987, Thistle et al. 1991, Aller 1989).

Table 5-4. Common species or taxa of two submarine canyons, listed by relative abundance (adapted from Hecker et al. 1980)

Depth Zone	Canyon	
	Lydonia	**Oceanographer**
Shallow (100-299 m)	Anemone (unidentified) *Munida valida* (galatheid crab) *Cerianthus borealis* (anemone) *Actinauge longicornis* (anemone) Fish (unidentified) Starfish *Cancer borealis* (Jonah crab) Hermit crab Rosefish *Bolocera tuediae* (anemone) Shrimp Rattail Eel Cerianthid anemone Hake	not sampled
Middle (300-1099 m)	Anemone (unidentified) *Hyalinoecia artifex* (quill worm) Shrimp (unidentified) Eel *Bolocera tuediae* (anemone) Sponge (unidentified) Fish (unidentified) *Eunephthya (=Duva) florida* (soft coral) *Pennatula aculeata* (sea pen) *Geryon (=Chaecon) quinquedens* (red crab) Rattail Cerianthid anemone Hake *Cerianthus borealis* (anemone) *Actinauge longicornis* (anemone) Hermit crab *Cancer borealis* (Jonah crab) Rosefish *Munida valida* (galatheid crab) Starfish	Shrimp (unidentified) Sponge (unidentified) *Ophiura* sp. (brittle star) Fish (unidentified) *Synaphobranchus kaupi* (eel) *Geryon (=Chaecon) quinquedens* (red crab) *Paramuricea grandis* (gorgonian coral) Rattail *Acanthogorgia armata* (gorgonian coral) Anemone (unidentified) Hermit crab Gastropod (unidentified) *Porania insignis* (starfish) *Hyalinoecia artifex* (quill worm) Starfish (unidentified) *Munida valida* (galatheid crab) *Asteronyx loveni* (brittle star) Hake *Eunephthya (=Capnella) florida* (soft coral) *Cancer borealis* (Jonah crab) Cerianthid anemone Soft coral (Unidentified)
Deep (1100-1799 m)	not sampled	*Ophiomusium lymani* (brittle star) Fish (unidentified) *Paramuricea grandis* (gorgonian coral) *Pennatula aculeata* (sea pen) Rattail Sponge (unidentified) Shrimp (unidentified) *Synaphobranchus kaupi* (eel) *Asteronyx loveni* (brittle star) *Distichoptilum gracile* (sea pen) Cerianthid anemone *Acanthogorgia armata* (gorgonian coral) Soft coral (Unidentified) Anemone (unidentified) Gastropod (unidentified) Hake Hermit crab Starfish (unidentified) *Geryon (=Chaecon) quinquedens* (red crab)

Abundance of many species at the HEBBLE site, including polychaetes, bivalves, tanaids, and isopods, was much greater than expected for the depth (Thistle et al. 1991). Except for the isopods, the abundance of these organisms was unaffected by the regular benthic storms over the ocean bottom. In fact, the periods of low current speed may have caused more disturbance to the benthic community at the site since sediments were regularly deposited on the seabed during low current periods (Aller 1989). The deposits buried organisms and filled in burrows of infauna.

Invertebrates as habitat

Epifauna contribute to the structure of the seabottom and provide habitat for other organisms. Sponges, anemones, corals, hydroids, and bryozoans all form structures above the sediments and habitat for other benthic invertebrates. Both attached and mobile organisms can provide habitat. For example, many organisms are found attached to the shells of scallops and other molluscs. Tube-forming worms create structure in and above the sediment. The availability of the habitat provided by particular benthic invertebrates may be a limiting factor for populations of certain species.

The sand dollar *Echinarachnius parma* is strongly associated with fine sandy sediments. They are found on top of and just under fine and medium-grain sands, more rarely with coarse sands (Stanley and James 1971). This species is fairly wide-spread throughout the Scotian Shelf on those sediments. Sand dollars in general are known to aggregate on the lee side of sand bars (Stanley and James 1971). On Sable Island Bank, *E. parma* has been known to modify surficial sediments (Stanley and James 1971). They appear to play a determining factor in creating or altering benthic community structure (Steimle 1989).

Glass sponges and colonial corals are organisms that may have only patchy distribution on the Scotian Shelf. These sessile filter feeders are long-lived and vulnerable to disturbances in the ocean bottom. Corals are affected by increased sediment load in the water column and thus can be good indicators of disturbances of the marine environment (Hecker et al. 1980, Breeze et al. 1997). Scleractinians (true or stony corals), gorgonaceans (horny corals) and alcyonaceans (soft corals) are found in Nova Scotia's waters. The soft corals seem to be somewhat widely distributed in shallow waters, for example, on the tops of banks. Some solitary stony corals are also found in shallow waters (e.g., *Flabellum* sp.). However, the colonial scleractinian and gorgonian species appear to be found

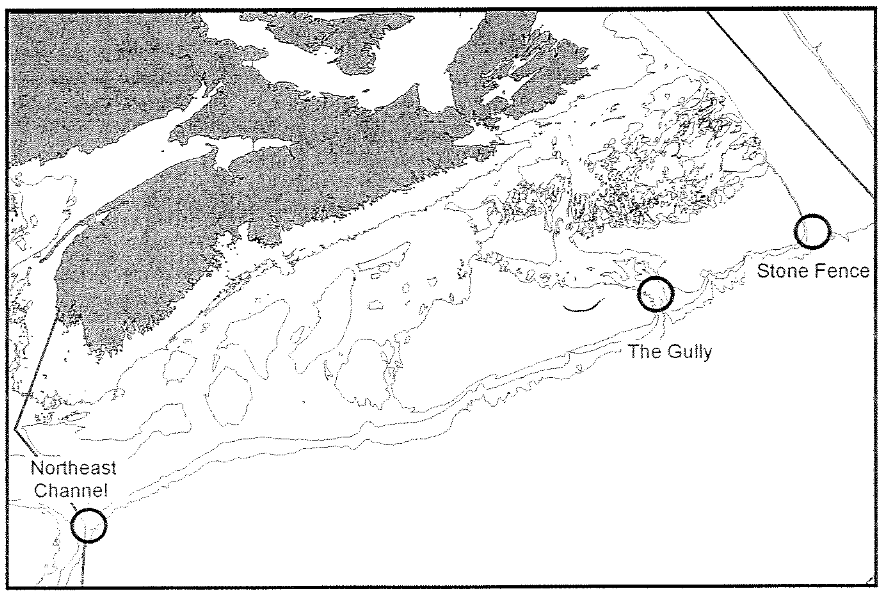


Figure 5-6. Known present distribution of two deep-sea gorgonian corals, *Primnoa resedaeformis* and *Paragorgia arborea*, on the Scotian Shelf. Boundaries of study area are indicated.

only in waters deeper than 200 metres on the Scotian Shelf. They may have only a localized distribution in patches with appropriate habitat. Many of the species found in our waters need hard substrate on which to settle. Smaller species such as the gorgonian *Acanella arbuscula* can anchor in soft substrate or on hard fragments of shell (Breeze et al. 1997). Figure 5-6 shows known distribution of two species of large gorgonian corals, *Paragorgia arborea* (bubblegum coral) and *Primnoa resedaeformis* (seacorn).

A variety of invertebrates have been observed living on or near corals on the Scotian Shelf (MacIsaac et al. 2000); however, their role in the ecosystem and importance as habitat are still not understood. In canyons indenting Georges Bank, researchers commonly observed shrimp associated with the large gorgonian corals *P. arborea*, *P. resedaeformis*, and *Paramuricea grandis* and the alcynocean (soft) coral *Eunepthya florida* (=*Capnella florida* or *Duva florida*) (Hecker et al. 1980). The brittle star *Asteronyx loveni* was viewed only in colonies of *Paramuricea grandis* in the canyons. It is found around the world in waters deeper than 100 metres and has been observed clinging to sea pens and other species of octocorals in other parts of the world (see e.g., Fujita and Ohta 1988). *A. loveni* and other species from that genus are commonly associated with pennatulids and gorgonian corals (Hyman 1955, Fujita and Ohta 1988).

Current understanding of Atlantic Canadian deep-sea corals comes from historical records of museums, observations by fishermen, and recent video and photograph observations (Breeze et al. 1997, MacIsaac et al. 2000). DFO and university researchers are working to better determine areas where corals are found and the species with which they are associated on the Scotian Shelf. Some species of corals are long-lived and can grow to large sizes. These animals may be particularly vulnerable to human activities on the ocean bottom.

Like corals, sponges need hard objects on which to attach. The Hexactinellida (glass sponges) are found in deep waters, while Desmospongiae are shallow-water sponges. The Calcarea are the only sponges with calcareous spicules.[4] Most are found in shallow, sheltered waters of the tropics. In the past, areas with glass sponges appear to have been fairly extensive off eastern Canada. For example, Honeyman (1889a, 1889b) remarked on the dense growths of sponges donated to Nova Scotia's museum from boulders and cables brought up from Atlantic Canadian waters. A Dalhousie researcher is studying the current extent of sponge distribution in Atlantic Canada (Fuller pers. communication).

Changes in benthic communities

Changes in benthic communities can be caused by natural events and human activities. Frid et al. (1999) suggested that fishing pressure has altered the benthic communities of the North Sea. They contended that fishing tends to remove the large groundfish that feed mostly on other fish. The remaining population is made up of smaller fish that tend to feed mostly on benthic invertebrates. As well, the type of invertebrates that are consumed have changed, influencing the structure of benthic communities. The authors concluded that this change in energy flow has likely caused further changes in marine ecosytems. Their research points to a need to both reassess old data to try to develop a picture of former benthic community structure, and carry out research now to assess current communities.

[4] Spicules form the skeleton of sponges and are used as an aid in identifying different species.

Many common non-commercial species are harvested as bycatch in commercial fisheries. For example, starfish, chitons, many gastropod species, polychaete worms, and other species are taken when Arctic surf calm are harvested (Roddick 1996). Sediments that benthic organisms live on or in are also disturbed by commercial fisheries. The degree that harvesting impacts the populations of non-commercial species and affects the entire Scotian Shelf ecosystem is not known. Studies are ongoing to assess the impacts of clam dredging and otter trawling on the Scotian Shelf.

Results from a similar study on the Grand Banks of Newfoundland has provided detailed information on the benthic community of the study area (see e.g., Gilkinson et al. 1998, Prena et al. 1999, Kenchington et al. 2001). The researchers found few changes in the infauna that could be attributed to trawling; however, they suggested that this could be a result of the area they picked and the number of times they trawled. Studies that trawled the same area more extensively or trawled in areas with more prominent bottom features could prove to have substantial impacts on benthic fauna (Kenchington et al. 2001).

Commercial Invertebrates

Fisheries and Oceans Canada carries out individual stock assessments for commercial species within separate invertebrate management regions. There are about 28 invertebrate fisheries (Table 5-5) that have full, exploratory, or potential fishery status on the Scotian Shelf, of which lobster, sea scallop, snow crab, and shrimp are the most important in terms of total landed value (NS Dept. of Aquaculture and Fisheries 2001). Squids are assessed by the Northwest Atlantic Fisheries Organization (NAFO), since the population is considered a single stock throughout its whole range in the northwest Atlantic (Black et al. 1987, Dawe and Hendrickson 1998). Most commercial species are assessed by NAFO divisions. As these divisions are referred to frequently in the text, a reference map is provided (Figure 5-7).

Table 5-5 Commercial* Invertebrate Species of the Scotian Shelf

Common Name	Scientific Name
Mollusks – Bivalves	
Blue mussel	*Mytilus edulis*
Sea scallop	*Placopecten magellanicus*
American oyster	*Crassostrea virginica*
Ocean quahaug	*Arctica islandica*
Northern quahaug	*Mercenaria mercenaria*
Arctic (Stimpson's) surf clam	*Mactromeris polynyma*
Atlantic surf clam	*Spisula solidissima*
Atlantic jack knife	*Ensis directus*
Soft-shell clam	*Mya arenaria*
Northern propellerclam	*Cyrtodaria siliqua*
Mollusks – Snails	
Periwinkle	*Littorina littorea*
Moon snail	*Lunatia heros*
Waved whelk	*Buccinum undatum*
Mollusks – Cephalopods	
Short-finned squid	*Illex illecebrosus*
Long-finned squid	*Loligo pealei*
Echinoderms	
Orange-footed sea cucumber	*Cucumaria frondosa*
Green sea urchin	*Strongylocentrotus droebachiensis*
Arthropods – Crustaceans	
Krill (horned krill shrimp)**	*Meganyctiphanes norvegica*
Northern shrimp	*Pandalus borealis*
American lobster	*Homarus americanus*
Northern stone crab	*Lithodes maja*
Snow crab	*Chinoecetes opilio*
Toad crab	*Hyas araneus*
Arctic lyre crab	*Hyas coarctatus*
Jonah crab	*Cancer borealis*
Rock crab	*Cancer irroratus*
Red crab	*Chaceon quinquedens*
Green crab (exotic species)	*Carcinus maenas*
Mud crab	*Neopanope sayi*

*Not all of these species are currently fished commercially but the commercial importance of most has been assessed by DFO in the last five years. Northern stone crab has not been assessed; however, exploratory multi-species crab licenses have been granted that include that species.
**Krill are discussed in Chapter 4, Plankton.

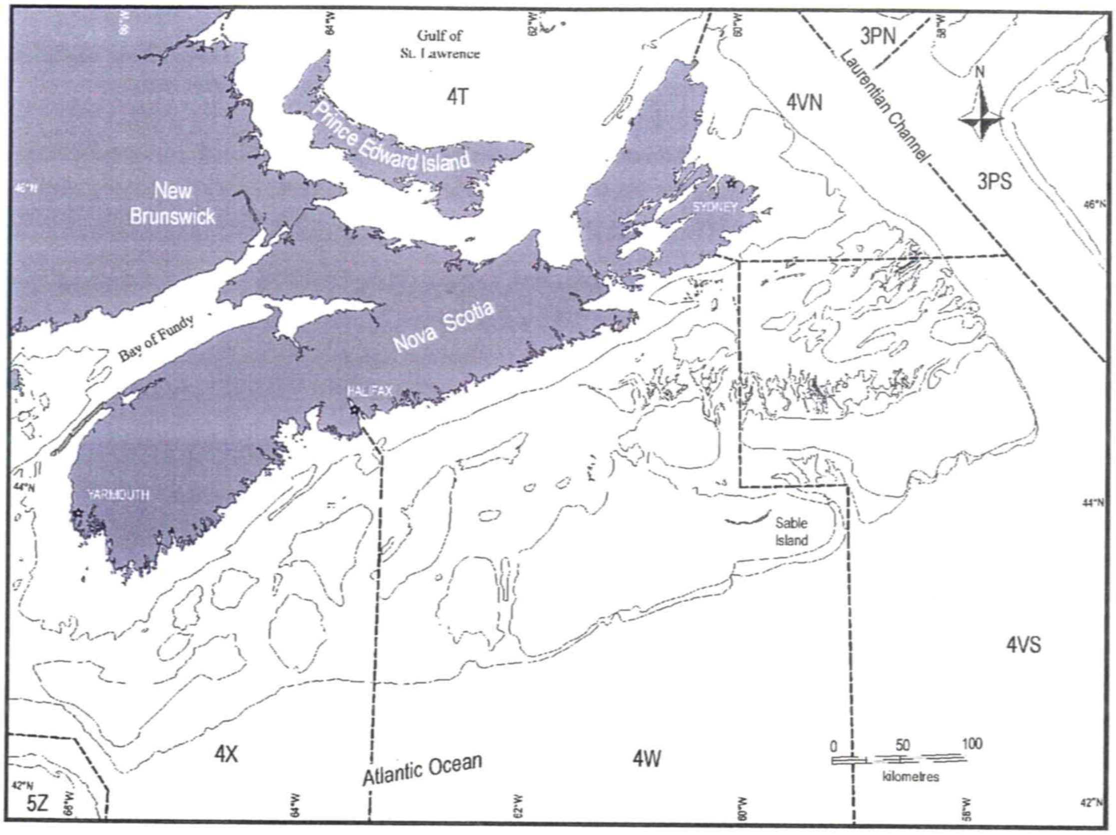


Figure 5-7. NAFO Divisions.

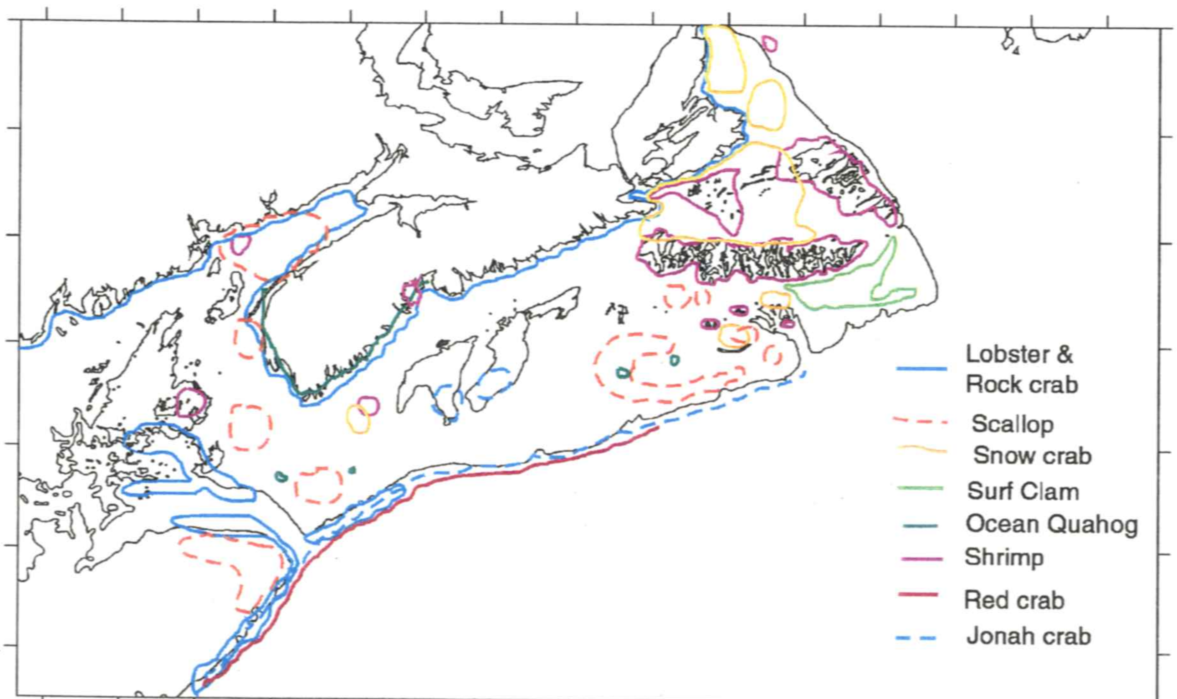


Figure 5-8. Distribution of selected commercial invertebrates on the Scotian Shelf (created by P. Koeller in 1998 as a coarse-scale schematic, used with permission).

With the decline in the groundfish fishery in the late 1980s and early 1990s, new invertebrate fisheries were developed, such as that for Jonah crab, and began to play an increasingly important economic role. Figure 5-8 shows areas known to be important for commercial invertebrates. The population status of some of the species newly part of the commercial harvest is still not clear, nor are aspects of their biology. For example, aspects of the deep-sea red crab's life cycle are still not well known (DFO 1998c).

In this chapter, five of the better known commercial species will be examined in detail: sea scallop, short-finned squid, lobster, northern shrimp, and snow crab. Squid are used as bait and are commercially fished on the Scotian Shelf only when plentiful. They are important food for whales, especially pilot whales, and the population variability of squid has repercussions for the entire ecosystem. For the commercial species that are described here, information from the Marine Fish Division database (both catch and effort data and research survey data) was used to map their distribution. The limitations of that data vary from species to species and are discussed in the individual species descriptions.[5] The areas used for commercial landings do not correspond to precisely the same areas as those from the research survey.

Species Descriptions

*Sea scallop (*Placopecten magellanicus*)*

The sea scallop is a bivalve mollusc; its soft body is enclosed in two shells held together by a hinge. Scallops are found on the Scotian Shelf sea bottom in depths of 35 to 120 metres and in association with sandy-gravel bottoms (DFO 2001). They aggregate in patches. Unlike other bivalves, scallops can swim short distances in response to disturbances (Packer et al. 1999). Undisturbed adult scallops move infrequently and become recessed in the sediment. Scallops are suspension feeders (Packer et al. 1999). In other words, they eat planktonic organisms they filter from the water

This species is found only in the northwest Atlantic and is distributed from Cape Hatteras to Labrador, forming large beds over shallow offshore banks (DFO 2001). More than half of all Canadian scallop landings come from Georges Bank (Jamieson 1981, Thouzeau et al. 1991b); however, for this commercially valuable species, aggregations on other banks are also highly utilized. Scallops are also found in inshore regions (Kenchington et al. 1991), although some inshore areas are closed to harvesting (see Appendix 4 for location of areas with fisheries closures).

Sexes are separate and most scallops are sexually mature by the spring of their third year, at a size of about 75 millimetres (Packer et al. 1999). The major spawning period appears to occur from August to October on the Scotian Shelf (Parsons et al. 1992, DFO 2001). Larvae can be planktonic from August through November (Tremblay and Sinclair 1988). There may be an additional spring spawning period for inshore populations (Kenchington et al. 1991). Fertilized eggs develop into a free swimming larvae (spat) that spend 30 to 40 days as plankton before settling on the bottom.

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[5] The groundfish research surveys are generally not effective in sampling invertebrate species. Of the invertebrates sampled, not all are consistently recorded in the database. A greater effort has been made since 1999 to record more invertebrate taxa, and Day and Tremblay (2000) recently prepared a invertebrate guide for use during standard trawl surveys on the Scotian Shelf.

Larvae tend to settle near or on the same grounds occupied by adults. The reasons for this are still being explored. Currents in those areas and movements of larvae through the water column may encourage larval retention, and the suitability of the habitat in those areas may result in better survivability for larvae that remain in areas with existing beds (Packer et al. 1999, see e.g. Tremblay and Sinclair 1988, Tremblay and Sinclair 1992). Larvae appear to prefer to settle on gravelly sand, often with shell fragments (Packer et al. 1999). Juveniles attach themselves to the bottom by means of byssal threads (Packer et al. 1999). A study on Georges Bank found that age one juveniles were concentrated in a gravel-pebble area on the bank (Thouzeau et al. 1991b). Older individuals were more widely dispersed, with a definite preference for gravel bottoms. A recent study of Browns Bank found scallops in the highest densities on parts of the bank with gravel substrate (Kostylev et al. in press).

Scallops are relatively slow growing animals. At age six, they reach a size between about 90 millimetres (Northumberland Strait and Scotian Shelf) and 120 millimetres (Georges Bank) (Jamieson 1981). Rates of growth are related to water temperature, food availability, depth, latitude, and age (Packer et al. 1999). Individuals up to 20 years of age have been found in areas with low rates of harvesting (Packer et al. 1999).

Fauna associated with scallops on the Scotian Shelf have not been examined in detail; however, there have been extensive studies in nearby areas. In the Bay of Fundy, Caddy (1970) recorded the fauna collected in scallop dredges in the late 1960s. Almost thirty years later, researchers surveyed commercial scallop grounds in the Bay, including Caddy's survey area, and recorded 261 species from the Lower Bay of Fundy (Fuller et al. 1998). The latter study recorded more species than Caddy, perhaps due to more intensive analysis by the researcher, and is considered to be a baseline list for comparison with future studies (Fuller et al. 1998). Further examination of the epibiotic organisms of scallop shells increased the number of associated species to 303 (Magee et al. 2000). Fuller et al. (1998) found different groupings of fauna in each of their three study areas. The distributions of the groupings were related to sediment type. Magee et al. (1999) mapped the distribution of several taxonomic groupings collected by Fuller et al. (1998).

Thouzeau et al. (1991a) examined the megafauna associated with sea scallop grounds on eastern Georges Bank. According to their classification, sea scallops were associated with *Asterias vulgaris* (boreal sea star), *Pagurus pubescens* (hermit crab), and *Hyas coarctatus* (Arctic lyre crab) – all likely predators of the scallops. Species inhabiting or attached to coarse sandy bottom sediments within this grouping included *Spisula solidissima* (Atlantic surf clam), *Cyclocardia borealis (=Venericardia borealis*, northern cardita), *Cerastoderma pinnulatum* (little cockle), *Astarte* spp., and *Strongylocentrotus droebachiensis* (green sea urchin). Other fauna found in the grouping included *Cancer irroratus* (rock crab), *Crossaster papposus* (spiny sunstar), *Pagurus acadianus* (hermit crab), whelks (*Buccinum undatum*, *Colus stimpsoni* and *Neptunea lyrata decemcostata*), and polychaetes (*Nereis zonata, Nephtys caeca, Harmonthoe imbricata*). In the Gulf of Maine, Langton and Uzmann (1989) and Langton and Robinson (1990) have examined fauna associated with scallop grounds.

A Browns Bank study based on the analysis of underwater imagery found that few other species of megafauna were associated with scallop beds; however, the study did not include infauna (Kostylev et al. 2001). Hydroids were commonly attached to scallop shells. Whelks and hermit crabs were also found in the scallop beds. The authors suggested that the megafauna associated with scallops may be changed by scallop dredging.

The red hake, *Urophycis chuss*, is associated with sea scallops in the Bay of Fundy, Scotian Shelf, and Georges Bank and likely other areas (Markle et al. 1982, Steimle et al. 1999). Demersal juvenile *U. chuss* seek refuge in and among scallops during the day, appearing to select scallops larger than themselves to hide in. When juveniles grow too large to hide in scallops, they still remain near the scallop beds for some time (Steimle et al. 1999).

Scallop stocks on Browns Bank are assessed separately from eastern Scotian Shelf scallops (see DFO 1998a and DFO 2001). The fishery is concentrated in the areas shown in Figure 5-9 which shows distribution of commercial catches.[6] Harvesting focuses on areas where scallops are highly concentrated in beds. On Browns Bank, catches declined in the mid-1990s, although biomass showed a slight increase during the same period (DFO 1998a). Landings from Sable Island and Western Banks varied from year to year through the 1990s (DFO 2001). The Middle Grounds fishing area, corresponding to Middle Bank, was closed to scallop fishing in 1997 because of poor stock status (DFO 2001). Thus, although few landings from Middle Bank are shown in Figure 5-9, it has historically had concentrations of scallops. Stock status has not significantly improved since the closure (DFO 2001).

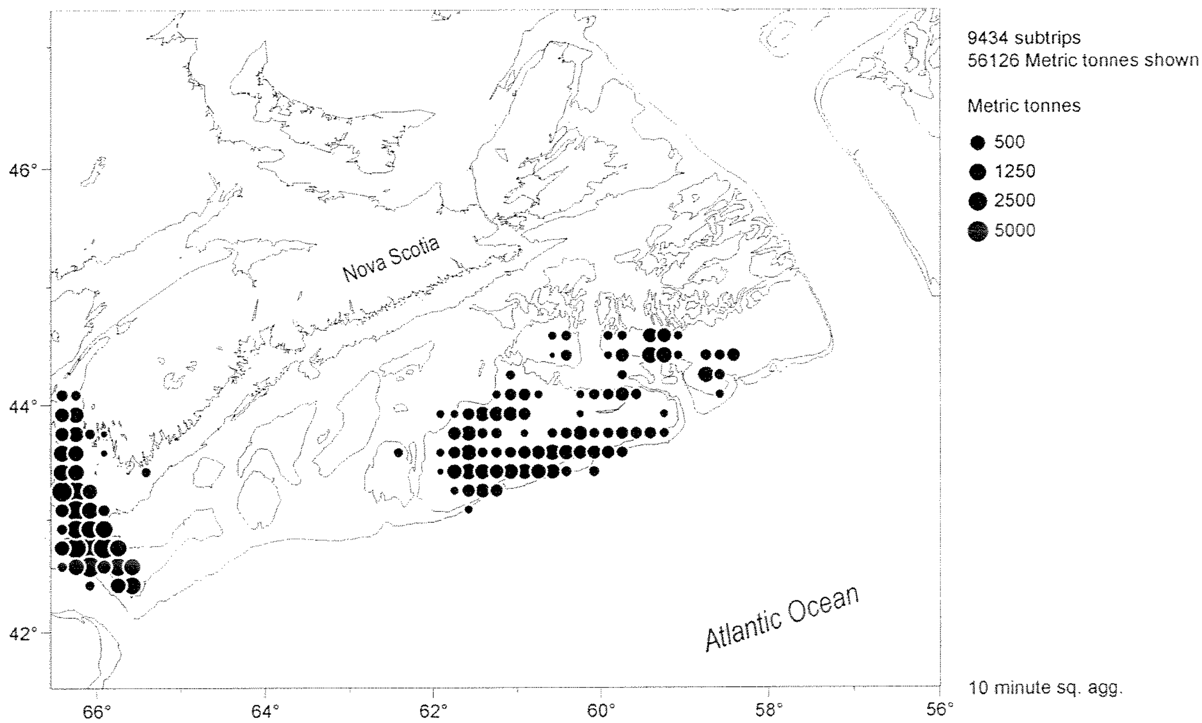

Figure 5-9. Location of scallop catches from commercial fisheries on the Scotian Shelf, 1996-2000, aggregated by 10 minute squares. Map shows landings from NAFO zones 4VWXlmnopqx (does not include Georges Bank and inner Bay of Fundy).

*Short-finned squid (*Illex illecebrosus*)*

Squids are free swimming molluscs that migrate widely over the shelf and through the water column. Their distribution is directly related to water temperature (Dawe and Hendrickson 1998). On the Scotian Shelf, squid are generally found in waters warmer than 6° C. Catches peak

[6] Figure 5-9 and other figures showing data from fisheries landings and groundfish summer research trawl surveys were created using software and data from the Marine Fish and Invertebrate Fisheries Divisions, Maritimes Region, Fisheries and Oceans Canada.

at bottom temperatures of 9 to 13°C and surface temperatures of 13 to 20°C. Earlier life stages tend to be associated with warmer surface temperatures (Dawe and Hendrickson 1998).

Squids are believed to live only one to one and half years. They reach adulthood and spawn only once during their short life span, dying shortly after spawning occurs. Sexes are separate. Short-finned squids have high growth rates and reach a maximum mantle length of about 30 centimetres and a total length of about 60 centimetres. Spawning for all short-finned squid is believed to occur south of Cape Hatteras during the winter (Black et al. 1987, Dawe and Hendrickson 1998). Larvae are carried northward by the Gulf Stream and live in the frontal zone between the Gulf Stream and slope water until they reach about 10 centimetres in length (Black et al. 1987, Dawe and Hendrickson 1998).

Short-finned squid are distributed from Florida to Southern Labrador and fished from Cape Hatteras to Newfoundland (Dawe and Hendrickson 1998). On the Scotian Shelf, they are most common from summer to early autumn (Black et al. 1987, Arkhipkin and Fetisov 2000). In June, they can be found along the edge of the shelf from Emerald to LaHave banks. In some years, they are common over the entire shelf-edge. They spread out over the entire shelf later in the summer before migrating southwestward down the North American east coast to reproduce.

The short-finned squid is a voracious visual feeder of fish, crustaceans, and molluscs, including other squids. They appear to compete with commercial fish species for food, particularly silver hake (Dawe and Hendrickson 1998), and may replace fish in heavily-fished ecosystems (Caddy 1983). Squid are important food for a variety of species, including fish (e.g., silver hake, haddock, cod, pollock, and tuna), marine mammals (e.g., toothed whales and dolphins), and seabirds (e.g., fulmars, gannets, gulls, and shearwaters).

The distributions of squid taken during the summer groundfish survey from 1978 to 1982 and 1996 to 2000 are shown in Figures 5-10 and 5-11. This survey does not target invertebrates; however, as a pelagic species that occurs on the shelf in the summer, squid are likely better sampled than most other invertebrates included in this section. Distribution from commercial landings is shown in Figure 5-12. Squid are most commonly found in the deeper waters of the shelf, in the basins, and along the shelf edge.

Squid populations are highly variable. Their abundance may be closely tied with that of their prey and with competitors (Dawe and Hendrickson 1998). Abundance also appears to be closely tied to shifts in the Gulf Stream and related fronts (Dawe et al. 2000). Hendrickson et al. (2001) characterized the level of short-finned squid biomass since 1970s. A highly productive period occurred between 1976 and 1981. The periods from 1970 to 1975 and from 1982 to 1999 were periods of low productivity. Surveys of NAFO Area 4 in 2000 (including the Scotian Shelf) gave indications that biomass abundance was at its lowest level since 1970.

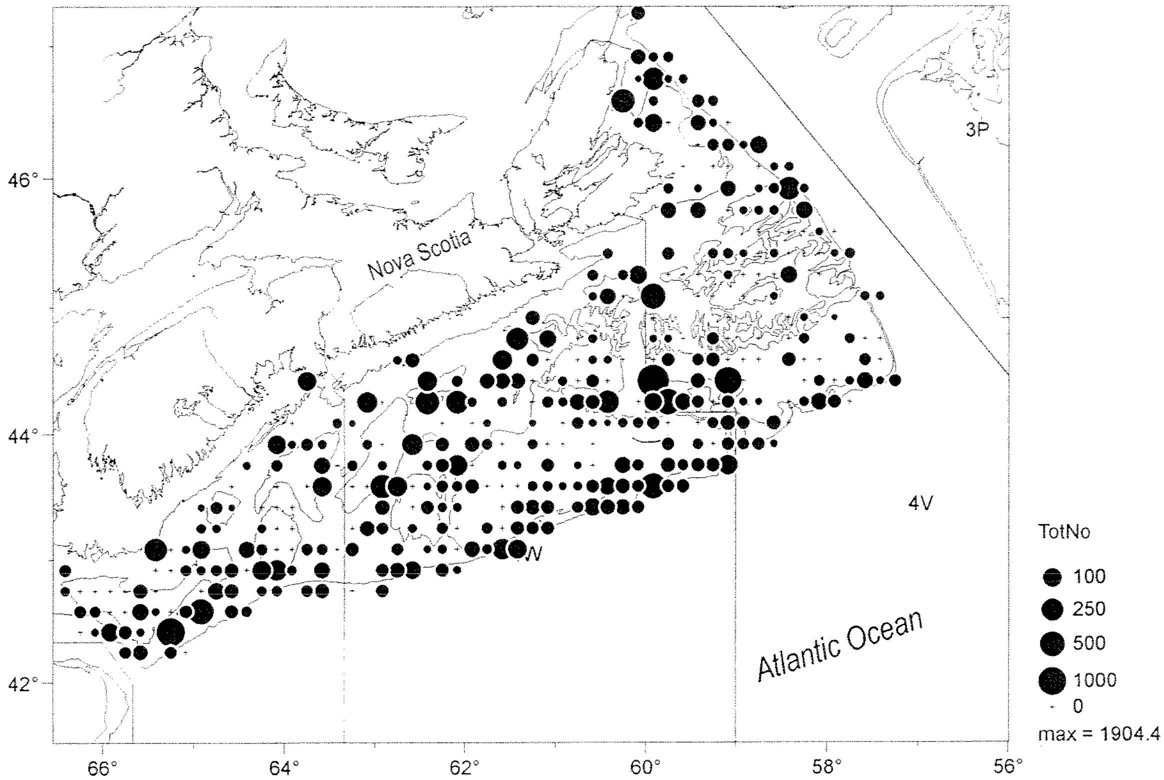

Figure 5-10. Location of short-finned squid caught during the summer stratified random groundfish survey, 1978-1982 (609 sets aggregated by 10 minute squares).

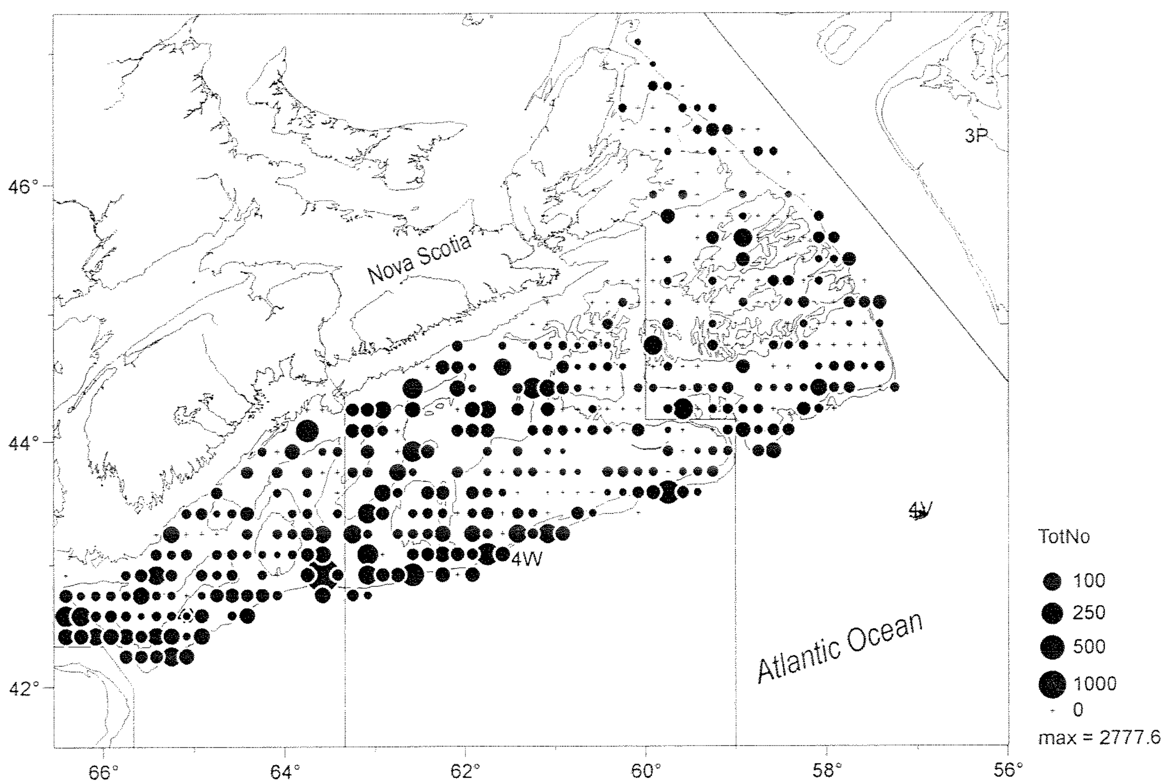

Figure 5-11. Location of short-finned squid caught during the summer stratified random groundfish survey, 1996-2000 (851 sets aggregated by 10 minute squares).

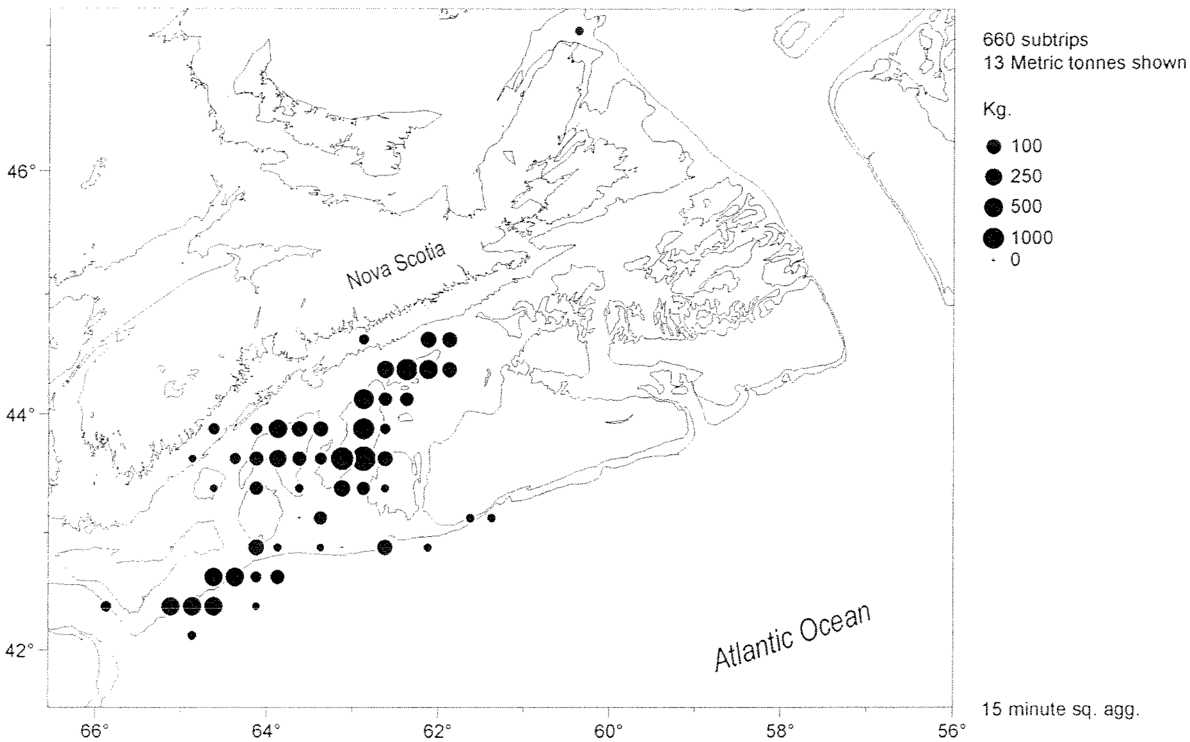

Figure 5-12. Location of short-finned squid catches from commercial fisheries, 1996-2000, aggregated by 10 minute squares.

Northern shrimp (Pandalus borealis)

The northern or pink shrimp is distributed from Greenland south to Martha's Vineyard in the northwest Atlantic and is also found in the northeast Atlantic (Squires 1990). They are more commonly found in specific habitats within that range. They prefer water temperatures of 2 to 6°C and areas with soft, muddy bottoms (DFO 2000b). They are found in depths of 10 to 500 metres (Parsons and Fréchette 1989).

These shrimp are protandrous hermaphrodites; that is, they function as males for the first part of their lives, then change sex to function as females (Squires 1990). On the Scotian Shelf, shrimp become sexually mature as males at age three. They change sex at age four and spend the next year or two as females (DFO 2000b). The rate of growth, years spent as males or females, and age that sex change occurs is at least somewhat related to temperature. Females occur earlier at warmer temperatures (Apollonio et al. 1986, Squires 1990). Females bear eggs in the late summer or early fall and carry them attached to their abdomens until the spring, when they hatch (DFO 2000b).

In the Gulf of Maine, juvenile shrimp stay in coastal waters for a year before migrating offshore. Females move inshore in late autumn before eggs hatch (Idoine 2001). This pattern appears to be similar on the western Scotian Shelf, with egg-bearing females concentrated inshore in Mahone Bay during winter and dispersed offshore in cool waters during the spring and summer (Koeller 2000). Breeding appears to occur both inshore and offshore on the eastern Scotian Shelf, with high densities of females and juveniles in both areas during the summer (Koeller 2000). There appear to be no large-scale inshore-offshore migrations on the eastern Scotian Shelf, perhaps due to the relatively stable temperature regime (Koeller 2000). Large females are known to concentrate in nearshore areas (Koeller et al. 1999).

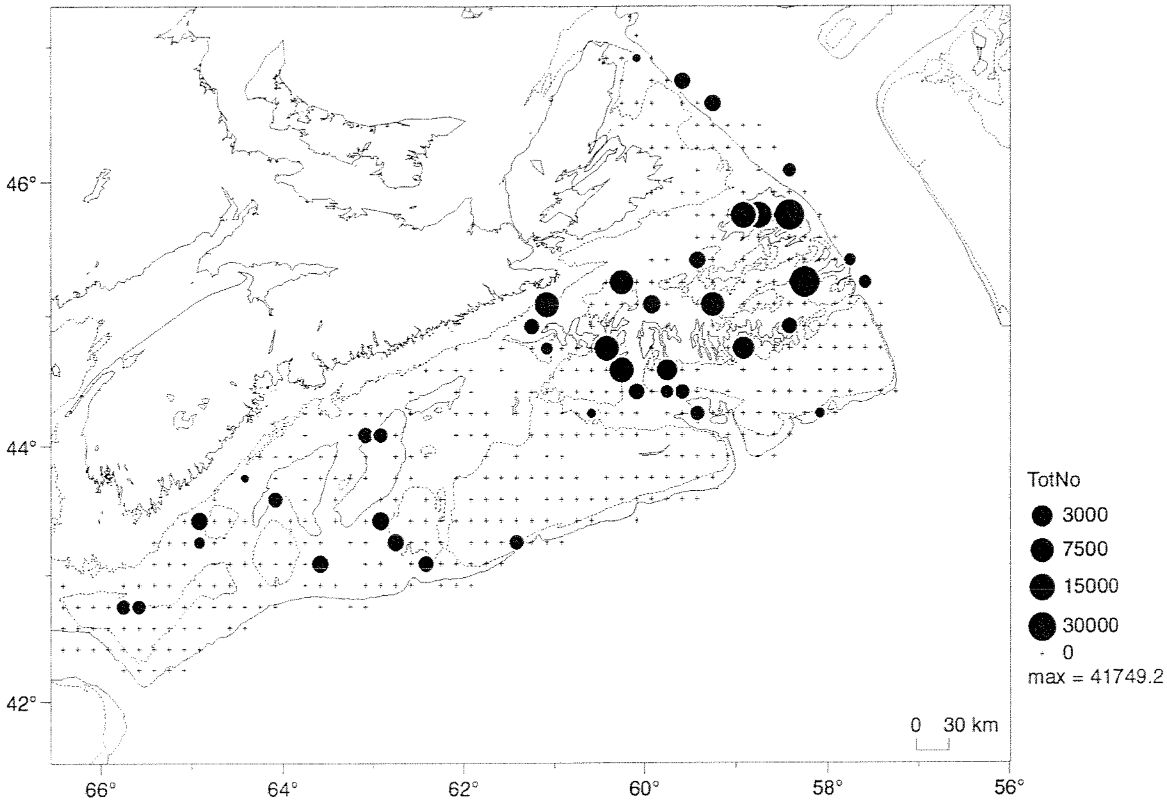

Figure 5-13. Location of northern shrimp caught during the summer stratified random groundfish survey, 1996-2000 (851 sets aggregated by 10 minute squares).

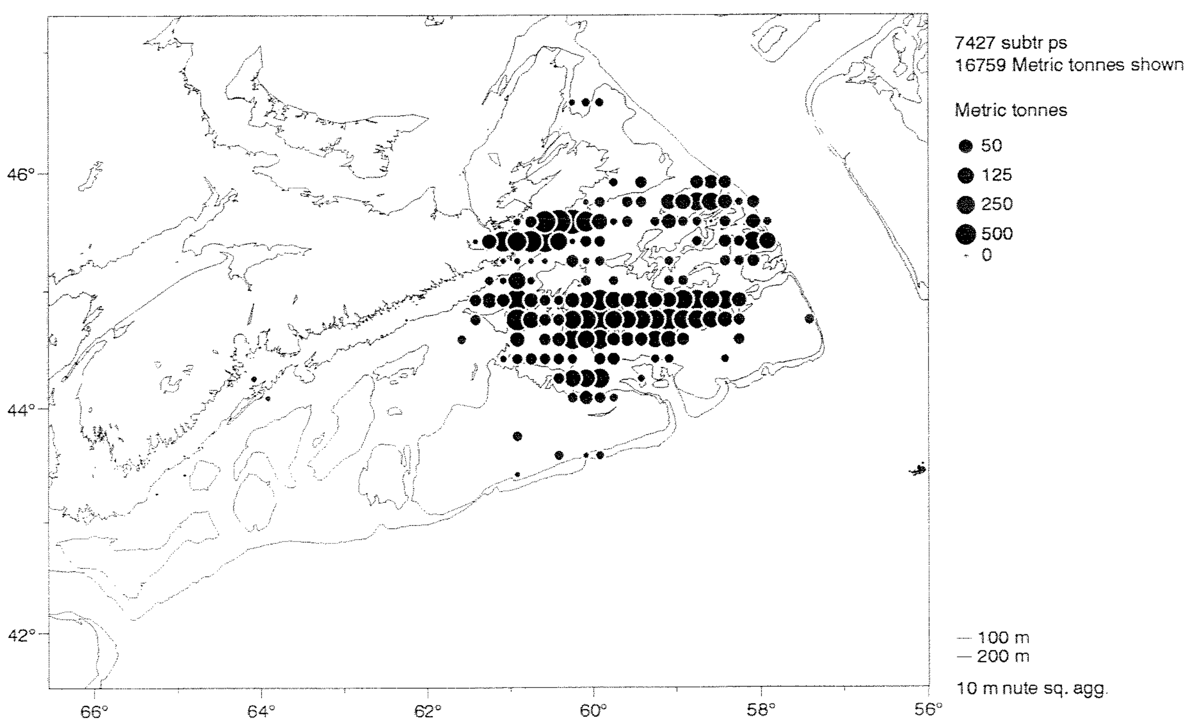

Figure 5-14. Location of shrimp catches (species not distinguished) from commercial fisheries, 1996-2000, aggregated by 10 minute squares.

Shrimp remain near the ocean bottom during the day, feeding on polycheate worms, detritus, and small crustaceans (Squires 1990). At night they rise through the water column to feed on small crustaceans such as copepods, amphipods, and euphausiids (Squires 1990). Many groundfish feed on shrimp, including cod, silver hake, Greenland halibut and other flatfish species, and redfish (Koeller 2000). Harp seals are known to feed on shrimp off Newfoundland (see e.g., Lawson and Hobson 2000) and other marine mammals may also prey on them.

Northern shrimp are concentrated in relatively small patches of habitat on the Scotian Shelf. They are found in the deep holes of the eastern Scotian Shelf near Misaine Bank (Louisbourg, Canso and Misaine Holes); in "the Noodles", an inshore area between Misaine Bank and Cape Breton; and in cool waters of bays along the Atlantic coast (Figures 5-13 and 5-14). There are small areas with low concentrations near Roseway Basin and in the Northeast Channel (Koeller 2000). They are associated with the soft muddy bottoms of the "Lahave Clay" surficial sediment (Koeller 2000). Recently, trap fisheries have developed in Chedabucto Bay and in Mahone Bay (DFO 2000b). There was a fishery in Roseway Basin in the early 1970s; however, catch rates declined quickly and the fishery was short-lived. Commercial concentrations of shrimp have not been found in that area since (Koeller 2000). Figures 5-13 and 5-14 show distributions of shrimp on the Scotian Shelf from recent summer groundfish trawl surveys and from commercial landings.[7]

*American lobster (*Homarus americanus*)*

This distinctive, wide-spread, and long-lived crustacean is one of the most commercially valuable species of the Scotian Shelf. Lobsters are commonly found between the low tide mark and depths of about 400 metres on the Scotian Shelf and can occur in depths of up to 750 metres (Pezzack et al. 1999). They are most common in shallow waters of 4 to 50 metres. During winter, lobster appear to migrate to deeper, warmer waters, moving back to shallow areas in spring (DFO 2000a). A tagging study by Pezzack and Duggan (1986) in southwest Nova Scotia showed that these migrations can be quite extensive, with some individual lobsters travelling more than 200 kilometres before returning to the area where originally tagged. In other areas, such as coastal Cape Breton, annual migrations of most lobster have been found to be limited to a few kilometres (Tremblay et al. 1998).

Lobsters grow through a series of molts that are relatively frequent prior to reaching sexual maturity, molting several times a year in the first few years. Molting then decreases to once or twice a year and even less frequently as they grow larger (Waddy et al. 1995). Lobsters found off Nova Scotia reach commercial size at about age six to nine years (DFO 1998b). Even when they have reached commercial size, individuals may not have yet reached sexual maturity (see DFO 1998b). A giant lobster caught off Nova Scotia in 1977 weighed more than 40 pounds and may have been 100 years old (Gulf of Maine Aquarium 2001). Most lobster are caught well before they reach that age or size.

Lobster mate in mid-summer, after the female lobster molt. The females produce eggs the following summer and carry them, attached to the underside of the tail, for 10 to 12 months (Pezzack et al. 1999). Females do not molt during this period. Eggs usually hatch in July and August. The planktonic larvae feed for one or two months near the surface before settling to the bottom, where they seek shelter under rocks or in burrows that they dig (Ennis 1995, DFO 2000a). These post-larvae prefer to settle on cobble bottoms and bottoms with algal cover.

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[7] Summer research trawl surveys from the earlier period, 1978 to 1982, did not regularly record shrimp and there are few records from that period.

Larvae may delay settlement if suitable substrate is not available (Ennis 1995). Juvenile lobster seek out shelter on cobble and boulder bottoms and will use other substrates that provide shelter, such as mussel beds (Lawton and Lavalli 1995). Adults are found living freely over a variety of substrates. They use spaces under boulders and in crevices for shelter, as well as shallow depressions that they dig, although the need for shelter is not as important for adults as for juveniles (Lawton and Lavalli 1995).

Larval and newly settled young lobster are prey for many species. Cod, sculpin, eelpout, and skates will attack juvenile lobster if they leave their shelters. Larval and post-larval lobster feed on a variety of planktonic organisms, including diatoms, copepods, and the larvae of other benthic crustaceans (Ennis 1995). Post-settlement juvenile lobster feed on sea urchins, brittle stars, mollusks, other decapod crustaceans, polychaetes, and many other species, based on availability (Lawton and Lavalli 1995). Newly settled postlarvae are more vulnerable to predators than adult lobsters and likely feed within their shelters, eating planktonic organisms carried by currents or using their tails to move water through their living space to bring in more prey (Lawton and Lavalli 1995, Gulf of Maine Aquarium 2001). As adults, lobster feed opportunistically on a variety of molluscs, crustaceans (especially crabs), small fish, sea urchins, marine plants, and marine worms (Scarratt 1979, Squires 1990).

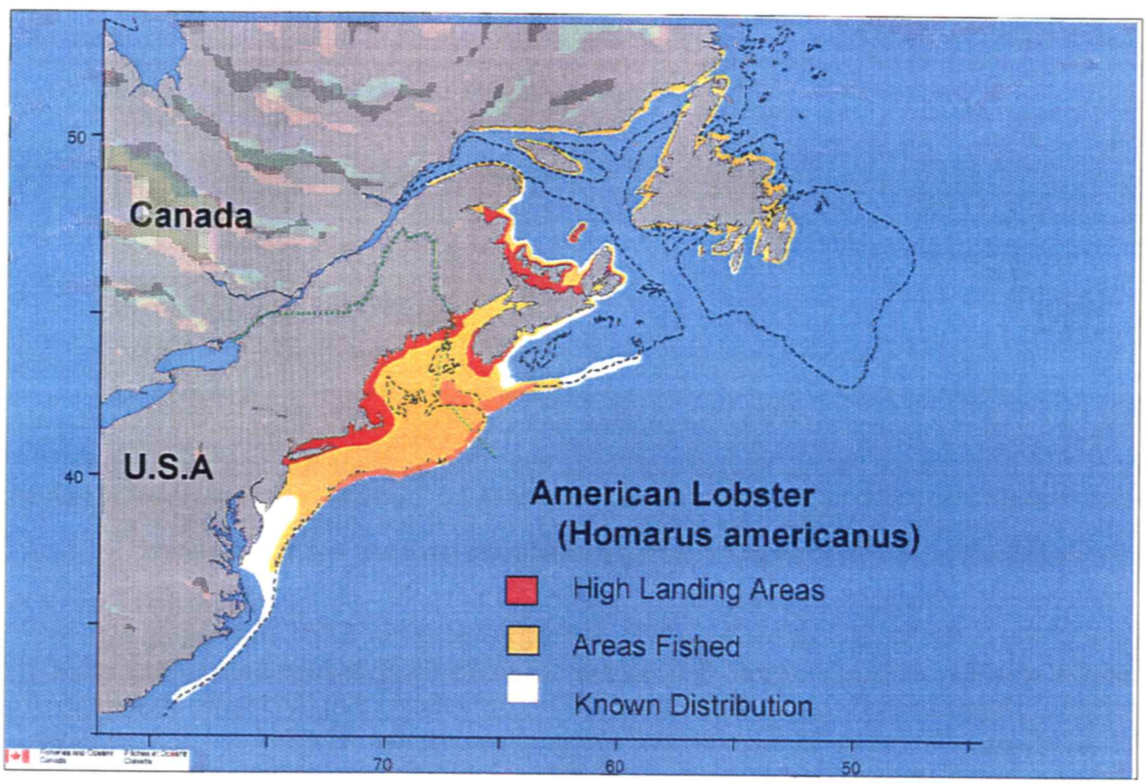

Figure 5-15. Areas fished and known distribution of American lobster (prepared by D.S. Pezzack, Maritimes Region, DFO).

Lobsters are distributed from Cape Hatteras to Labrador (Figure 5-15). The commercial fishery is concentrated in the Gulf of Maine, Bay of Fundy, Scotian Shelf, and Gulf of St. Lawrence. On the Scotian Shelf, lobster are found mostly in inshore coastal regions, although they can also be found in the offshore from Sable Island to the Gulf of Maine. There is a large offshore aggregation on

Browns Bank and an offshore fishery takes place on the shelf edge south of the Bank (see Figure 5-16). It has been suggested that the Browns Bank lobster is an important source of recruitment for populations in southwestern Nova Scotia and the Gulf of Maine (Harding and Trites 1988). Browns Bank has been closed to lobster fishing since 1979 to protect what was believed to be an important spawning area (Pezzack et al. 1999) (see Appendix 4 for areas with fishing restrictions). Fishing has continued adjacent to this area and there is no evidence that the expanded offshore fishery has affected landings in nearby coastal and midshore lobster fishing areas (DFO 2000a). Most catches come from inshore regions and coastal southwestern Nova Scotia is a particularly rich lobster fishery.

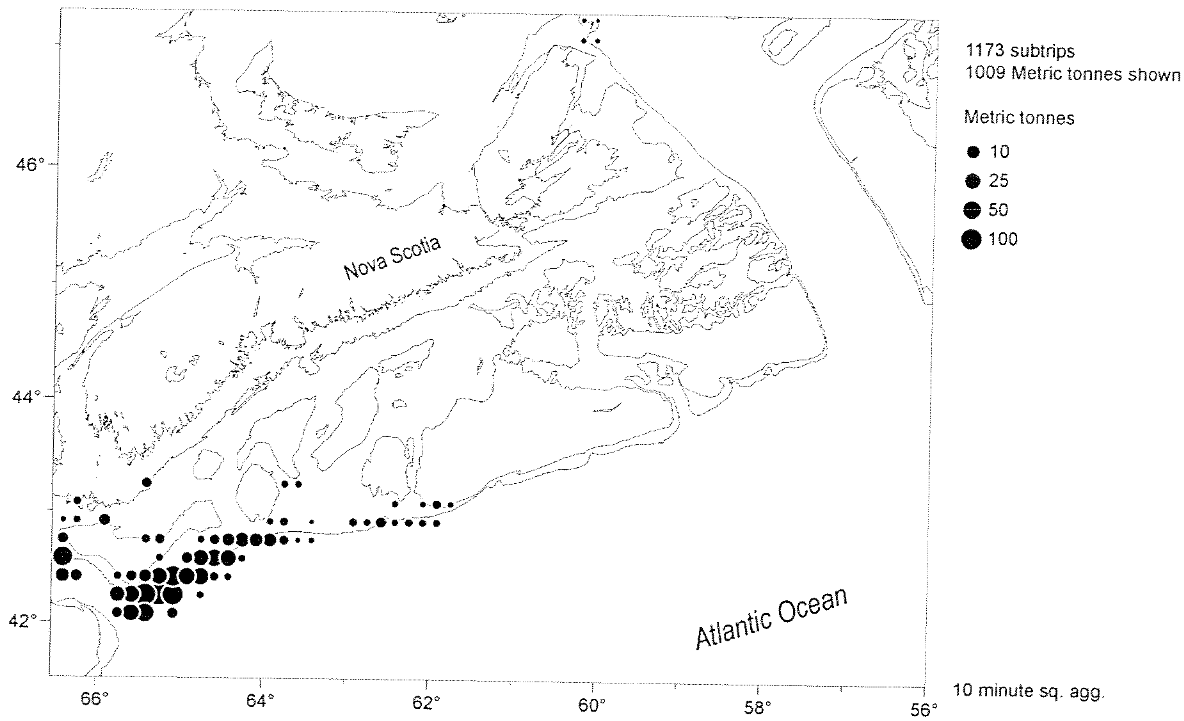

Figure 5-16. Location of lobster catches from offshore areas, 1996-2000, aggregated by 10 minute squares. Map shows landings from NAFO zones 4VWXlmnopqx. Because of the aggregation, catches appear to be from the closed area. These were likely taken from adjacent areas which were just outside the closed area. Locations of catches from nearshore areas are not aggregated in the same way and are not shown.

Lobster landings in the Maritimes increased dramatically during the 1980s and remain high in the Gulf of Maine-Bay of Fundy region. This increase is related both to increased fishing effort and increased abundance of lobster. Drinkwater et al. (1996) found that the higher abundance was not caused by a change in the Scotian Shelf temperature regime. The authors proposed two alternate hypotheses: improved survival of larval lobster due to reduced predation by groundfish or improved ecological conditions for lobster caused by a widespread change in wind patterns. Reasons for increased abundance remain unclear (DFO 2000a). Fisheries managers are considering expanding the offshore fishery east of 63°W to NAFO subarea 4W (DFO 2000a). Lobster have regularly been caught in offshore portions of 4W during groundfish research surveys although they are not well-sampled by this survey.

Snow crab (Chionoecetes opilio)

Snow crab, also known as queen crab, is a member of the spider crab family of crustaceans. The crabs are found on the ocean bottom in cool waters of the Scotian Shelf, mainly in temperatures between 0.5 and 4.5°C and depths between 20 and 310 metres (DFO 1999, Squires 1990). Most snow crabs are found in depths between 70 and 280 metres (Elner 1985). Snow crabs prefer muddy or sandy-mud soft bottom habitats (DFO 1999).

Snow crab have developmental stages similar to lobster. Females carry their eggs for about two years before eggs hatch in late spring and early summer. Larvae are planktonic for a period of about 12 to 15 weeks before settling to the bottom, where they remain. It takes 8 to 9 years to reach commercial size (DFO 1999). Unlike lobster, snow crabs do not continue to molt throughout their lives. Females stop molting before reaching 95 millimetres and males stop growing by the time they acquire large claws on the first pair of legs, at a size of 40 to 165 millimetres (DFO 1999). Only snow crab larger than 95 millimetres are harvested in the commercial fishery. Thus, only male crabs are taken in this fishery (DFO 1999).

The crabs appear to eat a wide variety of organisms. Prey found in the stomachs of small snow crabs included phytobenthos, foraminifers, crustacean fragments (shrimps, crabs, amphipods, copepods, isopods, cumaceans, and ostracods), bivalves, brittle stars, polychaetes, gastropods, chitons and hydroids (Squires 1965). Snow crabs are prey for groundfish.

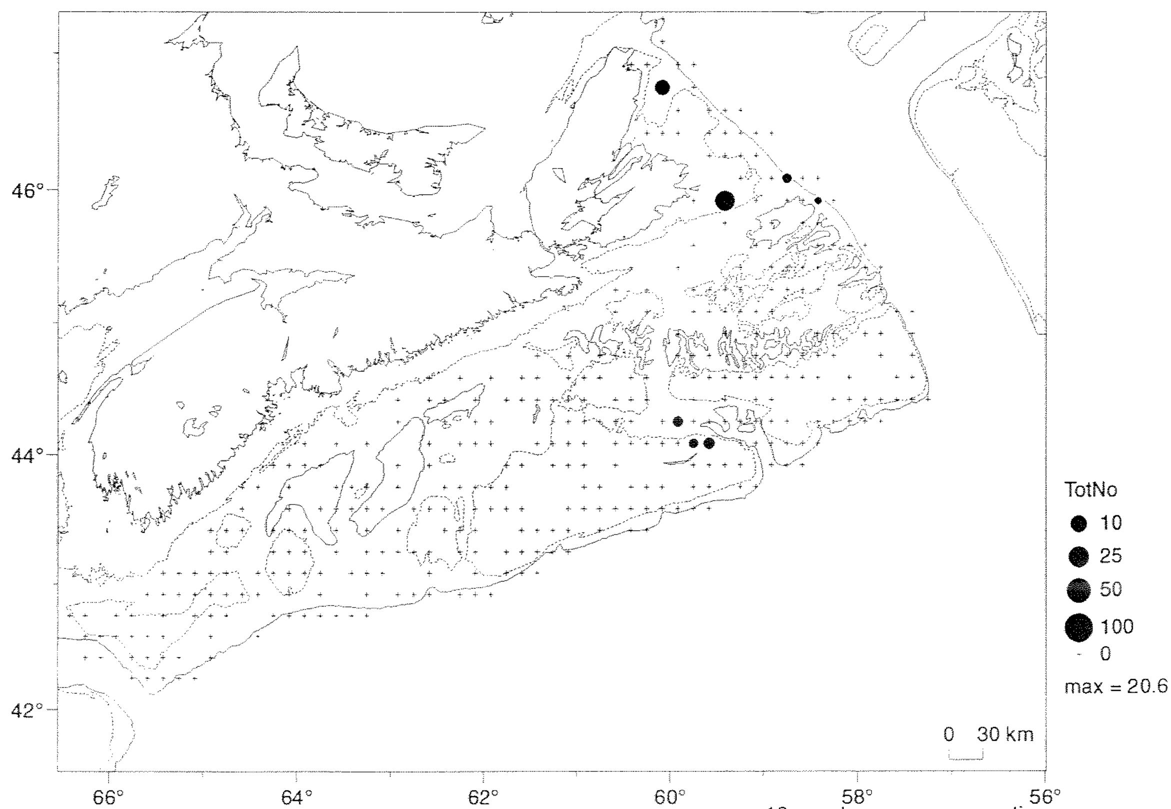

Figure 5-17. Location of snow crab caught during the summer stratified random groundfish survey, 1980-1984 (607 sets aggregated by 10 minute squares). Snow crabs were first enumerated in trawl surveys in 1980 (Tremblay 1997) and for that reason the 1978-1982 period is not used.

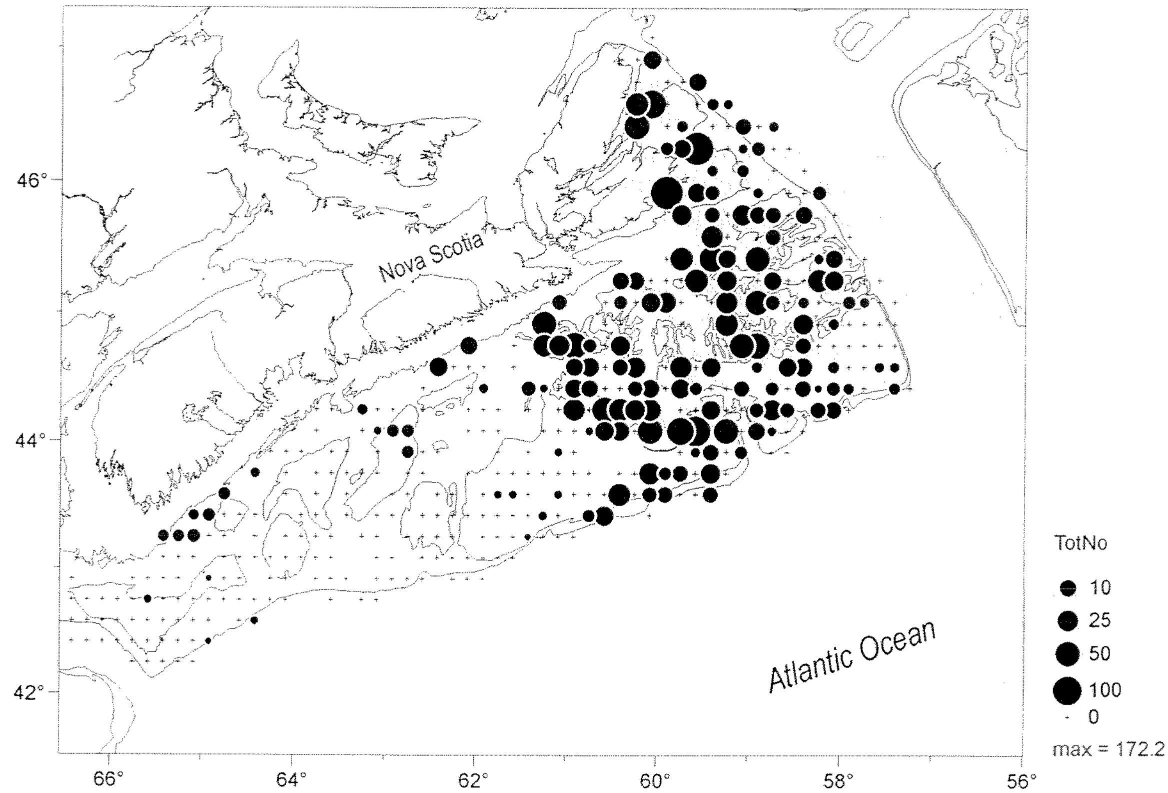

Figure 5-18. Location of snow crab caught during the summer stratified random groundfish survey, 1996-2000 (851 sets aggregated by 10 minute squares).

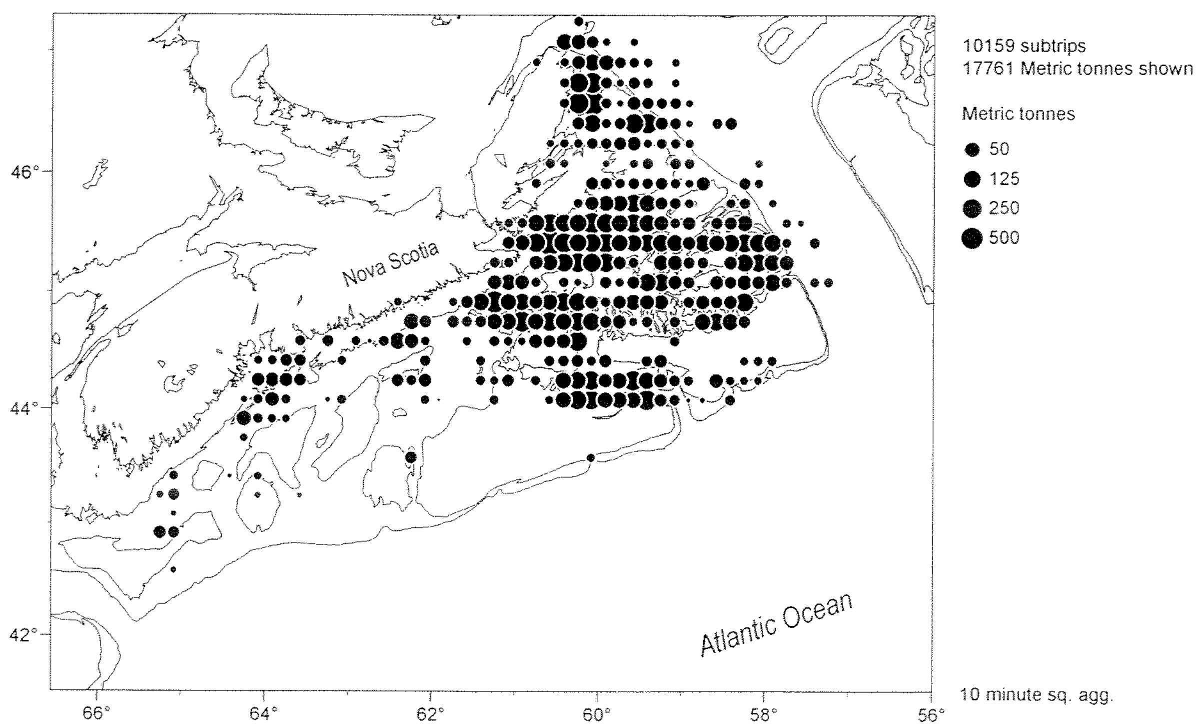

Figure 5-19. Location of snow crab catches from commercial fisheries, 1996-2000, aggregated by 10-minute squares. Map shows landings from NAFO zones 4VWXlmnopqx.

The eastern Scotian Shelf has the most southerly commercial concentration of the species (DFO 1999). Maps from the summer research survey and from landings data show that their Scotian Shelf distribution is centred on the eastern shelf, an area with cool bottom water temperatures (Figures 5-17, 5-18 and 5-19). The early 1980s was a period of low snow crab abundance on the Scotian Shelf as compared to the late 1990s.

The snow crab fishery collapsed in the mid-1980s due to reduced stocks (Tremblay 1997). Populations began to recover in the late 1980s and commercial landings peaked in 1993 (DFO 1999). The fishery and snow crab populations have been stable in the late 1990s (DFO 1999). Until recently, population status was based on the fishery. The first research trawl survey directed at crab was carried out in 1997. However, the trawl was unable to sample the rugged deep water areas between the small banks where many crab are concentrated (DFO 1999). Another survey was carried out in 1998. They showed concentrations of crab outside well-known fishing areas (DFO 1999) (see Figure 5-19 for areas of catches from commercial fisheries). Tremblay (1997) suggests that lower bottom temperatures on the Scotian Shelf may have contributed to the increased abundance of snow crab in the late 1980s and early 1990s. A decline in the populations of snow crab predators, groundfish, could also have contributed to the increasing numbers of crab. Because the Scotian Shelf represents the southern limit of the species, changes in water temperature and other aspects of the physical environment have an especially important influence on population status (Tremblay 1997).

Important Areas

From the data available, it is difficult to pinpoint important areas for invertebrate species, although they undoubtedly exist. Many invertebrate species have specialized temperature and substrate requirements, and roam little, if at all. Pelagic species, such as squid and shrimp, range farther but also have specific habitat requirements. Northern shrimp, for example, are regularly found in the cool waters of the deep holes around Misaine Bank. More research on species distributions and benthic communities on the shelf needs to be carried out before particular areas of importance to invertebrates can be selected.

There are many areas of potential importance on the Scotian Shelf. Important areas could include areas where large molluscs of breeding age are highly concentrated (brood stock areas), areas where juvenile invertebrates are concentrated, and areas where species with limited distribution are found. Some invertebrates form structures on or within the sea floor which provide habitat for other species. The importance of habitat provided by invertebrates, such as the structure provided by corals and sponges, is not well understood. Areas of high diversity, both biological diversity and habitat diversity, may be important for invertebrate populations and the functioning of the ecosystem as a whole.

Submarine canyons, which have diverse habitats within a fairly small area, may be important areas for benthic invertebrates. Canyons studied in other parts of the world appear to support distinct species assemblages or higher faunal biomass than adjacent areas (see e.g., Gage et al. 1995, Vetter and Dayton 1998). These canyons may also be areas of enhanced upwelling and thus, enhanced productivity. At a workshop to identify priority areas for protection in American Atlantic waters, submarine canyons were selected by scientists as a high priority for protection (NRDC 2001). Valentine et al. (1980) observed that a canyon on the margin of Georges Bank had been less used by the fishing industry than the adjacent Bank. Thus, it may represent a relatively unaltered marine ecosystem. The Scotian Shelf is indented by several submarine canyons and little is known about nearly all of them. The sole exception, The Gully, is an "Area of Interest" for DFO's marine protected areas program. Most records of gorgonian corals in Nova Scotia waters have been from these canyons as well as channels between large banks (Breeze et al. 1997, MacIsaac et al. 2000).

Channels between the banks may also be important for particular species or species groupings. The enhanced current flow in the channels may support large populations of filter feeders, if other environmental conditions are appropriate. For example, locations within the Northeast Channel have high numbers of soft corals, anemones, and brittle stars.

The early life stages of many invertebrates species are not well known, although a study was recently published that compared the mechanisms by which the early life stages of benthic invertebrates are transported with the mechanisms that transport larval groundfishes (Bradbury and Snelgrove 2001). Planktonic stages of benthic and pelagic invertebrates are food for many other animals and knowledge of their distribution during these stages of the life cycle is important to understanding the ecosystem as a whole.

Future directions

Descriptive studies of the benthic communities of the Scotian Shelf will provide new knowledge of ecosystem functioning and will help to identify important areas. Both re-analysis of existing data and collection of new information will be necessary to better understand bottom communities. For example, further examination of the database compiled by Stewart et al. (2001) will likely provide new information on the benthic communities of the Scotian Shelf. Re-examining and analyzing some of the studies that identified specimens to the species level may provide new insights on bottom communities. Other datasets on the marine benthos of the Scotian Shelf may also provide fodder for new analyses. The Nova Scotia Museum collected materials on at least two research trips in the early 1970s (Davis and Gilhen 1973, Davis 1976), the Geological Survey Canada may have further data (see e.g., Arenicola Marine 1995), the Atlantic Reference Centre has specimens from deep waters off the Scotian slope that have yet to be examined and there may be collections at other museums, such as the Canadian Museum of Nature, that can contribute to new analyses (Davis pers. communication).

Examination of the bycatch from research trawl surveys will provide new information on invertebrate distribution. However, dedicated invertebrate surveys would be the best way to collect information on invertebrate assemblages on the shelf. Such surveys were carried out on the slope of Georges Bank (U.S. side) when it seemed that oil and gas development could occur there (see e.g., Hecker et al. 1980). The fauna of this area was observed in situ, which provided an opportunity to view the organisms of the bottom and the sediments with which they are associated. Similar surveys should be carried out on the Scotian Shelf in order to examine the state of the ecosystem before further petroleum development occurs. At a minimum, these surveys could be carried out in areas adjacent to directly impacted sites.

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6 FISH[1]

Introduction

The *Atlantic Fishes of Canada* (Scott and Scott 1988) lists 538 fish species known to occur in the Canadian Atlantic Ocean and provides detailed descriptions of their life histories and distribution. The fish fauna found off Nova Scotia includes species at the northern and southern limits of their range, as well as visitors with tropical and Arctic ranges. Fish from four classes occur in the Canadian Atlantic: the class Myxini that includes hagfishes; the class Cephalaspidomorphi that includes lampreys; the class Chondrichthyes (cartilaginous fishes) that includes sharks and skates; and the class Actinopterygii (ray-finned fishes) that includes most common species such as herring, cod, and halibut. The ray-finned fishes are the most diverse group, with almost 500 species described in the Canadian Atlantic. Only one hagfish and one lamprey species have been captured in Atlantic Canadian waters while about 39 species of cartilaginous fishes are known to occur here.

Many of the fish listed in the *Atlantic Fishes of Canada* are rare species or strays from their usual ranges; however, many other species have been collected and identified since that listing was first compiled (Scott and Scott 1988, see e.g. Themelis 1996). Other new species could still be found in the deep waters of the slope and the abyssal plain. Less is known about the fish of the deep waters of the slope than those of the continental shelf and less is known about species not fished commercially than those of commercial importance.

Fish are by far the best monitored group of organisms of the Scotian Shelf. DFO has carried out surveys aimed at assessing the spatial and temporal variability and structure of groundfish populations found off eastern Canada since the 1950s. Survey methods were standardized in 1970. The consistently sampled summer period has the best information on spatial distribution of fish during a particular time of year. Not all species are equally catchable by otter trawl and information for some species is more reliable than for others. A vast amount of data is available on commercial fish species, since stock assessments of these species are regularly conducted for the purpose of fisheries management. About thirty marine and diadromous fish species are examined at least once every three or four years. Some species, for example cod and haddock, are examined on an annual basis. Assessments are carried out by geographic region as well as by stock for separate stocks of the same species (for example, separate assessments are carried out for cod on the eastern Scotian Shelf and cod on the southern Scotian Shelf and Bay of Fundy).

Because most research on fish has been directed towards fisheries management, it has resulted in a great deal of information about particular species. However, there is relatively less information about Scotian Shelf fish diversity, distribution, and assemblages as a whole. This chapter will provide a brief overview of the characteristics and general distribution of the fish of the Scotian Shelf before focusing on fifteen species in detail (Table 6-1). For those species, it will provide an overview of their life histories and spatial distribution on the Scotian Shelf. The fifteen species were selected on the basis of available information, current and historical importance to humans, and to illustrate some diversity in life cycles. Many of these species are commercially fished because they are abundant. This abundance means they are also important species ecologically. Nine groundfish species, three small and two large pelagic species, and one anadromous species

[1] The authors would like to thank Kenneth Frank, Jeff Hutchings, and Nancy Shackell for their comments on earlier versions of this chapter, and Peter Amiro, François Grégoire, Julie Porter, and Rob Stephenson for their comments on portions of the chapter.

will be examined. These species include two forage species – herring and sand lance – vital for commercial fish species, seabirds, and marine mammals. Herring is fished commercially as well as being important prey for other animals.

Characteristics and General Distribution

Fish have patterns of distribution linked to environmental factors, such as water temperature and salinity, bottom type, and availability of food. These patterns of distribution are often different at different life stages. For example, haddock have eggs and larvae that stay near the surface, while juvenile and adult haddock live near the ocean bottom. Certain species may be commonly found in coastal areas as juveniles but less commonly as adults, or may move seasonally from summer to winter habitats. Many species have preferred spawning grounds. By documenting where particular species have commonly been found, scientists have gained some understanding of preferred conditions for that species and other species that are likely to be associated with it.

Table 6-1. Fish Species Examined in Detail

Common name	Scientific name
Demersal fish	
Smooth skate	*Malacoraja senta*
Atlantic cod	*Gadus morhua*
Haddock	*Melanogrammus aeglefinus*
Pollock	*Pollachius virens*
Silver hake	*Merluccius bilinearis*
Redfishes	*Sebastes sp.*
Sand lances	*Ammodytes sp.*
American plaice	*Hippoglossoides platessoides*
Atlantic Halibut	*Hippoglossus hippoglossus*
Pelagic fish	
Atlantic herring	*Clupea harengus*
Capelin	*Mallotus villosus*
Atlantic mackerel	*Scomber scombrus*
Bluefin tuna	*Thunnus thynnus*
Swordfish	*Xiphias gladius*
Anadromous fish	
Atlantic salmon	*Salmo salar*

Fish of the Scotian Shelf can be grouped in three large classifications: demersal fishes that spend much of their life near the ocean bottom, pelagic fishes that live in the water column and at the surface, and diadromous fish that spend part of their lives in freshwater and part in salt or brackish water. Some generally freshwater species, such as brook trout, may spend time in coastal estuaries at particular times of the year. Within the pelagic species there are further subdivisions – mesopelagic fishes live in the water column between the euphotic zone and depths of about 1000 metres and bathypelagic fish live in the water column from 1000 metres to about 4000 metres in depth, still above the ocean bottom. Epipelagic fish are found in the open ocean but only near the surface, in about the first 100 metres of the water column. The epi-, meso-, and bathypelagic fishes are found along the slope of the continental shelf and open ocean areas of Canada's 200 nautical mile exclusive economic zone.

Demersal fish

Demersal fish or groundfish live near the bottom for much of their adult life but often have eggs and larvae that float near the surface or suspended in the water column.[2] Copepods and other zooplankton are an important part of larval fish diets. At some point, the fish larvae settle to the ocean floor where they develop into adults. Some juvenile fish move into coastal areas to feed on small crustaceans and, as they grow larger, other small fishes. Others settle on offshore banks.

[2] There are a few exceptions: the eggs of winter flounder, for example, are demersal and adhere to one another on the bottom. Details on the position of fish eggs in the water column can be found in Appendix 3.

Bottom-dwelling fish have a range of adult forms. For example, the shape and colouring of flatfishes allows them to lie flat on the seabed in almost complete camouflage, where they graze on benthic invertebrates. Pollock has more pelagic habits than the rest of its family, the cods. It has a streamlined shape and moves frequently through the water column in pursuit of its main prey: other fish, shrimp, and squid.

Pelagic fish

Scotian Shelf pelagic fishes include many highly migratory species that winter in southern latitudes and migrate up the Atlantic coast in spring and early summer as the waters warm. The smaller fish travel in schools and schools of herring and capelin attract feeding seabirds and whales. Small pelagic species are streamlined swimmers that depend on their speed and numbers to escape predators. Large pelagic species such as tuna and swordfish do not spawn on the Scotian Shelf, instead reproducing in warmer southern waters. Several of the smaller schooling species, such as capelin, herring, and menhaden, spawn in the temperate waters of the northwest Atlantic. The seasonal movements and reproduction of meso- and bathypelagic fish are less well-known.

Diadromous fish

Diadromous species found on the Scotian Shelf include the anadromous species of Atlantic salmon, gaspereau, sea lamprey, striped bass, Atlantic sturgeon, and American shad. Anadromous species are born in fresh water and migrate down rivers to the sea, returning to freshwater to spawn. The only catadromous species found regularly on the Scotian Shelf is the American eel that spawns in the Sargasso Sea near Bermuda. Young eels drift until they are carried to coastal areas and travel up lakes and rivers to spend most of their lives. The activities of many diadromous species while they are at sea are not well-known. Most of the species found on the Scotian Shelf likely live within the water column – above the ocean bottom – while in marine habitats.

Distribution of Spawning Fish, Fish Eggs, and Larvae

Research on spawning areas of adult fish and the distribution of fish eggs, larvae, and juvenile fish has generally focussed on individual species. This section gives a general overview of research on the location of spawning and the distribution of eggs and larvae on the Scotian Shelf. Spawning seasons have been described inconsistently, resulting in different and apparently contradictory conclusions, broad definitions of spawning seasons, or inconclusive evidence of episodic spawning. For example, silver hake spawning has been described with differing results using seasonal egg and larvae collections, capture of adults in ripe or spawning state, and inference based on spawning times in other areas (Fahay and Able 1989). Different results from research on the timing of spawning is also a reflection of annual variations in environmental conditions, such as temperature, and long-term changes in fish populations.

The various methods of estimating spawning have resulted in different ways of portraying peak spawning time and areas. Histograms showing month-by-month density of fish larvae can be found on a species-by-species basis later in this chapter and location maps showing concentrations of fish larvae by species can also be found in the species descriptions. A table showing the temporal overlap of larvae of several commercial species can be found in Appendix 2. Detail on particular species can be found in the section with species descriptions.

One of the earliest studies of ichthyoplankton of the Scotian Shelf was carried out by Dannevig (1919) as part of the Canadian fisheries expedition of 1914-1915. He created species maps showing the locations where the expedition collected fish eggs and larvae. Scott (1983) analyzed records from research survey cruises to determine where ripe and spawning groundfish were caught on the Scotian Shelf, summarizing data for nine species. Other Scotian Shelf programs have attempted to determine spawning areas by measuring concentrations of eggs and larvae in the water column. The Scotian Shelf Ichthyoplankton Program (SSIP), the Larval Herring Program (LHP), the Fisheries Ecology Program (FEP), and the Ocean Production Enhancement Network (OPEN) all examined the distribution of eggs and larvae as part of their research activities. The Fishermen's and Scientists' Research Society, in cooperation with other organizations, is researching and mapping fishermen's information on spawning and juvenile areas off Nova Scotia. This project will add spawning areas to those currently documented in the scientific literature.

Table 6-2. Inferred spawning areas and times on the Scotian Shelf, compiled from Scott (1983)

Species	Time of year of spawning fish (location)	Depth of spawning fish
Atlantic cod (*Gadus morhua*)	March (concentration on Browns Bank, less concentrated on Western and Emerald Banks) July (northern Sable Island Bank, Middle Bank, Banquereau, and Sydney Bight) August (insufficient data) September (insufficient data) October (Sable Island Bank, Middle Bank, and eastern Banquereau) November-December (sparse occurrences on Western and Sable Island Banks)	all areas: from less than 91 to 182 metres
Haddock (*Melanogrammus aeglefinus*)	High concentrations in March (Browns and Emerald Banks) April (Emerald Bank) time of year unknown (small numbers in Sydney Bight and eastern Banquereau) occasional occurrences year-round (Browns and Emerald Banks)	generally less than 91 metres, some to 182 metres
Red hake (*Urophycis chuss*)	few records of spawning fish in general July (scattered over central part of the shelf)	found at all survey depths
White hake (*Urophycis tenuis*)	July (scattered along edge of shelf, in Fundian and Laurentian Channel, and central shelf between Emerald and LaHave Banks)	deep waters (no depth specified)
Silver hake (*Merluccius bilinearis*)	March (few scattered along edge of shelf) July (concentrations on Sable Island and Western Banks, a few records on Banquereau and between Western Bank and Emerald Basin) September/October (northeast part of shelf)	depths not specified
American plaice (*Hippoglossoides platessoides*)	A spring-summer spawning season was suggested but records from all times of year (records from all over the shelf and shelf edge, greater number of records from Laurentian Channel to concentration on Emerald Bank)	within 182 metres; on banks, within 91 metres
Yellowtail flounder (*Limanda ferruginea*)	Concentrations in July but records from throughout the year (Banquereau, Sable Island, Western, and Browns Banks, concentration on west side of Emerald Bank, a few records from Roseway Bank)	within 91 metres
Witch flounder (*Glyptocephalus cynoglossus*)	March to July (major concentration widely scattered on northeastern shelf to Banquereau, otherwise widely scattered with local concentrations on western edges of Sable Island and Western Banks)	within 182 metres
Winter flounder (*Pseudopleuronectes americanus*)	No records of spawning fish on Scotian Shelf (ripe fish found on Sable Island and Browns Bank in March, and a few in January and July)	not applicable

Scott (1983) found evidence that fish were somewhat more concentrated during summer spawning periods. The distribution of ripe and spawning fish caught during research surveys corresponded with their general summer distribution. The distribution of spawning fish for the nine species included in Scott's report can be found in Table 6-2. Although Scott considered the Bay of Fundy in his work, information for the Bay of Fundy was not included in the table.

The SSIP carried out 30 surveys between 1978 and 1982.[3] O'Boyle et al. (1984) reported on 11 of those 30 surveys. They found that eggs and larvae of cod, haddock, pollock, and silver hake tended to be concentrated on the shallow outer banks of the shelf (Browns, Emerald, Western, Sable Island, and Banquereau Banks). The other two species considered in their paper, American plaice and redfish, had more widespread distribution of larvae. The authors suggested that fish larvae appeared to be retained on the central and southwestern banks, in particular Sable Island-Western and Browns Banks, perhaps due to clockwise gyres on those banks.

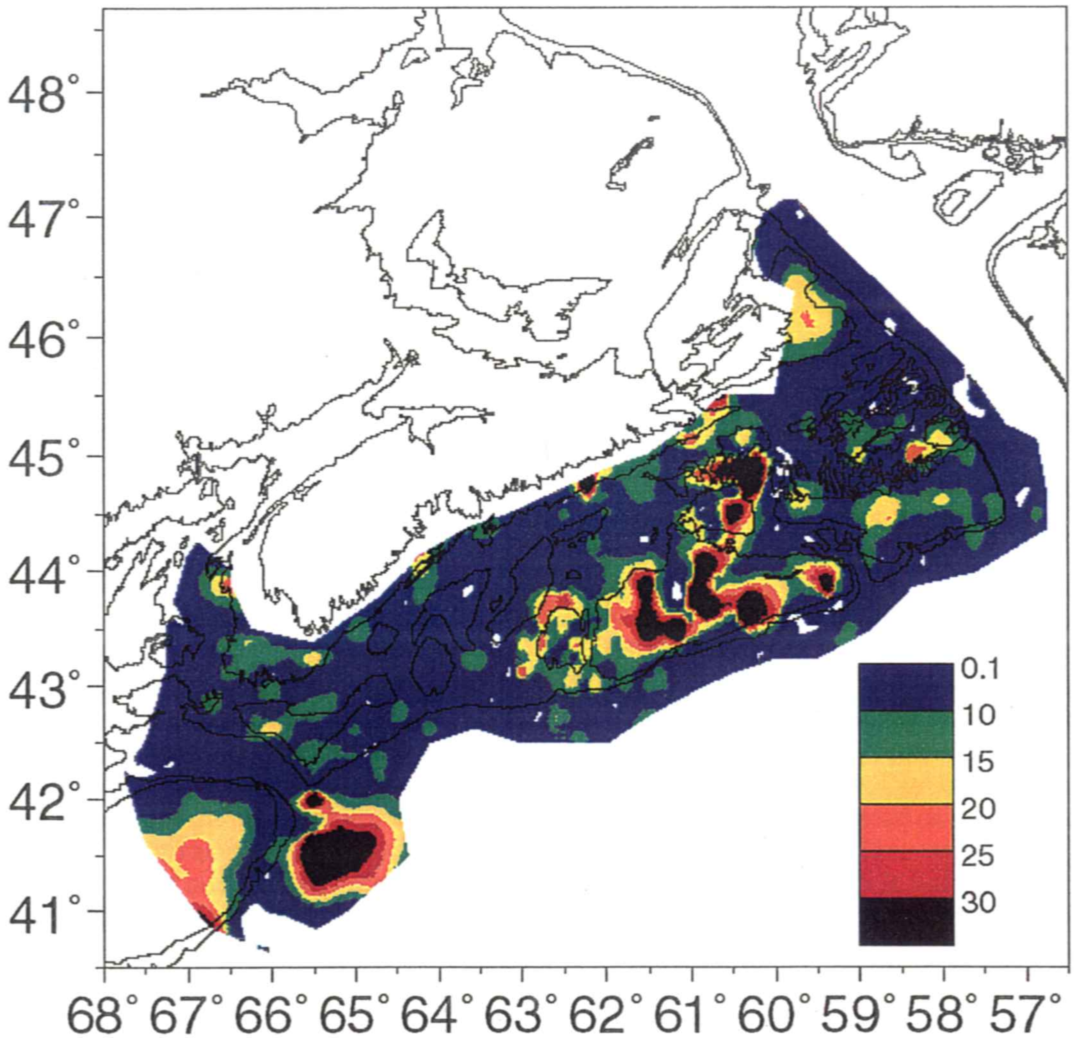

Figure 6-1. Larval fish diversity on the Scotian Shelf (no. of genera/per 1000 m^{-3}) (prepared by N. Shackell and K. Frank).

Shackell and Frank (2000) carried out a recent reassessment of SSIP data, examining the database to determine areas of high abundance and diversity of larval fish on the shelf. They

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3 The program started in 1976; however, sampling procedures were standardized in 1978.

found that the Western-Sable Island Banks area had high larval fish abundance at all times of year. That area also had high diversity (see Figure 6-1). Larval diversity was highest across the shelf from April to September-October. Abundance trends were similar, with larvae being most abundant across the shelf from March to June and with the lowest abundance in the winter months, December to February.

Shackell and Frank (2000) grouped the larval fish genera into 11 assemblages based on cluster analysis and characterized these groups by temperature and depth (see Appendix 3 for assemblages). Like O'Boyle et al. (1984), Shackell and Frank (2000) found that eggs of haddock and cod had similar distribution patterns, although they spawned at different times of year.

Unlike previous papers, Shackell and Frank found little evidence that diversity or abundance of larval fish in general coincided with seasonal abundance of zooplankton, although abundance of copepods was likely more relevant for particular species. However, peak zooplankton concentrations could be found in the same locations as areas of high larval fish abundance, though not necessarily at the same time, suggesting these are highly productive areas in general (Shackell and Frank 2000). The authors recommended smaller-scale studies, as opposed to the shelf-wide study they carried out, to find if larval fish were concentrated in fronts. They suggested that larval fish diversity was high in the Western-Sable Island banks area because the bank itself was larger and perhaps had more heterogeneous habitat, and the partial gyre acted to retain larval fish and concentrate them with their prey (Shackell and Frank 2000).

The larval herring program (LHP) was intended to increase knowledge about herring larvae and was set up to coincide with areas assumed to be abundant in larval herring. Surveys have been carried out since 1972 focussing on the Bay of Fundy, an area off southwest Nova Scotia, and Georges Bank (Hanke et al. 2000). Since the focus was on herring, other species of ichthyoplankton were identified in some but not all of the samples. Nonetheless, this data set provides more recent information on ichthyoplankton than the SSIP; however, only Hanke et al. (2000, 2001a, 2001b) have used it for other species. They described the occurrence of cod, haddock, and pollock eggs and larvae using information from the SSIP, LHP, and the Fisheries Ecology Program (FEP).

The Ocean Production Enhancement Network (OPEN) supported research on the processes that affected the survival, growth, and reproduction of fish and commercial invertebrates, especially cod and scallop. As part of that program, samples of cod eggs were taken periodically at 45 stations on the central Scotian Shelf, from March 1991 to May 1993 (Miller et al. 1995). Eggs were incubated and larvae hatched on the ship after sampling. The study focussed on seasonal size variation of the eggs and larvae. Data collected under the auspices of OPEN was compared with SSIP data by Frank et al. (1994), who described changes in spawning patterns on the Scotian Shelf. OPEN also supported research on mackerel larvae on the Scotian Shelf (see e.g., Fortier and Villeneuve 1991).

The FEP examined factors affecting commercial fish of the western Scotian Shelf, particularly haddock (Dickie and Smith 1989). As part of this program, samples of haddock and cod eggs and larvae were collected from 1983 to 1985 in the months from February to June, a period when spawning was known to occur (Hurley and Campana 1989). Browns Bank was found to be a key spawning area for those species in southwestern Nova Scotia. No other species were considered. Brickman and Frank (2000) re-examined the FEP data to look at dispersal of egg and larval haddock from Browns Bank.

The GLOBEC-Canada program is examining how changes in the marine environment affect marine organisms. Several of its projects target the early life stages of fish and their prey on the Scotian Shelf. The Shackell and Frank (2000) reassessment of the SSIP was a contribution to GLOBEC. Other projects under GLOBEC have collected new data from the Scotian Shelf. For example, Taggart and others are sampling zooplankton and ichthyoplankton on Western Bank to examine the spatial and temporal occurrence of larval fish and zooplankton (Taggart et al. 1999, McLaren et al. 1997). Herman and others are sampling in Cabot Strait, the Louisbourg line, Western Bank, and the Halifax line during spring and fall to examine the relationship between larval fish growth and zooplankton (Herman et al. 1999, Head 2001).

Data from the SSIP have been the basis for most works on larval fish distribution on the Scotian Shelf despite having been collected two decades ago. Changing oceanic conditions and overexploitation of some species could mean that the current distribution of fish eggs and larvae has changed. Some authors have speculated that the survivability of fish at early life stages is a major limiting factor of adult populations (see Campana et al. 1989 for a discussion of determining factors for adult populations of cod and haddock). For that reason, it is important to obtain up-to-date distribution information on spawning locations and the distribution of larval fish – perhaps more important than tracking the distribution of non-spawning adult fish. Adult fish distribution on the Scotian Shelf is somewhat better known than the location of spawning and early life stages due to information from research surveys and commercial catches.

Distribution of Juvenile Fish

When larvae of many groundfish reach a certain size they move to the ocean bottom and feed on invertebrates and small fish living there. Many authors have proposed that demersal juvenile fish move into nursery areas with specific habitat characteristics that promote the survival of the young fish. For example, inshore regions have been proposed as important nursery areas for juvenile groundfish. Inshore regions could provide protection from predators in the complex habitats found there. In the winter, these fish migrate to deeper, warmer waters of the shelf. As they grow, the juvenile fish can be found at a greater distance from the coast, moving to offshore banks as adults. Another line of argument suggests that nursery areas for juvenile fish will be areas where they spawn. There, loose gyres will retain larvae over the offshore banks, where they will be held in proximity with their prey and develop into juveniles (see Suthers and Frank 1989 for discussion of these hypotheses).

There is some evidence for both of these arguments as the presence of juvenile fish has been established in both coastal areas and offshore areas. Particular species appear to have preferences for specific habitats. For example, juvenile winter flounder, *Pseudopleuronectes americanus*, is found predominantly in coastal habitats (see e.g., Horne and Campana 1989, Howell et al. 1999), while silver hake, *Merluccius bilinearis*, is found predominantly in the offshore (see e.g., Koeller et al. 1989). Juvenile red hake, *Urophycis chuss*, is found in association with scallop beds in the Bay of Fundy, Scotian Shelf, and Georges Bank (Markle et al. 1982). Juvenile cod and haddock appear to have both coastal and offshore nursery areas throughout their range (see e.g., Scott 1982a, Lough et al. 1989, Tupper and Boutilier 1995, Dalley and Anderson 1997, Brickman and Frank 2000).

Larvae of pelagic fishes that spawn in Nova Scotia's waters can also be found in coastal areas. As juveniles, herring form schools and live in coastal areas in the summer, overwintering near the bottom farther offshore before returning to coastal areas in summer (Reid et al. 1999). Capelin larvae are washed from the intertidal zone by waves. Their drift out to sea is promoted by onshore winds (Frank and Leggett 1983). The larvae remain in nearshore areas in the summer and move offshore into deeper waters in the fall (Scott and Scott 1988).

On the Scotian Shelf, nursery areas for juvenile fish are generally ill-defined. Sections of Emerald and Western Banks were closed to mobile groundfish gear in 1987 to protect juvenile haddock concentrated in that area (see Appendix 4 for map of areas closed to fishing). Nova Scotia's Atlantic coast has been shown to have nursery areas for cod (see e.g., Suthers and Frank 1989, Tupper and Boutilier 1995), but the extent of these areas and their importance to the cod population are not known. In Newfoundland, habitat preferences of juvenile cod have been shown to vary with age, with the smallest, youngest fish preferring the shallowest depths (Methven and Schneider 1998). Rocky coastal areas provide habitat for juvenile pollock (Fahay et al. 1999, Cargnelli et al. 1999b).

There is some evidence for variability in nursery areas. As environmental conditions change, spawning or nursery areas may be abandoned in favour of others with better conditions. Decreases in fish populations may also cause changes in the areas used as nurseries. For example, the shallows around Sable Island were found to support large concentrations of juvenile haddock in the early 1980s (age groups 0 and 1, size of 6 to 29 centimetres) (Scott 1982a). Most of the 0 group were concentrated in waters 27 to 37 metres deep. The age 1 group showed a slight preference for waters slightly deeper (37 to 46 metres). Later surveys did not show juvenile haddock in high concentrations in the area (Scott 1987). Further discussion of habitat preferences of juvenile fish can be found in the species descriptions.

Adult Fish Diversity and Assemblages

Demersal fishes

Research on fish assemblages in the Northwest Atlantic has focussed on species caught in research trawl surveys carried out by DFO and American agencies. Based on these data, various authors have suggested groupings of fish species (Mahon et al. 1984, Mahon and Smith 1989, Mahon 1997, Mahon et al. 1998) and fish distribution patterns (Kulka and Stobo 1981, Mahon and Sandeman 1985, Scott 1988, Simon and Comeau 1994, Strong and Hanke 1995) for areas including the Scotian Shelf. The government research surveys generally have focussed on the shelf itself, not the deeper waters of the slope and further offshore. Zwanenburg (1998) proposed assemblages for deeper waters based on surveys of the slope taken in The Gully region. The work on assemblages and distribution attempts to predict where particular fish can be found and with which species they are most likely to occur.

Mahon et al. (1998) have made the most recent attempt at defining the fish assemblages of the Northwest Atlantic. This work, part of the East Coast of North America Strategic Assessment Project (ECNASAP), used data collected by demersal research trawl surveys from Cape Hatteras to Cape Chidley. The authors grouped 108 common demersal fish species into nine groupings using visual classification, and eighteen assemblages using principal components and cluster analyses. They compared the three different classifications and found that there were both similarities and differences, suggesting that members of an assemblage were loosely associated. The authors concluded that assemblages were flexible and likely adapted to different environmental conditions. Membership in the loose assemblage groups remained constant over the 24-year period of the surveys; however, the location where the fish occurred varied over time. The authors characterized the assemblages by temperature and by water depth. They found that the groupings did not conform to accepted biogeographical boundaries. For example, using latitude to define groupings was too simplistic to define patterns of faunal distribution. Of particular interest is their conclusion that generally accepted boundaries of large marine ecosystems – such as the Scotian Shelf – have little importance as boundaries for distribution of demersal fish species. Some species were widespread on the continental shelves but had patchy distribution, suggesting that they preferred particular habitats within the shelf environment.

Mahon et al. (1998) found that wide-ranging species, such as Atlantic halibut, did not fit particularly well with principal components analysis, since they may occur with many other species and may artificially expand the geographic range of assemblages in which they are placed. The assemblages they derived, using principal components analysis, can be found in Table 6-3.

Mahon et al. (1998) concluded that more detailed work that focussed on the ecology of particular assemblages was needed to determine if the species had functional relationships within the groupings. ECNASAP has made distribution maps of 99 of the groundfish species considered in its work available on the internet (www.orca.nos.noaa.gov/projects/ecnasap/ecnasap.html).

Table 6-3. Assemblages of demersal fishes of the Northwest Atlantic, from Mahon et al. (1998)

Assemblage	Characteristics	Area	Species
1	Southern, very warm, shallow-middle depths, aggregated	Mid Atlantic Bight to southern Georges Bank, shallow-middle depths in warm water	Gulf stream flounder Fourspot flounder Fawn cusk-eel Spotted hake Butterfish *Red hake** *Goosefish*
2	North, cold, very deep, aggregated	Deepest assemblage in the north, found in the Laurentian Channel, slope of the Grand Banks and Labrador Shelf, around Flemish Cap	Blue hake Rock grenadier Longnose/slatjaw cutthroat eel Large-scale tapirfish Roughhead grenadier *Common grenadier/marlin-spike*
3	Southern, warm shallow-middle depths, dispersed	A southern assemblage, commonly occurring on Georges Bank, Mid Atlantic Bight, mouth of the Bay of Fundy, scattered sites as far north as the Grand Banks	Scup Summer flounder Northern (common) searobin Black sea bass Smooth dogfish
4	South-central, warm, shallow-middle depths, aggregated	Concentrated in the Gulf of Maine, southern Scotian Shelf, and outer edges of Georges Bank and the Mid-Atlantic Bight	Silver hake Red hake Cusk Pollock Spiny dogfish *White hake* *Ocean pout* *Goosefish* *Haddock* *Shortfin squid*
5	Central, medium temperature, very shallow, fragmented	Shallowest assemblage, occurring on bank tops and some coastal areas in the middle of the study range, fragmented distribution	Longhorn sculpin Sea raven Yellowtail flounder Winter flounder *Ocean pout*
6	Central, medium temperature, deep, localized	Primarily in the Laurentian Channel into the mouth of the St. Lawrence River	Common grenadier/marlin-spike Redfishes (*sebastes* spp.) Witch flounder Black dogfish *Atlantic argentine* *White hake* *Longfin hake*
7	Southern (Georges Bank), very warm, shallow, aggregated	Occurs most strongly on Georges Bank, to a lesser extent on other banks	Windowpane Winter skate Little skate *Northern sand lance*

Table 6-3. Assemblages of demersal fishes of the Northwest Atlantic, from Mahon et al. (1998)			
Assemblage	**Characteristics**	**Area**	**Species**
8	Northern, cold, deep, aggregated	Occurs on the northeastern Newfoundland and southern Labrador shelves	Spotted wolffish Atlantic wolffish Northern wolffish *Roughhead grenadier* *Atlantic cod* *Greenland halibut* *Redfishes (sebastes spp.)*
9	Southern, widespread, warm, medium depths	Occurs in the deeper shelf areas of the Scotian Shelf and Gulf of Maine, and along the shelf slope from the southwestern Grand Banks to Cape Hatteras	Blackbelly rosefish Offshore hake Shortnose greeneye
10	North-central, cool, medium-deep depths, disaggregated	Occurs on the northeastern Newfoundland Shelf, Grand Banks, northern Scotian Shelf, and in the Gulf of St. Lawrence	Thorny skate American plaice Witch flounder *Atlantic cod* *Smooth skate*
11	Northern, cold, deep, aggregated	Coldest water assemblage, occurs on the northeastern Newfoundland and Labrador shelves	Arctic cod Atlantic sea poacher Greenland halibut *Polar sculpin*
12	Central, medium temperature, medium depth	Northern Gulf of St. Lawrence and Gulf of Maine	Fourbeard rockling Atlantic hagfish *Smooth skate*
13	Central, cool, shallow, scattered aggregations	Occurs at several scattered localities north of Cape Cod	Moustache sculpin Alligatorfish Snowflake hookear sculpin
14	Central, medium temperature, deep, localized	Concentrated in the Laurentian Channel and in the Gulf of St. Lawrence up to the mouth of the St. Lawrence River, also along the slope of the Labrador and Scotian Shelves	Roughnose grenadier Longfin hake Black dogfish
15	Central, medium temperature, medium depths	Mainly on the outer banks of the Scotian Shelf and the southwestern edge of the Grand Banks into the northeastern Gulf of St. Lawrence	Atlantic halibut Haddock
16	Northern, cool, deep	Essentially a single-species assemblage concentrated on northeastern Newfoundland and Labrador slope, scattered into the Gulf of St. Lawrence, Gulf of Maine and Georges Bank	Polar sculpin *Roughhead grenadier* *Greenland halibut*
17	North-central, very cold, medium depths	Localized on the shelf south of Newfoundland, around into the northeastern Gulf of St. Lawrence	Lumpfish Shorthorn sculpin *Sea raven*
18	Southern, warm, shallow	Essentially a single-species assemblage, occurs in the southeastern Gulf of St. Lawrence, Bay of Fundy, Georges Bank, and Mid Atlantic Bight	Cunner *Winter flounder* *Snake blenny*

*Species in italics are less strongly associated with the assemblage.

Earlier attempts at describing faunal assemblages on the Scotian Shelf used only Canadian data. Mahon and Smith (1989) characterized the groundfish populations of different areas of the Scotian Shelf and Bay of Fundy based on the groundfish research trawl survey. They grouped fish in assemblages and associated those assemblages with specific areas. The fish groupings are listed below:

- longfin hake/grenadier
- redfish/argentine/cusk
- white hake/witch flounder/silver hake
- spiny dogfish/pollock
- angler/smooth skate/red hake
- haddock/halibut/wolffish

- plaice/thorny skate/cod
- yellowtail flounder/winter skate/longhorn sculpin

The areas where the particular groupings occur can be found in Table 6-4. The groupings did not hold strongly for all seasons (Mahon and Smith 1989), suggesting that environmental parameters played a role in determining fish distributions and groupings.

Table 6-4. Assemblages of demersal fishes of the Scotian Shelf, from Mahon and Smith (1989)

Stratum Groupings	Area	Species
Northeast mixed	Northeastern shelf, including St. Anns, Canso and Misaine Banks	Plaice/thorny skate/cod Eelpouts Mailed sculpin
Eastern Banks	Banquereau, Sable Island, and Middle Banks, Western Bank for some time periods	Plaice/thorny skate/cod Yellowtail flounder/winter skate/longhorn sculpin
Bay of Fundy	Bay of Fundy	Plaice/thorny skate/cod Little skate/sea raven/winter flounder Spiny dogfish/pollock
Western Banks	Western Bank (for some time periods), Emerald, LaHave, Roseway, Baccaro, and Browns Banks	Wolffish/halibut/haddock Plaice/thorny skate/cod (present but less prominent)
Southeast corner	Southeastern shelf break, from The Gully to the Stone Fence	Plaice/thorny skate/cod Smooth skate
Outer central	Mid-depth areas between outer banks from Browns Bank to Western Bank	No outstanding species groups Occurrence of wolffish/halibut/haddock, among others
Inner central	Mid-depth areas of inner central shelf	No outstanding species groups Occurrence of: Redfish Pollock White hake/witch flounder/silver hake Angler/smooth skate/red hake
Shelf basins	Emerald and LaHave basins and adjacent areas, Roseway Basin (for some time periods)	Redfish/argentine/cusk Occurrence of white hake/witch flounder/silver hake
Northeast Channel and basins	Northeast Channel, Georges, and Jordan Basins and adjacent area	Similar to Shelf basins and Inner central groupings, plus spiny dogfish/pollock
Laurentian Slope	Slope of Laurentian Channel and The Gully	Longfin hake/grenadier
Outer Slope	Slope of Scotian Shelf from the Northeast Channel to The Gully	Longfin hake/grenadier

Works on fish distribution and diversity support conclusions that environmental conditions affect spatial and temporal distribution. Strong and Hanke (1995) assembled data on groundfish trends from the 1970 to 1993 summer research surveys and the 1979 to 1985 spring and fall surveys. The Scotian Shelf and Bay of Fundy is divided into strata for groundfish surveys (see Figure 6-2). The authors compared species diversity in each of the strata over time. Although each stratum appeared to be generally well sampled, the strata along the shelf edge were not as thoroughly investigated, with new species being recorded regularly. The authors found that areas of high diversity varied. At different periods, areas along coastal Nova Scotia, north and west of Middle Bank, in Emerald Basin, in The Gully, west of Sable Island, and on Western Bank showed high species diversity. The period between 1982 to 1985 was a period of high diversity in many of the strata and the autumn was generally a period of high diversity. Their findings suggest that both geographic area and hydrographic conditions influence fish diversity. The section on specific species will look at some of the preferred environmental conditions for those species.

Frank and Shackell (2001) examined patterns of finfish diversity on the Scotian Shelf using data collected by the groundfish research trawl survey. They used cumulative number of species collected from each bank as an indicator of diversity. Preliminary findings from their research suggest that area has a strong influence on species diversity, i.e., larger banks had more species recorded than smaller banks. The rarer species were more likely to be recorded from the larger banks. They suggested that larger banks may have higher resources, such as higher prey diversity or productivity, per unit area than the smaller banks.

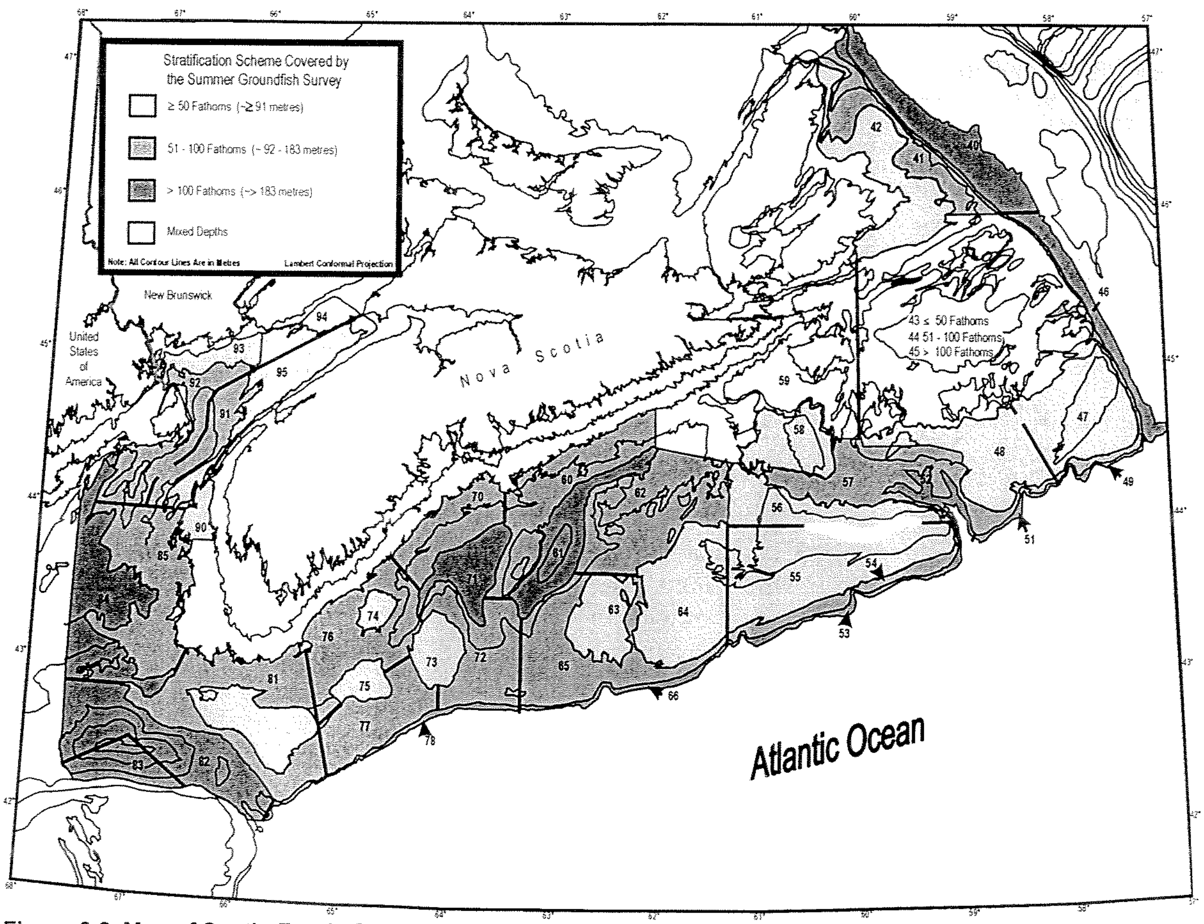

Figure 6-2. Map of Scotia-Fundy Summer Survey Stratification Scheme (adapted from Strong and Hanke 1995).

Changes in distribution, assemblages, and diversity may have occurred over time due to changes in stock size and populations. A study of long-term changes of demersal fish diversity and abundance on the Scotian Shelf may well identify stronger assemblages at particular periods. Zwanenburg et al. (in press) examined changes on the Scotian Shelf over the last 40 years, with a detailed discussion of changes in demersal fish. In the late 1990s, the biomass of demersal fish available for trawling was at the lowest level observed in 30 years (Zwanenburg et al. in press). It had particularly declined on the eastern Scotian Shelf and other species have replaced commercial groundfish in research trawls. Most of this decline happened since the early 1980s; on the western Scotian Shelf the decline was less precipitous and occurred later (Zwanenburg et al. in press). The average size of demersal fish caught generally declined from the late 1970s to the mid-1990s (Zwanenburg 2000). Since 1995, average size has remained stable or increased. The changes in abundance and population structure have profound implications for the ability of fish populations to recover from the decline. Changes in groundfish populations may have resulted in permanent changes in the ecosystem.

Deep-sea species

Merrett and Haedrich (1997) produced an overview of knowledge of deep-sea benthic fish around the world. Most sampling of areas beyond the depths of the continental shelves has been very patchy and it is difficult to characterize the species of any region. The authors looked at the demersal fish species identified in the North Atlantic basin and described the ichthyofauna by the number of species found in each order. Species of cod-like fishes were the most numerous, consisting of 19 percent of demersal open ocean species. The cusk-eels, benthic rockfishes, perciformes, and salmoniformes were other prominent orders. More information on the distribution of deep water fishes of the North Atlantic basin can be found in Haedrich and Merrett (1988). Thus far, there has been little evidence of communities of deep-sea demersal fishes, except perhaps in quite localized areas (Haedrich and Merrett 1990).

Markle et al. (1988) found evidence of zonation in their study of demersal fish and crustaceans in their study of the continental slope off Nova Scotia from 400 to 1200 metres in depth. They found that redfishes, longfin hake, and witch flounder were the most numerous species from 400 to 800 metres. From 800 to 1200 metres, black dogfish, longnose eel (*Synaphobranchus kaupi*), and rock grenadier were most numerous. Marlin-spike (common grenadier) was fairly abundant over the whole depth range, from 400 to 1200 metres. The authors found the fauna of the upper slope of the Scotian Shelf to be similar but less diverse than that of the mid-Atlantic Bight (see Markle and Musick 1974) and similar but more diverse than that off Newfoundland (see Snelgrove and Haedrich 1985).

Pohle et al. (1992) examined the deep water fishes and invertebrates known to occur off Nova Scotia with a view to assessing their potential for fisheries. They listed the fishes known to occur in waters deeper than 300 metres off Atlantic Canada. Detailed descriptions of the five fish species thought to have the most fishery potential were included: Atlantic saury, blue hake, black scabbardfish, black dogfish, and orange roughy.

Zwanenburg et al. (1998) grouped the demersal species found at all depths in The Gully. Species were grouped by the depths in which they were most commonly caught by bottom trawl surveys. The groupings are as follows:

Most abundant at depths of less than 180 metres:

- American plaice
- Atlantic cod
- haddock
- longhorn sculpin
- lumpfish
- Atlantic mackerel
- sea raven
- smooth skate
- Atlantic (striped) wolffish
- thorny skate
- winter skate
- yellowtail flounder

Upper slope – most abundant between 180 and 360 metres:

- freckled skate
- little skate
- monkfish, goosefish, angler
- northern hagfish
- ocean pout
- pollock
- short-fin squid

Slope – most abundant between 360 and 900 metres:

- American straptail grenadier
- *Apristurus laurussoni* (Iceland cat shark)
- Arctic eelpout
- Atlantic argentine
- backfin tapirfish
- barndoor skate
- cusk
- eelpouts (unspecified)
- Gray's cutthroat eel
- Atlantic halibut
- Jensen's skate
- knifenose chimera
- lanternfish (unspecified)

- longfin hake
- longnose grenadier
- marlin-spike (common grenadier)
- northern wolffish
- offshore hake
- redfish (unspecified)
- rock (roundnose) grenadier
- round skate
- shortspine tapirfish
- snubnose slime eel
- spiny eel
- spinytail skate
- spotted wolffish
- trunkfish
- Greenland halibut (turbot)

Deep slope – most abundant at or below 900 metres:

- roughhead grenadier
- longnose chimera
- *Apristurus profundorum* (deep-sea cat shark)
- boa dragonfish
- blue hake/blue antimora
- black dogfish

New species continue to be identified from deep water ocean environments – including whole new families of fishes (Merrett and Haedrich 1997). Exploratory deep-sea fishing carried out along the New England continental slope from 1995 to 1997 resulted in 80 new species identified – a 15 percent increase in the number of deep-sea species identified in that area (Moore and Galbraith 1998). The number of new species identified was surprising considering that the deep sea off New England is one of the better-investigated deep-sea environments.[4]

Pelagic fishes

Studies of assemblages of fish of the Scotian Shelf have not considered pelagic fishes in general. Many large pelagic species found on the Scotian Shelf are highly migratory and may not have strong associations with other fishes. Information on pelagic fish distribution is available on a species-by-species basis in the section on individual species. There has been some research on assemblages and distribution of mesopelagic fishes.

Mesopelagic fishes

From 1984 – 1989, DFO carried out an inventory of the mesopelagic fish of the continental slope off Nova Scotia (see Halliday et al. 1995 for a description of the research). Themelis (1996) listed the fish found and examined the distribution of the mesopelagic fish of the continental slope as part of this research. Ninety of the 227 species had not been recorded in Atlantic Canada previously (Themelis 1996). The families with the greatest number of new species records for Atlantic Canada were the scaleless dragonfishes (Melanostomiidae), with twenty-one species not listed by Scott and Scott (1988), and the lanternfishes (Myctophidae), with twenty species. Overall, Themelis (1996) found that mesopelagic fish were much more diverse in the Canadian Atlantic than previously known. Many species thought to be tropical or subtropical were sampled in the survey trawls. Themelis (1996) suggested that species that are bathypelagic and do not migrate to the top 200 metres of the water column may have been missed in the survey, meaning that a concentrated effort may record more species from deep waters off Nova Scotia.

The lanternfishes are among the most abundant mesopelagic fishes. Most species spend the day in depths of 300 to 1200 metres (some species much deeper) and migrate to near surface waters at night to feed in depths of 30 to 100 metres, and occasionally shallower (Scott and Scott 1988).

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[4] Of 1094 deep-sea fish species documented in the North Atlantic from the equator to the Arctic Basin, 529 have been recorded off New England. This perhaps represents a greater effort to document deep-sea fishes in that region, although it may also be an area of high diversity (Moore and Galbraith 1998).

On the Scotian Shelf, they are most abundant along the slope of the shelf and in The Gully, in areas where depths are 500 metres and greater, as well as the open ocean. They can also be found in the Laurentian Channel and Cabot Strait (Sameoto pers. communication). The most common species above 40°N in the Northwest Atlantic is the glacier lanternfish, *Benthosema glaciale* (Sameoto pers. communication, Scott and Scott 1988).

Species Descriptions

Because this document is meant to be an overview and not a comprehensive listing of all species, only fifteen fish species are described here. Information on other species is available in Scott and Scott (1988). The species were selected based on the available information and further selected to describe differing life histories and roles in the larger ecosystem. Except for the sand lances (*Ammodytes* spp.) and smooth skate, all species are of commercial importance. This emphasis reflects where research has been concentrated. The life histories and habitat for the fifteen species are described from the perspective of determining areas of important fish habitat. Areas identified tend to be specific to individual species.

For the groundfish species, summer research trawl survey data were used to create distribution maps for two periods, 1978-1982 and 1996-2000, inclusive.[5] The period from 1978 to 1982 was a time of high fisheries activity and groundfish landings. That period is compared with the more recent period to give a sense of change over time, as well as the areas persistently used by particular species. Trawl surveys generally do not sample beyond 365 metres in depth, thus there are no distribution records from the continental slope at that depth to Canada's 200-mile limit. Inshore areas are also not sampled by the survey (see Figure 6-2 for the strata that are sampled). The pelagic fishes and halibut are not consistently sampled by groundfish survey gear. Data from other research surveys, from landings, or in some cases from groundfish surveys, were used to create distribution maps for those species. The data plotted on the maps correspond roughly to the study area and do not include information for the Bay of Fundy or Georges Bank.

Stock assessments prepared by DFO correspond to NAFO Divisions and subdivisions. These divisions will be referred to in many of the species descriptions. A reference map of the NAFO Divisions is provided in Chapter 5 (Figure 5-6).

Many species not targetted in commercial fisheries are still harvested as bycatch. The status of their populations has rarely been assessed and it is not known to what degree fisheries have impacted them. The barndoor skate has recently been held up as an example of a non-commercial species impacted by a fishery. Populations of the fish seriously declined in the 1970s and 80s and it was speculated that the skate was nearing extinction as a result of bottom trawling (Casey and Myers 1998).[6] Other fishes may have also been seriously affected by fishing practices. Several species of sharks are often caught as bycatch in pelagic longlining. The removal of these predators has impacts throughout the ecosystem, which have not been well researched. Although only a few species are described below, the status of many other species has repercussions for the ecology of the Scotian Shelf.

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[5] Jerry Black of the Marine Fish Division, Maritimes Region, DFO, assisted in preparing maps on the spatial distribution of the selected fish species.

[6] A recent American stock assessment report concluded that the habitat or range of the barndoor skate had not been reduced to an extent that threatened the existence of the species (NFSC 2000). Abundance in the northeastern part of its range has been substantially reduced since the early 1960s and it has not been sampled by research trawl survey on the Scotian Shelf east of Baccaro Bank since 1980.

Smooth skate (Malacoraja senta)

The smooth skate is the only cartilaginous species described here. Skates have distinctive flat, kite-shaped bodies that allow them to move quickly along the sea floor in pursuit of prey. Smooth skates feed mostly on decapod crustaceans and euphausiids, as well as mysids, small shrimp-like crustaceans (Scott and Scott 1988). Smooth skates live on soft mud and clay bottoms in deep basins and have been caught on banks in sand, sand and shells, and pebbles (Scott and Scott 1988, McEchran and Dunn 1998). They range in depth from 46 to 914 metres. Preferred depths and temperatures have been listed as 73 to 163 metres and 3 to 8°C (McEchran and Dunn 1998, Scott 1982b).

Smooth skates are distributed from Newfoundland and the Gulf of St. Lawrence to New Jersey in the western Atlantic (Scott and Scott 1988). The areas where they were caught during demersal research trawl surveys during two periods, 1978 to 1982 and 1996 to 2000, can be found in Figures 6-3 and 6-4. The distribution shows skates clustered in areas along the shelf edge and the edges of deep basins, with few caught on the tops of banks. Fewer skates were caught in the latter period. For example, the area between Emerald and Western Banks had relatively high catches of skate in the 1978 to 1982 period, but no skate were caught during the 1996 to 2000 period.

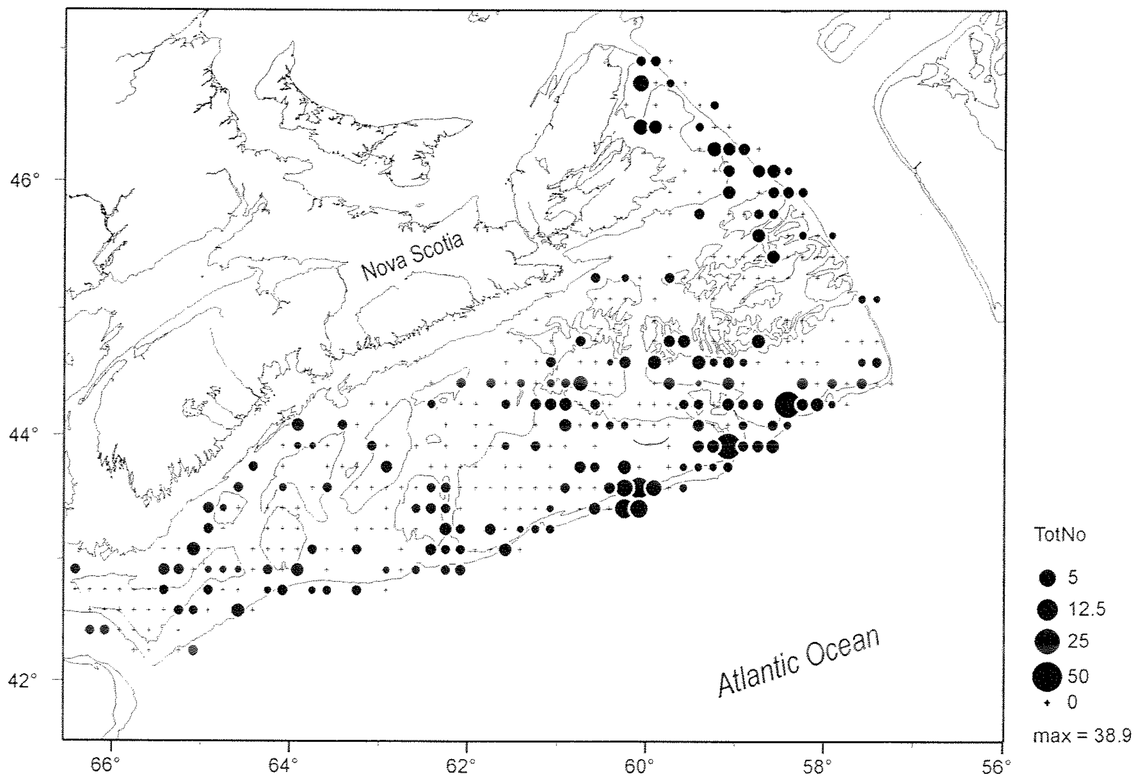

Figure 6-3. Location of smooth skate caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

Each skate egg is encased in a distinctive four-tipped capsule known commonly as a mermaid's purse. Spawning time for the smooth skate is not well known and it is thought that it spawns throughout its range (Scott and Scott 1988). Skates in general are caught as bycatch in commercial fisheries. There is a directed fishery for winter skate, one of the larger species of skates.

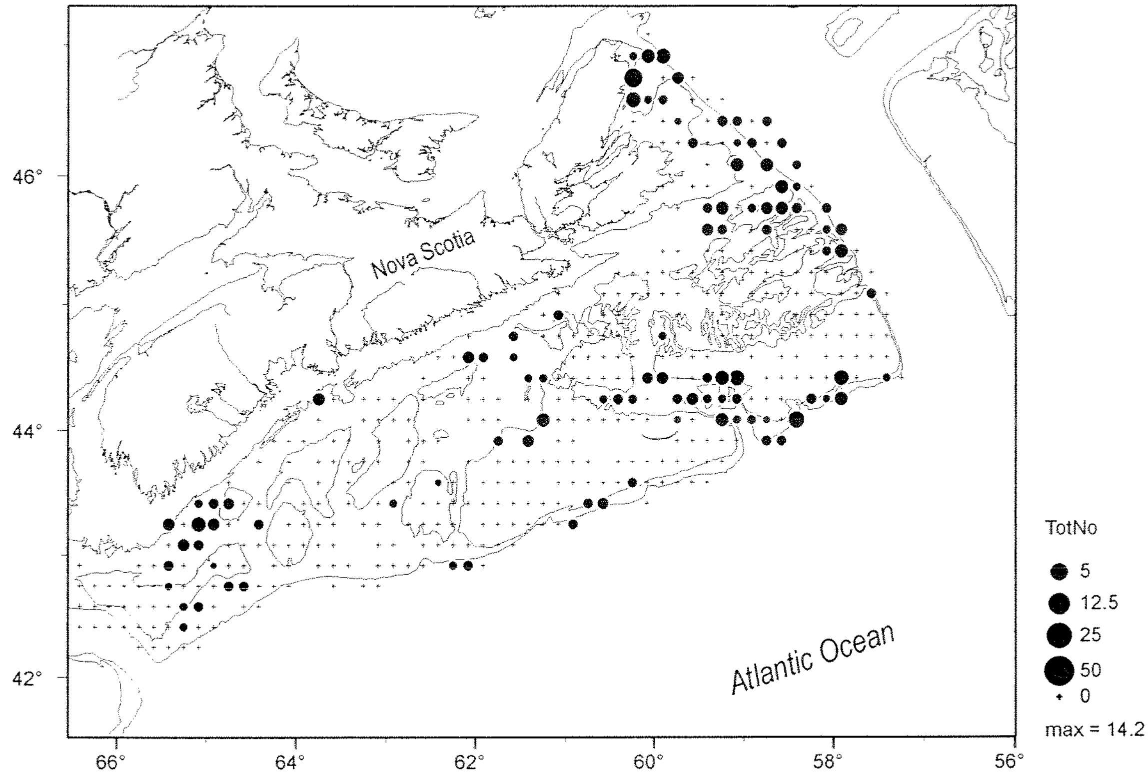

Figure 6-4. Location of smooth skate caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Atlantic herring (Clupea harengus)

Herring are small, schooling pelagic fish that are important prey for marine mammals, seabirds, and other fish, and are also the target of a directed fishery. They feed on planktonic creatures such as krill and copepods, fish eggs, and fish larvae (Scott and Scott 1988). Herring are widely distributed along the continental shelf from western Greenland and Labrador south to Cape Hatteras (Scott and Scott 1988). They are also found in the Northeast Atlantic. They occur in coastal areas and on offshore banks to about the 200 metre isobath. Each stock migrates between spawning grounds and feeding and wintering areas (Scott and Scott 1988). Herring that spawn in separate areas may mix with other herring outside of the spawning period (Stephenson et al. in press). The use of different spawning areas has been the main characteristic used by assessment biologists to distinguish between different stocks.

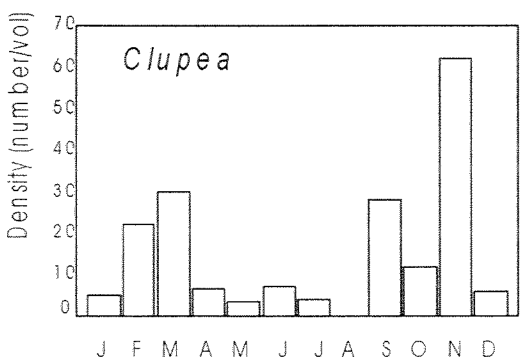

Figure 6-5. Concentrations of herring larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Herring eggs are demersal and deposited on a variety of sediments, predominantly gravel. The eggs are adherent and remain in the same area, sometimes attached to marine algae, until hatching. On the Scotian Shelf, there are both offshore and coastal spawning populations. Herring spawn off southwestern Nova Scotia (near the mouth of the Bay of Fundy), on offshore banks (generally

Western-Sable Island Bank),[7] and along the Atlantic coast of Nova Scotia. Herring found on the Scotian Shelf outside the spawning period may spawn in other areas, such as the Bay of Fundy and in coastal areas of New Brunswick (DFO 2000a). Traditionally, herring spawned in the Seal Island area off southwest Nova Scotia but none have been observed spawning there in recent years, a cause for concern (DFO 2000a). Most stocks in the Scotian Shelf/Bay of Fundy area are fall spawners; however, some spawn in summer and even spring. Most of the offshore spawning takes place on central Sable Island Bank in late October (Harris and Stephenson 1999). Figure 6-5 shows concentrations of herring larvae by month, according to the SSIP, and Figure 6-6 shows locations where larvae were sampled. The SSIP records come from a time when herring were not particularly abundant on the shelf (Stephenson, pers. communication). Figure 6-7 shows known herring spawning areas, as compiled from various studies. Areas with herring fishery closures – because of spawning, gear conflicts, or concerns about other species – can be found in Appendix 4.

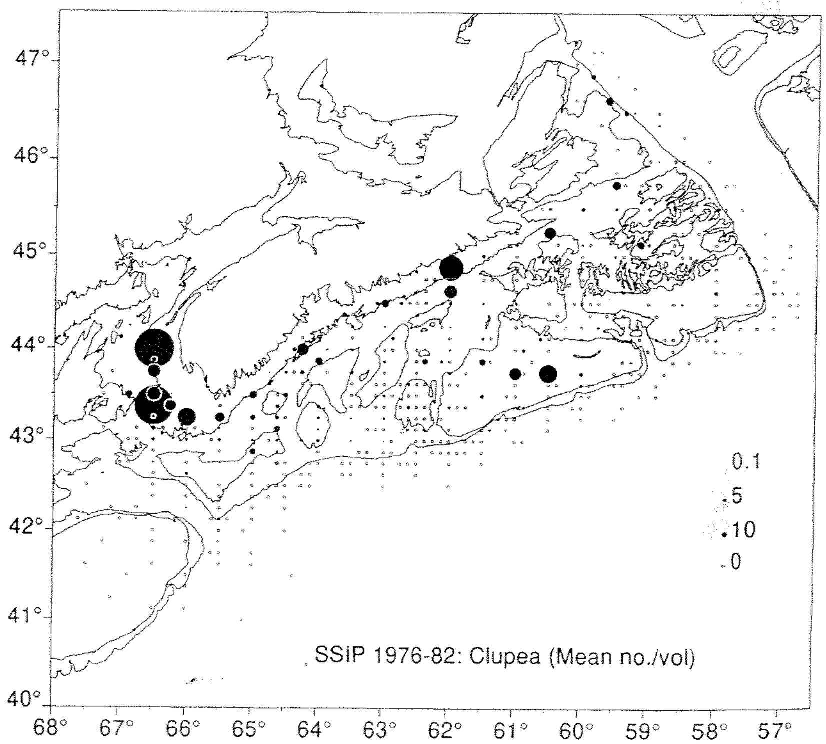

Figure 6-6. Locations where larval herring were sampled by the SSIP (prepared by N. Shackell).

Most herring landings come from southwest Nova Scotia and the mouth of the Bay of Fundy. An area of the eastern shore near Halifax, Chedabucto Bay and nearby areas, Sydney Bight near Glace Bay, and off Little Hope on the South Shore are locally important coastal fishing areas. In the 1960s and early 1970s, there was a foreign offshore herring fishery. This ended in 1974 with the extension of Canada's jursidiction. A small domestic fishery has taken place in LaHave and Emerald Basins and nearby areas for the past 5 years (Harris and Stephenson 1999). Herring landings from coastal and offshore areas correspond to places where herring are known to congregate to spawn, feed, or winter (DFO 2000a).

Large congregations of herring winter in Chedabucto Bay and off Chebucto Head near Halifax (P. Lane 1992, DFO 2000a). Herring from the southern Gulf of St. Lawrence winter off eastern Cape Breton, in division 4Vn (DFO 2001a). Distribution of adult herring on the Scotian Shelf in the 1996-2000 period, from the summer demersal research trawl survey, is shown in Figure 6-8. Herring are not well-sampled by this survey. Very few herring were caught in the 1978-1982 period by the research survey and a map of that period is not included here.

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[7] Prior to 1997, the Larval Herring program did not cover the Scotian Shelf since it was thought that little spawning occurred on the shelf. The timing and location of offshore spawning was determined by fall ichthyoplankton surveys in 1997 and 1998 (Harris and Stephenson 1999).

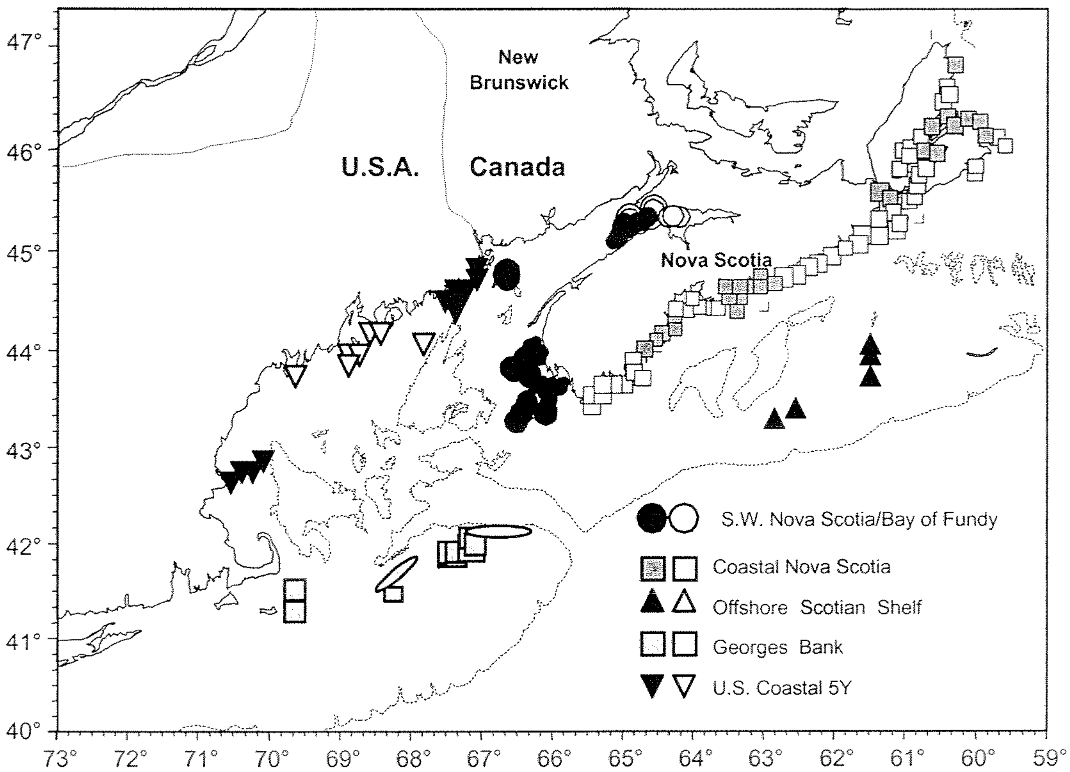


Figure 6-7. Atlantic herring spawning locations of the stock complexes used in management of Scotian Shelf, Bay of Fundy, and Gulf of Maine herring. Solid symbols indicate current spawning and open symbols indicate locations of spawning within the last two decades (from Stephenson et al. in press).

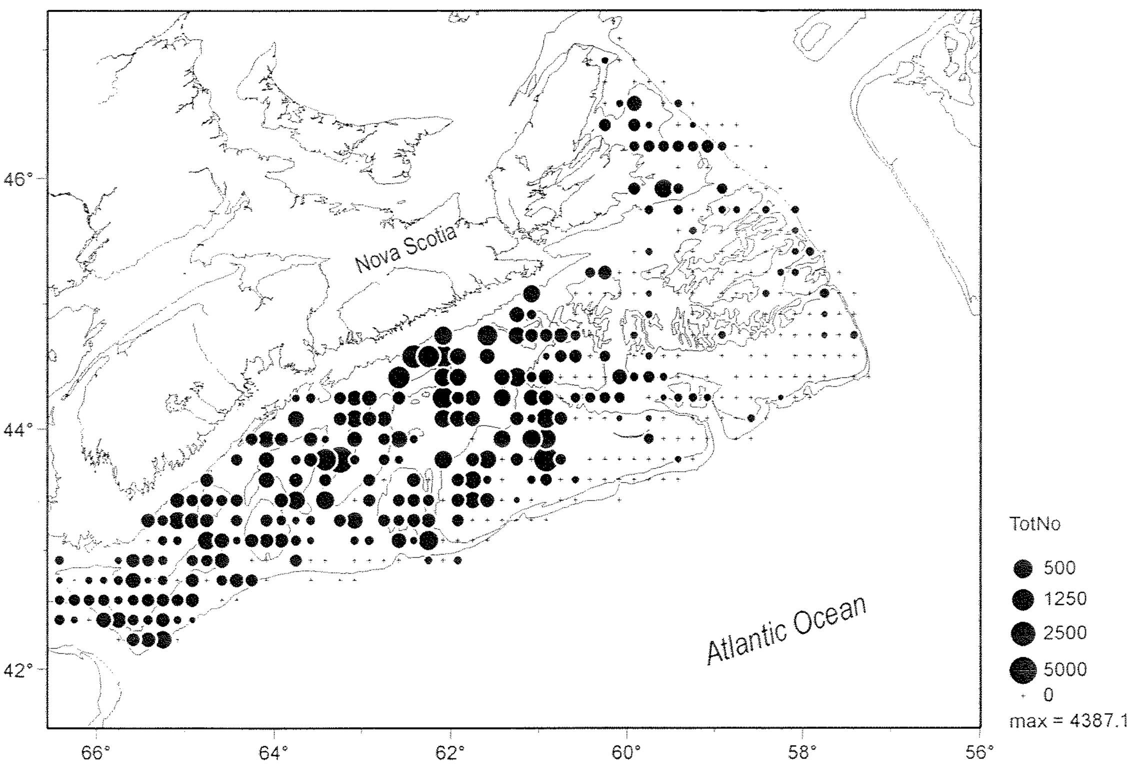
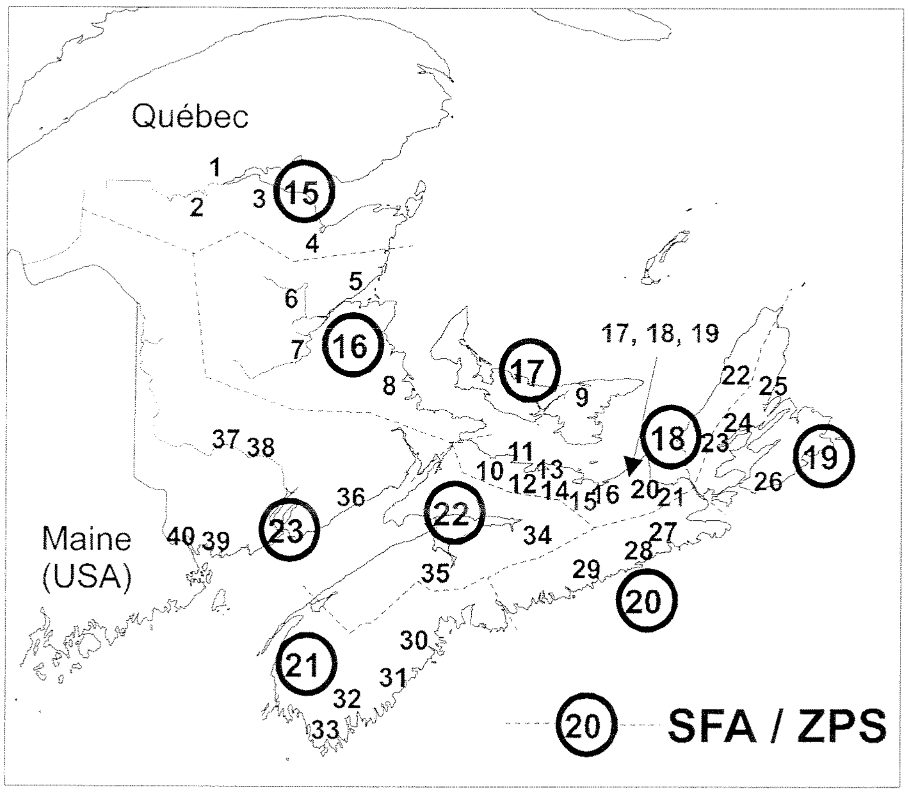


Figure 6-8. Location of herring caught during the summer (July) stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Atlantic salmon (Salmo salar)

Salmon are anadromous, spawning in freshwater streams and rivers and maturing at sea. They spend one to five years in fresh water before travelling to the ocean. After one or more years at sea, they return to their home river to spawn (Scott and Scott 1988). Rivers in the Maritimes where the status of Atlantic salmon was assessed in 2000 are shown in Figure 6-9.



Index of Rivers
1&2 Restigouche system
1. Matapedia
2. Restigouche
3. Jacquet
4. Nepisguit
5. Tabusintac
6&7 Miramichi
6. NW Miramichi
7. SW Miramichi
8. Buctouche
9. Morell
10. River Philip
11. Wallace
12. French (Colchester Co.)
13. Waugh
14. River John
15. West (Pictou County)
16. East (Pictou)
17. Sutherlands
18. French (Pictou)
19. Barney's
20. West (Antigonish County)
21. South
22. Margaree
23. Middle
24. Baddeck
25. North
26. Grand
27. St. Mary's
28. Liscomb
29. West Sheet Harbour
30. LaHave
31. Mersey
32. Jordan
33. Clyde
34. Stewiacke
35. Gaspereau
36. Big Salmon
37. Mactaquac
38. Nashwaak
39. Magaguadavic
40. St. Croix

Figure 6-9. Rivers in the Maritimes where salmon assessments were conducted in 2000 (from DFO 2000h). SFA refers to Salmon Fishing Area, the management zones used by DFO.

While much about the movements of Atlantic salmon at sea is not well-known, tagging of wild and hatchery smolts and capture and re-captures of salmon in the historic commercial salmon fisheries has contributed to many observations and hypotheses concerning the distribution and timing of salmon migrations. Salmon were more frequently captured in surface water temperatures between 4 and 10°C during research fishing cruises (Reddin and Friedland 1993). Some salmon that originate in Atlantic Canada migrate to feed in areas off western Greenland and the Faroe Islands while others forage closer to home (ICES 2000). While at sea, salmon eat smelt, sand lance, capelin, *Paralepis coregonoides* (a small barracudina), Arctic squid, herring, mackerel, alewives, small cod, and other fish. Smaller salmon (pre-grilse) feed on aerial and terrestrial insects at the surface and in the neuston, as well as euphausiids, decapod crustaceans, and amphipods (Lear 1980, Scott and Scott 1988, Hislop and Shelton 1993).

There are aboriginal as well as socially-important recreational fisheries for salmon in the Atlantic provinces. Commerically-important recreational fisheries for salmon, using local guides, remain active in New Brunswick and in Newfoundland and Labrador. Despite fishery closures and management for sustainable harvests, salmon stocks have declined precipitously in recent years.

Declines have been noted throughout eastern North America and in parts of Europe and salmon stocks in rivers of the Bay of Fundy and along the Atlantic coast of Nova Scotia are extirpated or at risk of extirpation. Salmon production has been lost due to acidification caused by acid rain and many formerly productive salmon rivers in southwest Nova Scotia no longer provide suitable habitat. Some rivers have been stocked with hatchery spawned and raised fish to maintain the stock or provide harvest fisheries (Marshall et al. 1998). The remaining non-impacted rivers have declining populations of the fish resulting from their lower relative productivity and a decline in marine survival of salmon.

The U.S. Fish and Wildlife Service recently listed the Atlantic salmon population in Maine rivers as an endangered species, after nearly 10 years of studies reviewing its status (USFWS 2000). In Canada, populations that spawn in rivers bordering the inner Bay of Fundy were declared endangered by COSEWIC in May 2001 (COSEWIC 2001).

The Scotian Shelf is a known transit area for emigrating post-smolts and returning adult Atlantic salmon. It is also a possible wintering area for the endangered inner Bay of Fundy populations (Amiro, pers. communication). While there are few reported captures of Atlantic salmon in the commercial or research marine fisheries databases, this cannot be interpreted as evidence to reject a Scotian Shelf winter habitat hypothesis. There are likely few captures because traditional groundfish trawl and longline gear is known to be inefficient for harvesting Atlantic salmon. To effectively catch Atlantic salmon at sea, pelagic trawls need to be large, fast, and towed outside of the wake zone. Using these methods, salmon distributions in the North Sea have recently been described that were previously suspected but undocumented. It may also be postulated from the distribution of recaptured tagged salmon that the onshore and northerly current in the Gulf of Maine and southwest Nova Scotia is a continental approach route for many Maritime salmon stocks (Amiro, pers. communication). In the future, development of high speed pelagic trawl gear, live capture boxes, and miniaturised acoustic and archival tags will allow opportunities to better define the contribution that the Scotian Shelf ocean habitat provides to Atlantic salmon in eastern North America.

Capelin (Mallotus villosus)

Capelin are small, pelagic fish that are important food for seabirds, whales, seals, and other fish. They are found in cold waters offshore and move inshore in great numbers to spawn. Capelin feed mainly on euphausiids as well as other zooplankton, such as copepods and amphipods (Scott and Scott 1988). In the western Atlantic, they are distributed from the Gulf of Maine north to Arctic waters but generally are not abundant on the Scotian Shelf. They have occurred on the eastern Scotian Shelf in much greater numbers since the mid-1980s. Their occurrence has been attributed to cooler bottom water temperatures on the eastern shelf (DFO 1997). Areas where capelin were collected in summer research trawl surveys can be found in Figures 6-10 and 6-11. Very few were captured during the surveys from 1978 to 1982.

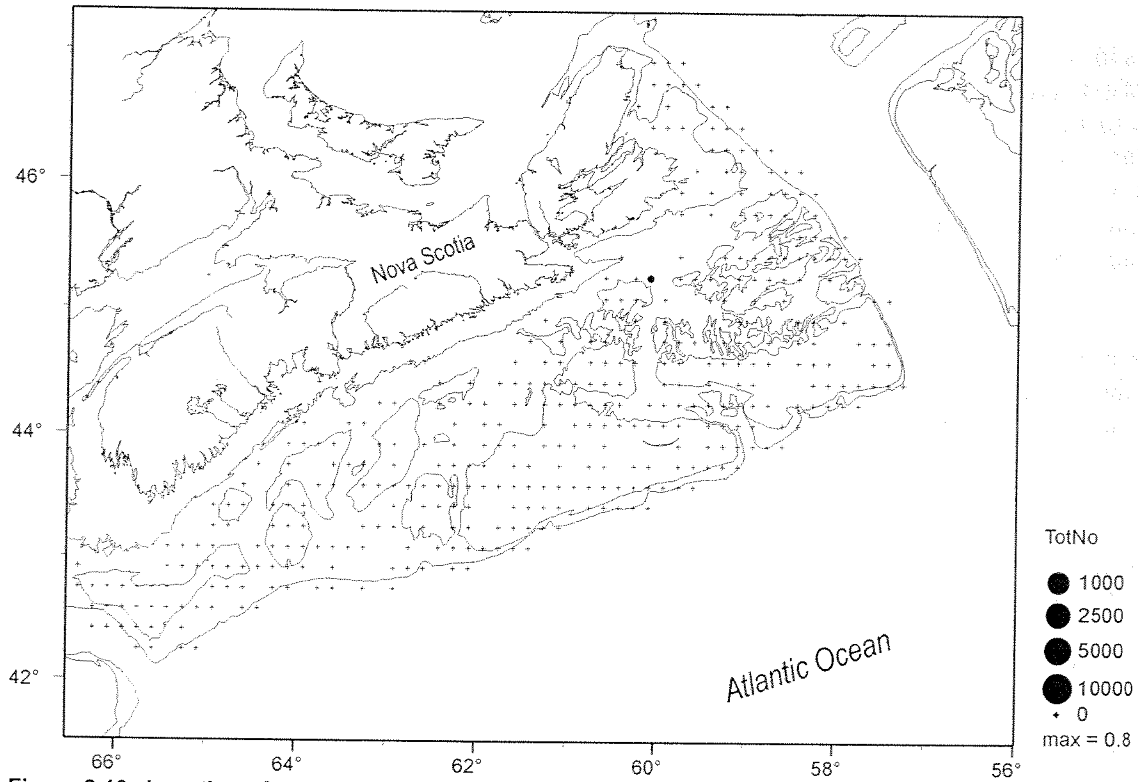


Figure 6-10. Location of capelin caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

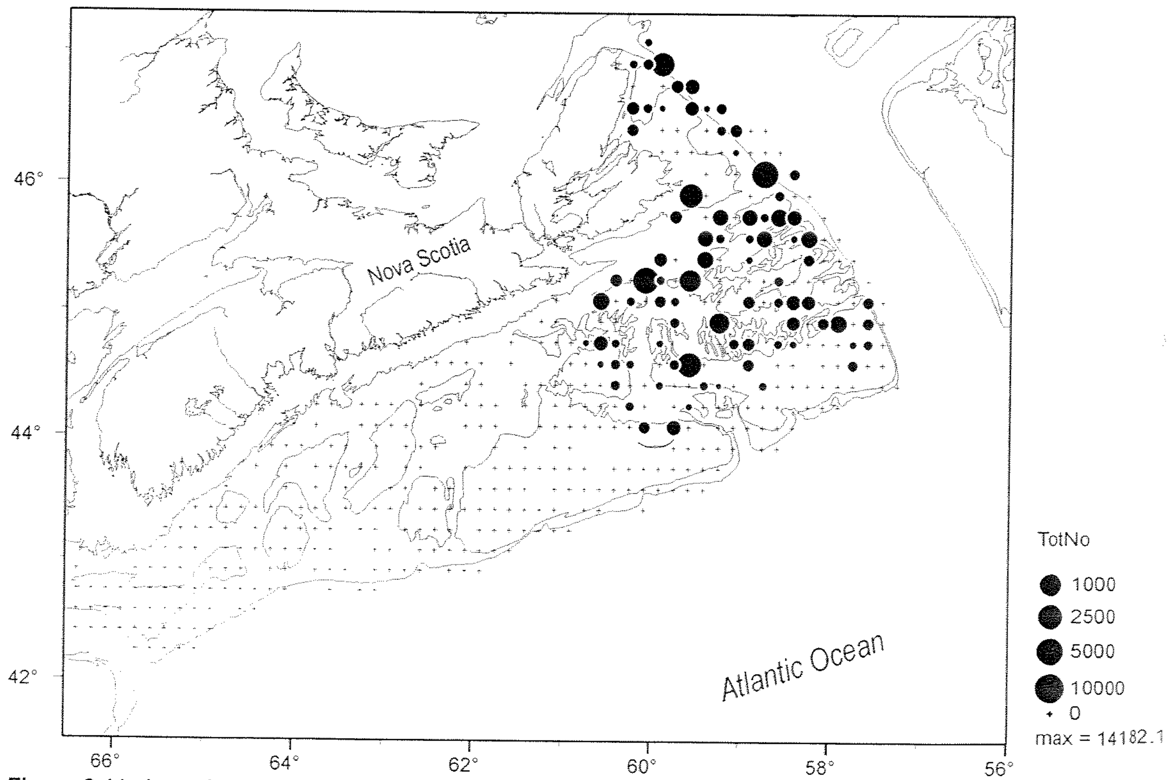


Figure 6-11. Location of capelin caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares.

Most capelin found in the Northwest Atlantic spawn on Newfoundland and Labrador beaches and on the Southeast Shoal of the Grand Bank, a drowned beach that was exposed during the last ice age. They have very specific substrate needs when spawning, choosing beaches with coarse sand or fine gravel (Scott and Scott 1988). Eggs may be buried more than 15 centimetres deep in the sediment (Frank and Leggett 1983). The occurrence of capelin larvae on the Scotian Shelf from the SSIP data can be found in Figure 6-12 (see also Appendix 2 for timing of spawning). Figure 6-13 shows locations where larvae were sampled. It should be noted that these data were collected before capelin were abundant on the eastern shelf.

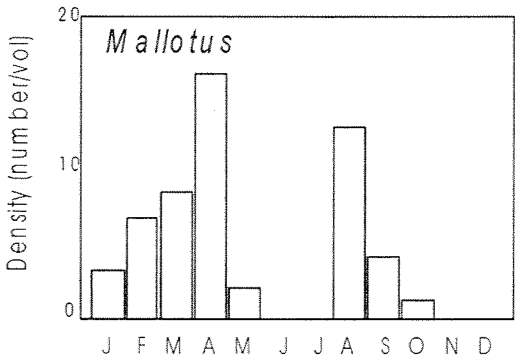


Figure 6-12. Concentrations of capelin larvae in the water column by month, from SSIP data (prepared by N. Shackell).

The presence of capelin in cool waters of the eastern shelf may have resulted in more of their predators in that area, such as seals, whales, and seabirds. If hydrographic conditions return to normal, capelin may leave the area (although they appear to have established a spawning population) (DFO 1997). In the late 1990s, water temperatures were rising and are presently approaching the normal long-term average (Zwanenburg et al. in press).

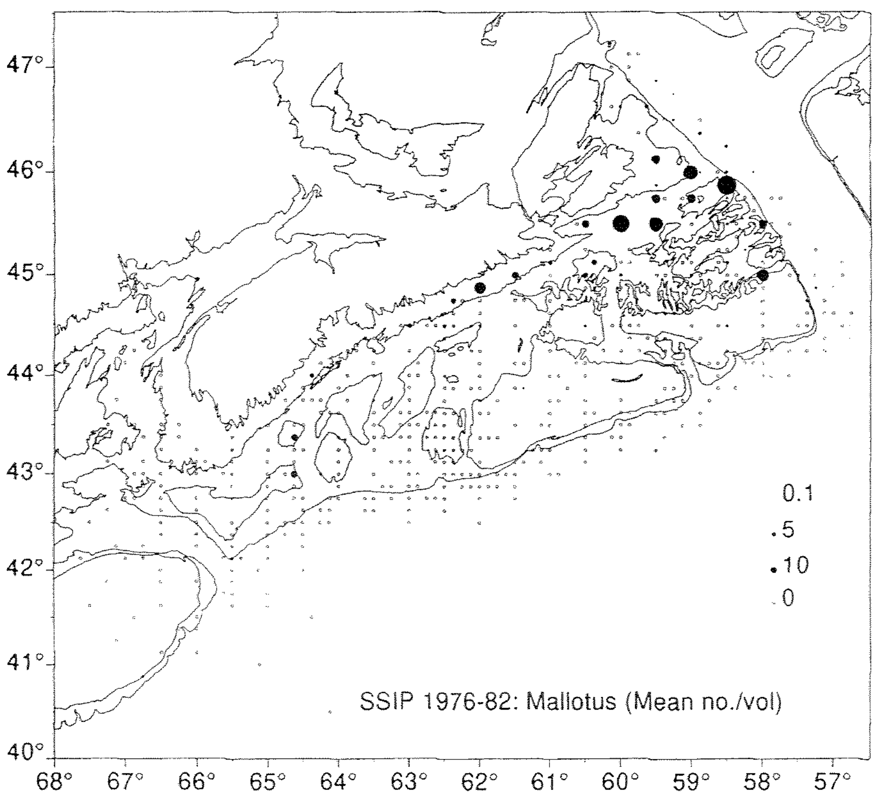


Figure 6-13. Locations where larval capelin were sampled by the SSIP (prepared by N. Shackell).

Atlantic cod (Gadus morhua)

Atlantic cod occur from Greenland to Cape Hatteras in the western Atlantic, within a wide range of temperatures, from about -0.5 to 10°C (Scott and Scott 1988). Preferred temperatures on the Scotian Shelf during summer months are from 3 to 8°C. Habitats are similarly varied, from shallow coastal areas to deep waters at the edge of the continental shelf to about 457 metres (Scott and Scott 1988). There is a general movement of cod from inshore areas and banks in the summer to deeper waters in the winter (Scott and Scott 1988, Swain et al. 1998). Cod from the southern Gulf of St. Lawrence winter in Sydney Bight and further south along the Laurentian Channel (DFO 2001b).

Cod feed on a variety of organisms. Cod larvae eat copepods, amphipods, and other zooplankton, the juveniles eat larger crustaceans, and adults feed on a variety of fish and invertebrates, including other cod (Methven 1999, Scott and Scott 1988). Adults are visual feeders who respond to the movement of prey and diets vary widely according to prey availability (Methven 1999).

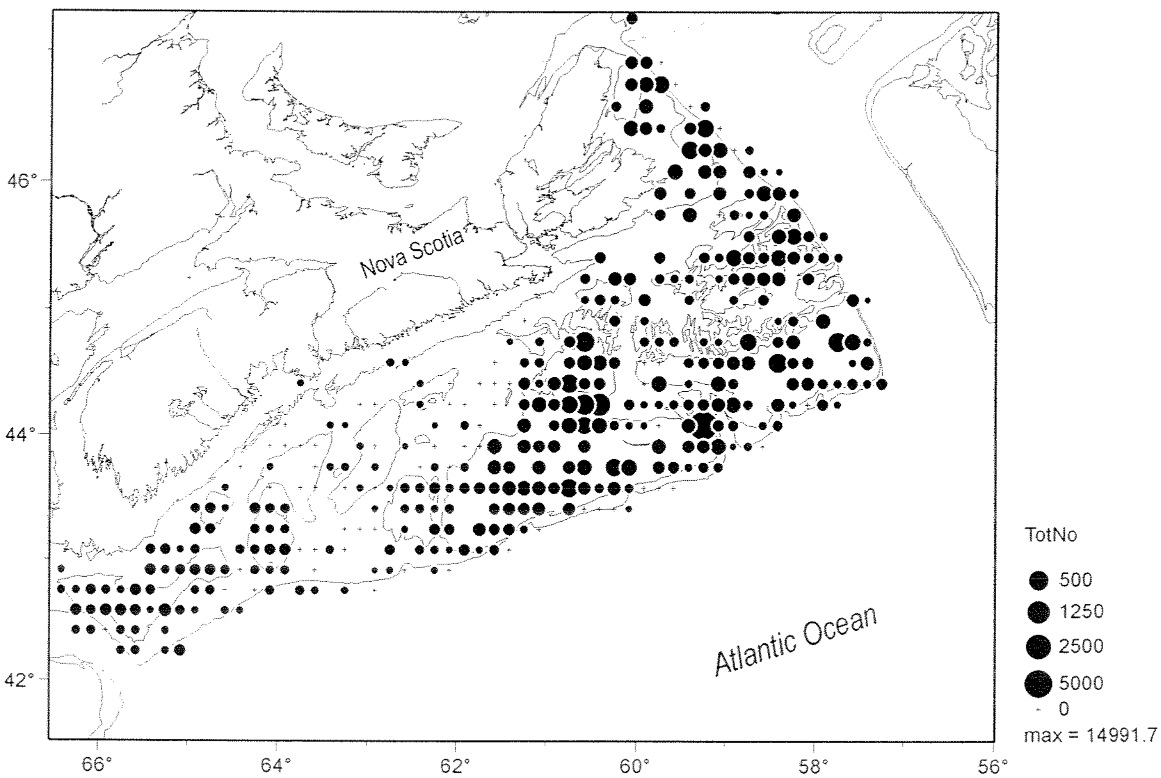


Figure 6-14. Location of cod caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

Northwest Atlantic cod populations severely declined in the late 1980s and 1990s, with the recovery of some populations uncertain. On the Scotian Shelf, cod on the eastern shelf (including the Sydney Bight stock) were most seriously impacted and cod fisheries in these areas have been closed since 1993 (DFO 1998a, DFO 1998b) (see Appendix 4 for closed areas). Both pressure from fisheries and cooling temperatures may have affected fish populations in the eastern area. Work by Castonguay et al. (1999) has demonstrated that cooler mid-depth waters resulted in shifts in cod distribution in the Gulf of St. Lawrence. It has been suggested that there have been changes in the trophic structure of these ecosystems since the collapse of cod and other demersal fish populations (DFO 2000c). On the western Scotian Shelf, populations have also declined; however, the fishery has remained open.[8] Distribution of cod for two periods, 1978 to 1982 and 1996 to 2000, can be found in Figures 6-14 and 6-15. The distribution for these two periods reflects changes in cod populations. Cod were less abundant on the eastern Scotian Shelf during the later period and concentrations were in areas where there was highest abundance during the earlier period.

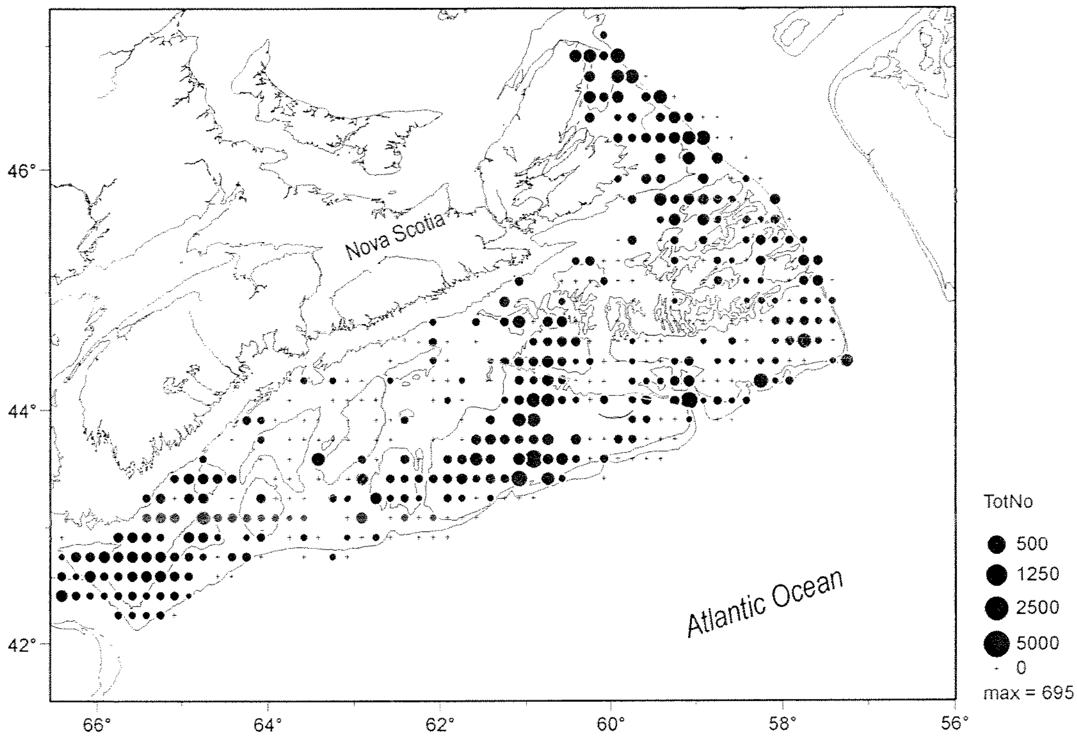


Figure 6-15. Location of cod caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Cod spawn in several locations and various times on the Scotian Shelf. The timing and location of spawning are still not completely understood. Hanke et al. (2000) analyzed data from the SSIP, LHP, and FEP to examine the distribution of cod eggs and larvae at several stages in their life cycle, four stages of eggs and two larval stages. The early stages of cod eggs (stage I and II) cannot be distinguished from haddock or witch flounder. Late stage III eggs are the first that can be identified positively as cod. Advanced stage cod larvae are less widely distributed than eggs. Table 6-5 shows presence and absence of cod at these early life stages on the Scotian Shelf, adapted from Hanke et al. (2000).

Overall, there appears to be two spawning peaks, one starting in January-February on Georges Bank (not included in the table) and spreading northward over the Scotian Shelf into the spring and early summer (Hanke et al. 2000, see also Appendix 2). During the months of July and August, few eggs or larvae are on the shelf. A second spawning period appears to begin in September-October, when eggs have been sampled in the Sable Island Bank and Banquereau Bank areas. Larvae are present in that area into November and December. In inshore regions, early stage cod/haddock/witch flounder eggs have been sampled in March-April and November-

[8] Browns Bank is closed from 1 February to 15 June to protect spawning haddock (see Appendix 4 for closed areas).

December. Inshore areas have not been thoroughly sampled for eggs and larvae and larval cod may be more widespread in coastal areas than suggested by Table 6-5.

Hanke et al. (2000) used presence and absence as the criteria to describe the distribution of cod larvae and eggs, and did not describe their abundance. Data from the SSIP show areas where larvae are concentrated (Figure 6-16). Emerald and Western-Sable Island Banks and Banquereau Banks show the highest density of cod. Again it should be noted that these observations are from the period 1976-1982, well before cod populations dramatically declined. Figure 6-17 shows concentrations of cod larvae, by month.

Table 6-5. Temporal Distribution of Cod Eggs and Larvae, 1975-1995 (adapted from Hanke et al. 2000)*

Region	Months												Life Cycle Stages
	J	F	M	A	M	J	J	A	S	O	N	D	
Misaine Bank and Banquereau			- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	I, II cod/haddock/witch flounder eggs
	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	III cod eggs
					- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	IV cod eggs
					- - -	- - -	- - -	- - -			- - -	- - -	Cod larvae 1-7 mm
											- - -	- - -	Cod larvae >7 mm
Sable Island, Western, and Emerald Banks	- - -	- - -	- - -	- - -					- - -	- - -	- - -	- - -	I, II cod/haddock/witch flounder eggs
	- - -	- - -	- - -	- - -	- - -	- - -			- - -	- - -	- - -	- - -	III cod eggs
	- - -	- - -	- - -	- - -	- - -	- - -			- - -	- - -	- - -	- - -	IV cod eggs
			- - -	- - -	- - -	- - -					- - -	- - -	Cod larvae 1-7 mm
	- - -	- - -			- - -	- - -					- - -	- - -	Cod larvae >7 mm
Browns and Baccaro Banks			- - -	- - -	- - -	- - -	- - -	- - -			- - -	- - -	I, II cod/haddock/witch flounder eggs
			- - -	- - -	- - -	- - -					- - -	- - -	III cod eggs
			- - -	- - -	- - -	- - -					- - -	- - -	IV cod eggs
			- - -	- - -	- - -	- - -							Cod larvae 1-7 mm
			- - -	- - -	- - -	- - -							Cod larvae >7 mm
German Bank and Lurcher shoals			- - -	- - -							- - -	- - -	I, II cod/haddock/witch flounder eggs
					- - -	- - -			- - -	- - -	- - -	- - -	III cod eggs
			- - -	- - -	- - -	- - -			- - -	- - -	- - -	- - -	IV cod eggs
			- - -	- - -	- - -	- - -					- - -	- - -	Cod larvae 1-7 mm
			- - -	- - -									Cod larvae >7 mm
Nearshore areas of Nova Scotia's south shore			- - -	- - -							- - -	- - -	I, II cod/haddock/witch flounder eggs
	- - -	- - -	- - -	- - -	- - -	- - -			- - -	- - -	- - -	- - -	III cod eggs
			- - -	- - -	- - -	- - -					- - -	- - -	IV cod eggs
	- - -	- - -							- - -	- - -	- - -	- - -	Cod larvae 1-7 mm
					- - -	- - -							Cod larvae >7 mm

*Dotted lines signify the presence of a particular cod developmental stage.

Miller et al. (1995) produced somewhat different findings on the timing of cod reproduction. As part of the Ocean Production Enhancement Network (OPEN) program, they sampled cod eggs and larvae in the central Scotian Shelf over a three-year period, 1991-1993. They found a strong autumn (November-December) peak in concentrations of cod eggs, with a prolonged occurrence of eggs from October until May. They found less evidence for strong spring spawning in the years they sampled than other authors, who used data from the SSIP. The area sampled by Miller et al. (1995) covered Emerald Basin in the west to Sable Island Bank in the east.

Frank et al. (1994) compared the data from the OPEN program with the SSIP data and found that the spawning pattern had dramatically changed on the eastern Scotian Shelf. The very low levels of larvae found during the OPEN program suggested that spring spawning had ceased. They concluded that the spring spawning portion of the cod stock had been lost due to overfishing or due to changes in the maturation rate of cod. This change in spawning patterns could be a contributing factor to the continuing low abundance of cod on the eastern Scotian Shelf.

A recent sampling program carried out by Reiss et al. (2000) found evidence suggesting that Western Bank was the only substantial autumn spawning location for cod on the central Scotian Shelf. McLaren et al. (1997) found that conditions of retention provided by the Western Bank system provided better feeding conditions for larval cod than surrounding waters. Their work suggests that certain water masses provide better conditions for larval fish than others. It also suggests that Western Bank may serve as a nursery area for juvenile cod.

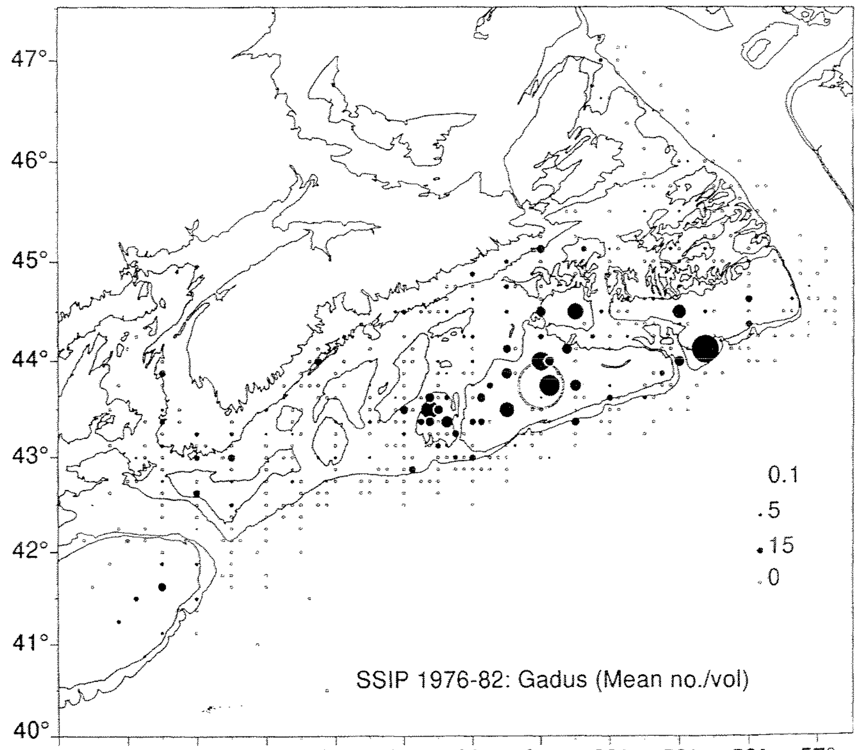


Figure 6-16. Locations where cod larvae were sampled by the SSIP (prepared by N. Shackell).

Cod eggs and larvae are pelagic. When juvenile cod reach a certain stage in their development, they settle to the ocean bottom. Their food preferences change from largely planktonic to largely benthic organisms (see e.g., Bowman 1981). Nova Scotia's Atlantic coast likely has important nursery areas for young demersal cod. However, the distribution of juvenile cod along the coast and preferred habitats in coastal areas have not been well-studied and the importance of these areas to the cod populations of the Scotian Shelf is not known.

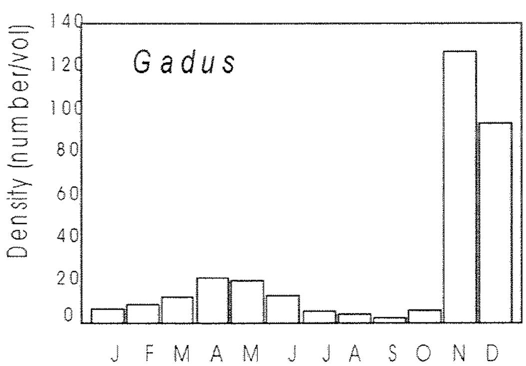


Figure 6-17. Concentrations of cod larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Suthers and Frank (1989) sampled an area off southwestern Nova Scotia that encompassed both offshore and nearshore habitats. They found high concentrations of cod larvae and juveniles in nearshore areas less than 50 metres deep. These cod had likely been spawned on Browns Bank and been carried inshore. Horne and Campana (1989) sampled nearshore habitats on the Bay of Fundy and the southwest Atlantic coast of Nova Scotia for juvenile demersal species in the summer of 1986. The juvenile species were grouped into two assemblages – estuarine and coastal. Cod were part of their coastal assemblage – species that preferred higher surface salinity, water clarity, and larger substrate particles than the estuarine grouping.

Tupper and Boutilier (1995) examined the settlement and growth of cod in four different nearshore habitats in St. Margaret's Bay: sand, seagrass (*Zostera marina*), cobble, and rock reefs (bedrock with large granite boulders). There was little macroalgae cover at these sites. Juveniles showed little preference in choosing one of these sites as a settlement area; however, outcomes were quite different at each settlement site. Survival rate was higher in the rock reef and cobble bottom areas but growth rates were higher in the sea grass areas. After spending the late spring to fall in nearshore habitats, the young-of-the-year cod moved farther offshore.

In Newfoundland, preferred habitats of juvenile cod have been studied in some detail in recent years. Keats (1990) reported that juvenile cod moved into shallow water in coastal areas at night. Age 1 and 2 fish move to waters deeper than 20 metres during the day, while younger cod remained in shallow waters day and night (Keats 1990). Methven and Schneider (1998) also found that the smallest, youngest fish preferred the shallowest depths. Juvenile cod in Newfoundland's coastal waters appear to have a variety of mechanisms to escape predation. Several studies have found that young juvenile cod (up to age 2) prefer habitats with fleshy macroalgae or eelgrass over adjacent habitats with no vegetation (see e.g., Keats et al. 1987, Gotceitas et al. 1997). Gregory and Anderson (1997) found that older juvenile cod (age one to four) showed no preference for habitats with macroalgae, and perhaps associate with it only during summer and fall.

Cobble was the preferred substrate of cod in the presence of foraging predators (Gotceitas et al. 1995). Several other studies have also associated juvenile cod with cobble substrates rather than finer sediments (Fahay et al. 1999). The larger sediment size and the macroalgae and eelgrass seem to be selected because of the protection they afford from predation (Keats et al. 1987, Gotceitas et al. 1995).

Areas in the offshore serve as nursery areas for cod as well. Older juveniles (age three and four) from the Gulf of St. Lawrence cod stock overwinter off northern Cape Breton and along the edge of the Laurentian Channel as far south as Misaine Bank. Younger juveniles are found in the southern Gulf and off northern Cape Breton (Hanson 1996). During the spring, the older juveniles move back into the Gulf, becoming widely dispersed in the summer. Younger juveniles disperse throughout coastal areas during the summer. Other cod nursery areas in offshore Nova Scotia are not as well-known; as mentioned above, it is likely that Western Bank is important for at least early settlement stages.

Haddock (Melanogrammus aeglefinus)

Haddock live from nearshore waters to the edge of the continental shelf. They occupy a wide temperature range, from about 1 to 13°C, and depths from 27 to 366 metres (Scott and Scott 1988). Their preferred summer temperatures and depths are 4 to 8 °C and 55 to 126 metres (Scott 1982b). In winter they move to cooler, deeper waters (2.3 to 3.4°C, 145 to 366 metres) along the edges of banks and basins (Scott and Scott 1988). There are several discrete stocks off Nova Scotia, one in the Georges Bank area, one in the southern Scotian Shelf/ Bay of Fundy area, and one in the area from Emerald Bank to the Laurentian Channel. Fish from the southern Gulf of St. Lawrence population winter on the Scotian Shelf. Distribution of haddock from summer research surveys is shown in Figures 6-18 and 6-19.

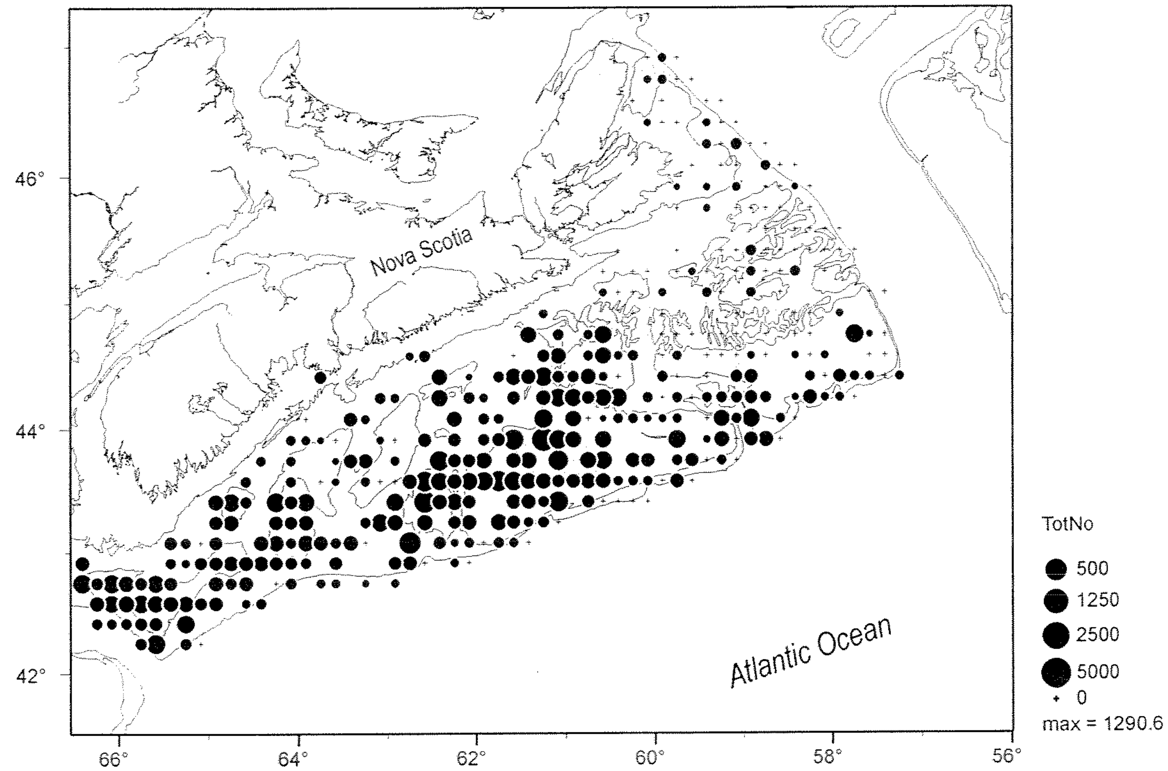


Figure 6-18. Location of haddock caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

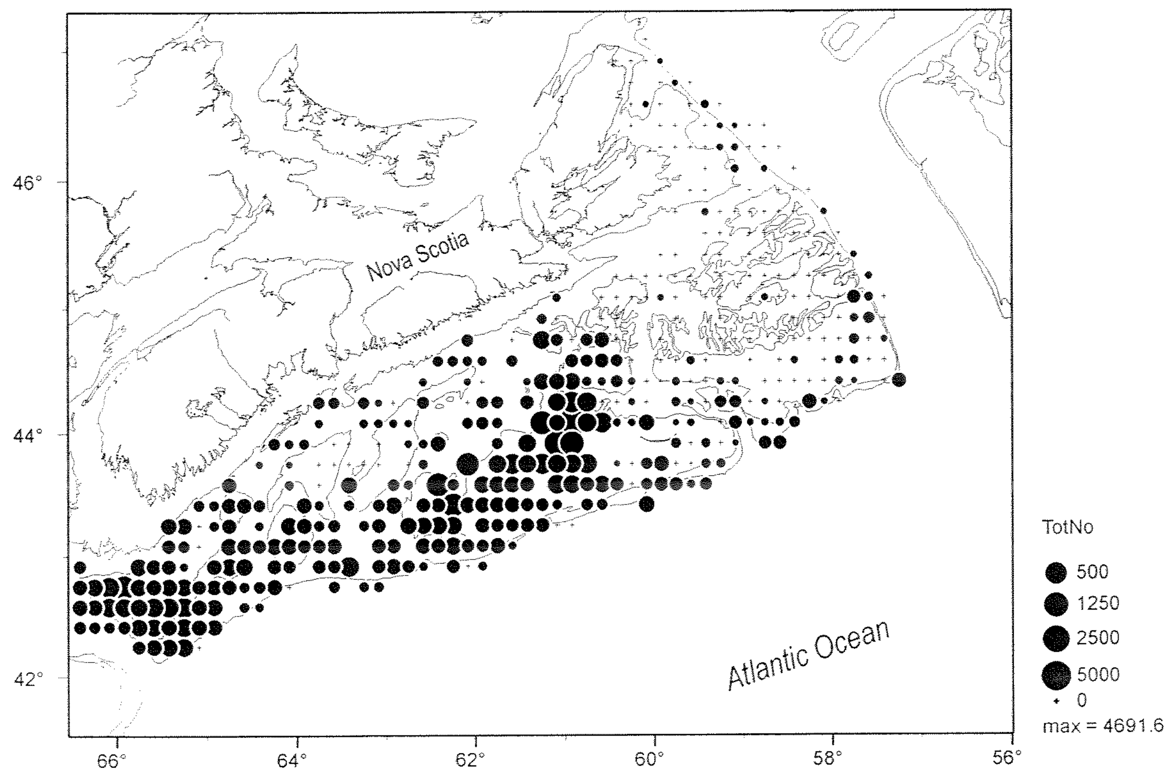


Figure 6-19. Location of haddock caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Haddock eat a variety of bottom-dwelling organisms, including crustaceans, molluscs, starfishes, annelids (segmented worms), fish eggs, and other fish, such as sand lance, capelin, silver hake, herring, and juvenile eels (Scott and Scott 1988). Juvenile fish feed on zooplankton while in the pelagic stage (Methven 1999). When they settle to the bottom they feed generally on the same food as adults (O'Boyle 1985, Methven 1999). Young haddock are prey for other fish, especially cod, pollock, and silver hake (Scott and Scott 1988).

Haddock populations declined in the early 1980s and continue to be low on the eastern Scotian Shelf. Haddock fisheries on the eastern shelf were closed in 1993 and remain closed. On the western shelf, landings were substantially reduced in the early 1990s, as was the total allowable catch (TAC). The TAC continues to be lower than the long-term average (DFO 1999a).

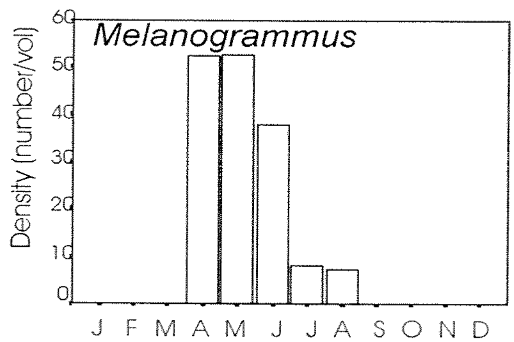


Figure 6-20. Concentrations of haddock larvae in the water column by month, from SSIP data (prepared by N. Shackell).

The occurrence and location of haddock spawning is fairly well-defined when compared to cod. The Scotian Shelf has at least two spawning populations of haddock, one spawning on Browns Bank and off southwestern Nova Scotia and one spawning on Emerald/Western Bank (Hanke et al. 2001a). Another population spawns on eastern Georges Bank and adults from that population inhabit areas of the Scotian Shelf. Spawning off southwestern Nova Scotia occurs on Browns Bank from February to June with peak spawning anytime from April to June (DFO 1999a, see also Appendix 2). Figure 6-20 shows concentrations of haddock larvae in the water column by month, according to the SSIP.

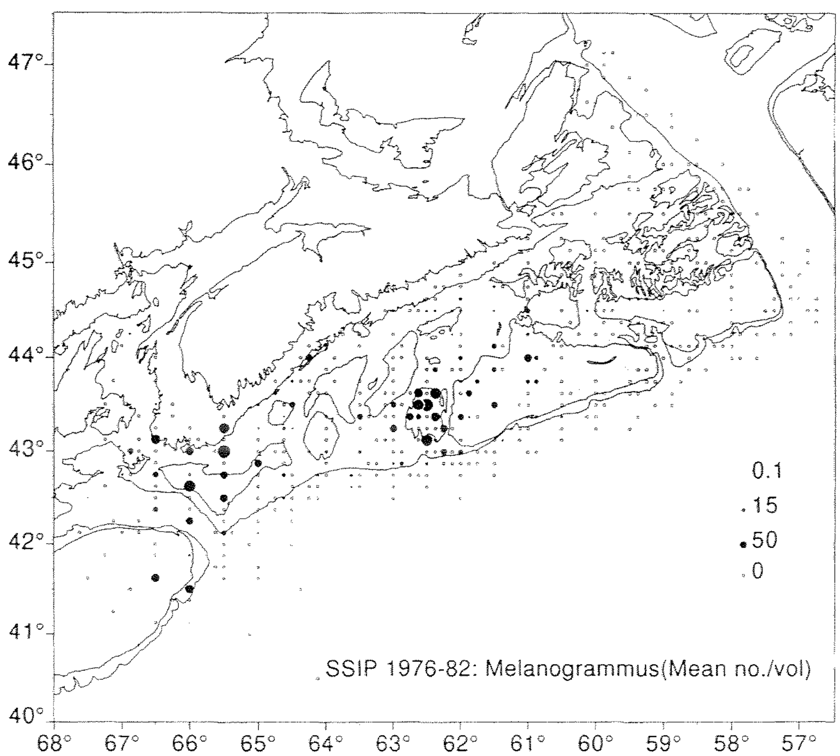


Figure 6-21. Locations where haddock larvae were sampled by the SSIP (prepared by N. Shackell).

Further east, spawning is concentrated on Western and Emerald Banks during March and April (Scott and Scott 1988, Shackell et al. 1999, Hanke et al. 2001a). Distribution of haddock larvae from the SSIP data can be found in Figure 6-21.

An area of Browns Bank is closed to fishing from 1 February to 15 June to protect spawning fish (DFO 2000c). Shackell et al. (1999) and Brickman and Frank (2000) investigated the dispersal of egg and larval haddock from Browns Bank. Some of the larvae were retained on Browns Bank, others were dispersed into the Bay of Fundy and inshore waters of southwest Nova Scotia, and still others moved west into the Gulf of Maine. Young haddock appear to prefer sand or gravel bottoms and have better survival rates when they settle on those sediments (O'Boyle 1985, Brickman 2001). Both Browns Bank and the inshore waters of southwest Nova Scotia are important areas for juvenile haddock.

Spawning further east on the shelf is concentrated on Emerald and Western-Sable Island banks. Eggs, larvae, and juvenile haddock are found in this area. A section of Emerald and Western Banks, which became known as the haddock nursery area or haddock box, was closed to mobile groundfish gear in 1987 to protect juvenile haddock concentrated in that area (see Appendix 4, closed areas). An evaluation of the closure concluded that impacts of the closure on juvenile haddock were not clear; however, other haddock year classes experienced lowered mortality, as did other species (DFO 1998c, Frank et al. 2000). The area adjacent to the closed area has been closed to all haddock and cod fishing since 1993, and all groundfish fishing (including fixed gear) ceased in the juvenile haddock closed area in 1993 as well. Scallop dragging and invertebrate fishing are not restricted in the haddock box.

Juvenile haddock (age groups 0 and 1) were caught in great numbers in the shallows around Sable Island during trawl surveys for juvenile fish in 1981 (Scott 1982a, Scott 1987). Fish in their first year were found in the shallowest waters (27 to 37 metres), while the age one fish were generally in slightly deeper waters (37 to 46 metres). There was a rapid decline in the catch of juvenile haddock in subsequent years of the survey, from 1982 to 1985 (Scott 1984, Scott 1987). Scott (1987) speculated that the Sable Island shallows were an overspill nursery area, used only in years of exceptional abundance, or that the young fish had shifted location due to changed hydrographic conditions.

Pollock (Pollachius virens)

Pollock occur from southwestern Greenland to Cape Hatteras in the western Atlantic, with greatest concentrations in the Georges Bank, Gulf of Maine, and Scotian Shelf areas (Scott and Scott 1988, DFO 1999c). They are also found in the eastern Atlantic. Pollock prefer temperatures from 0 to 10°C (McGlade et al. 1984) and depths of 110 to 181 meters, with an overall depth range from 37 to 364 metres (Scott 1982b). Young pollock migrate inshore in summer and spend the winters in offshore areas (Scott and Scott 1988). They move permanently to deeper waters when two years old (Scott and Scott 1988). Distribution of pollock from summer research surveys is show in Figures 6-22 and 6-23.

Although considered a demersal species, pollock range throughout the water column in pursuit of prey and show schooling behaviour like pelagic fishes (DFO 1999c). Pollock eat fish and crustaceans, shrimp, herring, sand lance, silver hake, and redfish, as well as squid (DFO 1999c, McGlade et al. 1984, Scott and Scott 1988, Methven 1999). The krill *Meganyctiphanes norvegica* is an important component of the diet, especially for fish less than 61 centimetres (Methven 1999). Larval pollock feed on copepods. When juvenile fish settle to the bottom and move inshore, they feed mostly on small crustaceans (Scott and Scott 1988).

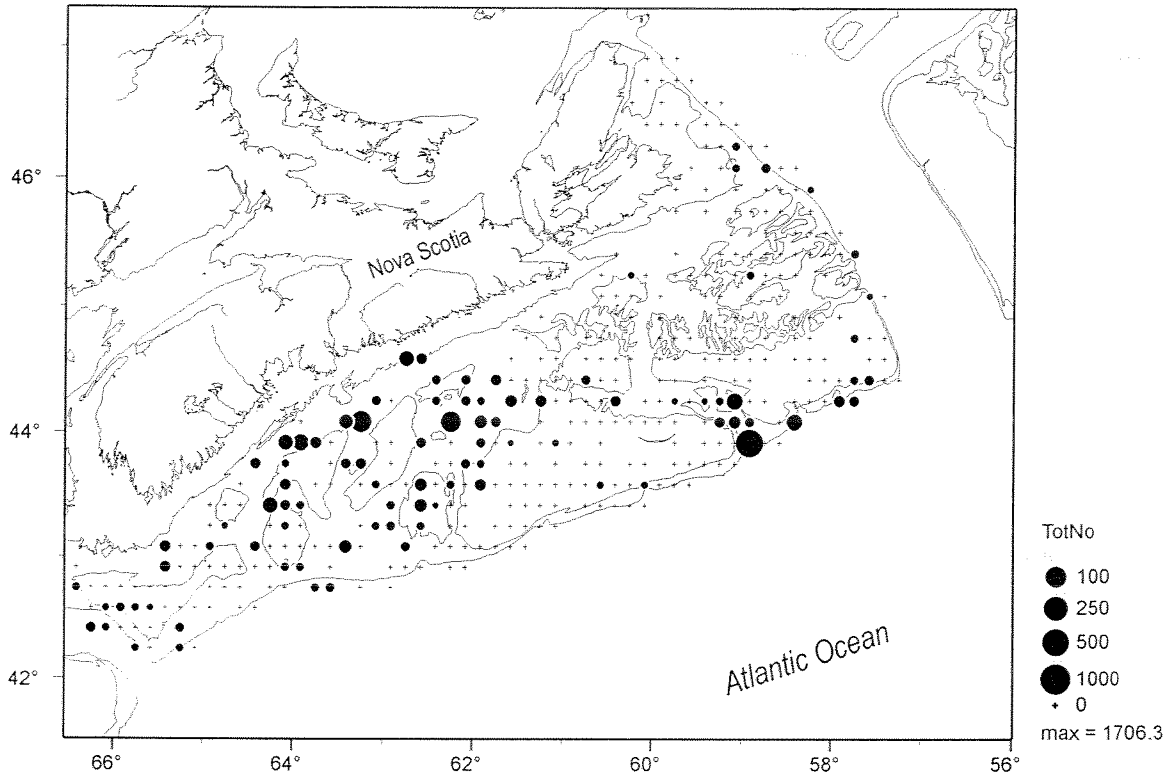


Figure 6-22. Location of pollock caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

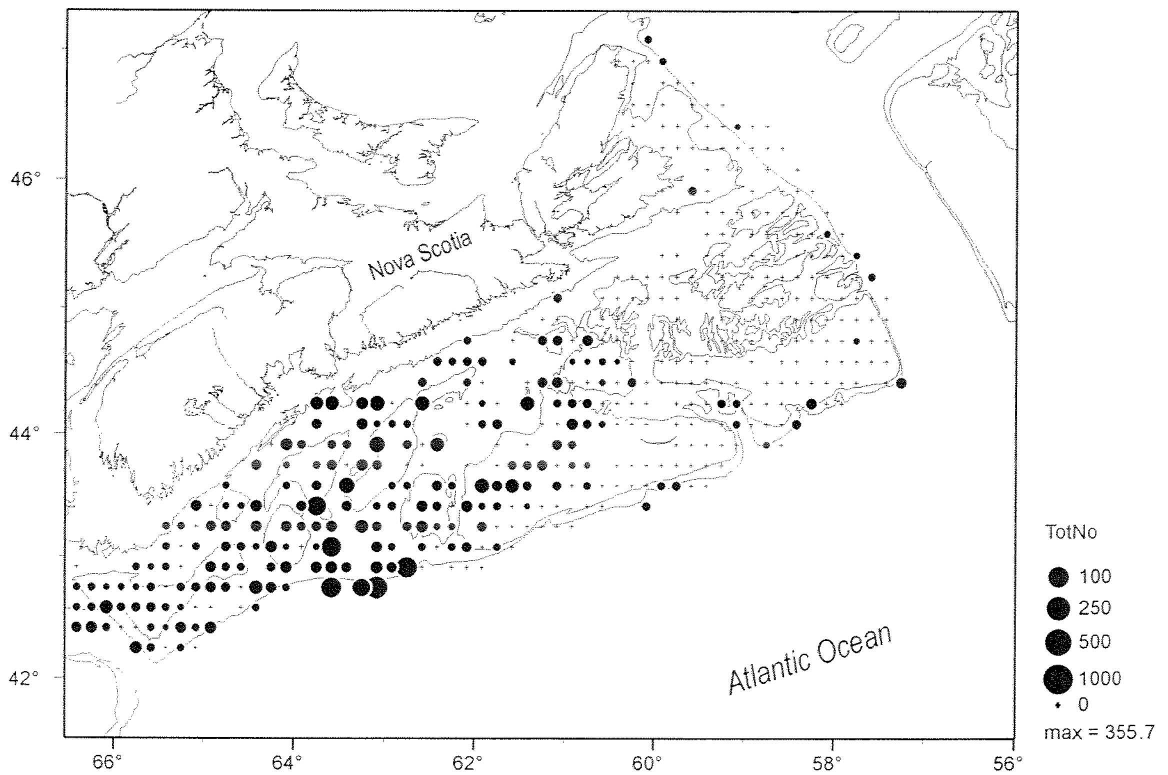


Figure 6-23. Location of pollock caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

O'Boyle et al. (1984) found that pollock appeared to spawn mostly in the Emerald-Western Bank area from November to February, with perhaps another spawning aggregation in March-April. However, a recent compilation of all available ichthyoplankton data inferred other primary spawning areas: Browns Bank, coastal Nova Scotia, and the shelf off southwest Nova Scotia (Hanke et al. 2001b). Another population spawns on Georges Bank. Spawning appears to occur at different times in different areas, with stage 1 eggs appearing on Browns Bank in September-October and persisting until May-June. Southwest Nova Scotia had concentrations of stage 1 eggs from September-October until January-February. The Emerald-Western Bank area showed few occurrences of stage 1 eggs; however, later developmental stages were found there in some concentration (see also Appendix 2 for spawning times). Figure 6-24 shows concentrations of pollock larvae in the water column, by month, from the SSIP data. Distribution of pollock larvae from SSIP data is found in Figure 6-25.

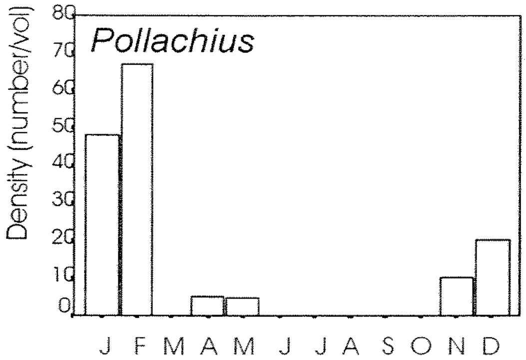


Figure 6-24. Concentrations of pollock larvae in the water column by month, from SSIP data (prepared by N. Shackell). See text for other times eggs and larvae are present on the Scotian Shelf.

Juvenile pollock migrate inshore at about 3 to 6 months of age and remain there until near the end of their second year (Clay et al. 1989, Cargnelli et al. 1999b). Subtidal and intertidal zones are thought to be important nursery areas for juvenile pollock (Rangeley and Kramer 1995, Cargnelli et al. 1999b). A study of juvenile fish in nearshore areas in southwestern Nova Scotia and the Bay of Fundy found numerous juvenile pollock in two areas, and few or none in the other six nearshore habitats considered in the study (Horne and Campana 1989). They are found over a variety of substrates and a wide temperature range (Cargnelli et al. 1999b).

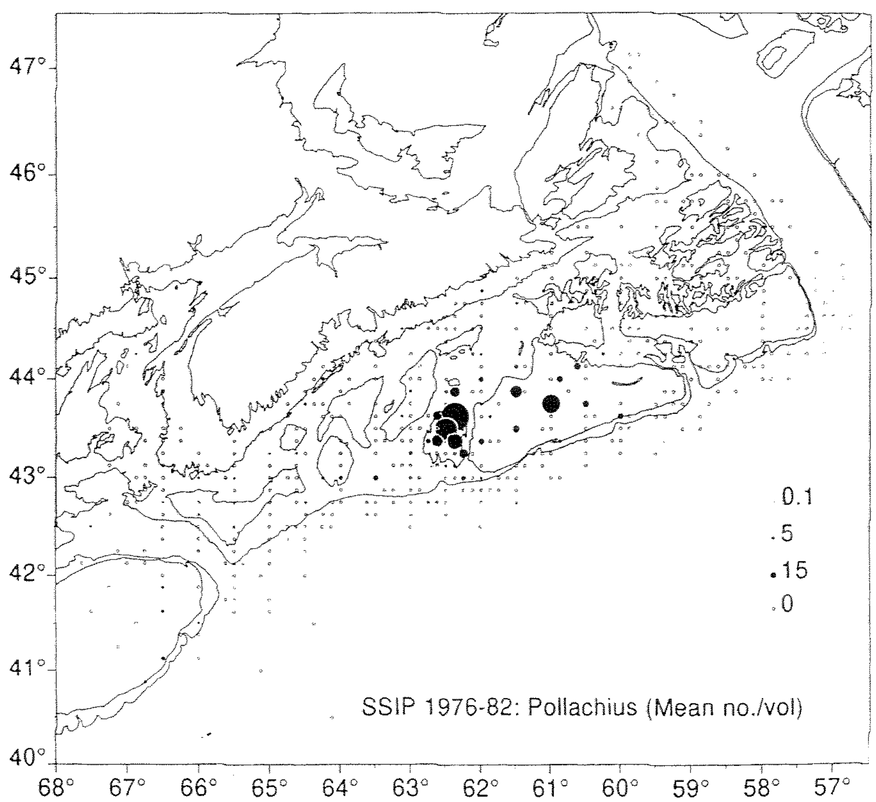


Figure 6-25. Locations where pollock larvae were sampled by the SSIP (prepared by N. Shackell).

Pollock stocks on the Scotian Shelf have not declined to the same degree as those of haddock and cod, although landings and the total allowable catch have declined fairly steadily since the early 1990s (DFO 1999c).

Silver hake (Merluccius bilinearis)

Silver hake are distributed from the Strait of Belle Isle to the Bahamas, but are most common from southern Newfoundland to South Carolina (Cohen et al. 1990). They live in a wider range of depths than cod, haddock, and pollock, the other Gadiformes described here. Silver hake occur from very shallow waters along the coast to depths over 910 metres (Scott and Scott 1988). On the Scotian Shelf, they are most common along the shelf edge and in Emerald and LaHave Basins (DFO 1999b). They live in shallower waters in the summer and move to deeper waters in the winter as the shallow waters cool (Scott and Scott 1988). Sigaev (1996) found that silver hake preferred temperatures of 7.5 to 10.5°C during the summer and the shelf-slope front appeared to provide optimal conditions for them. Distribution of silver hake from summer research surveys can be found in Figures 6-26 and 6-27.

Adult silver hake feed on many other fish species, especially members of the cod family and juvenile silver hake (Scott and Scott 1988). They will also feed on pelagic fish, squid, and crustaceans. Although silver hake are considered a demersal species they migrate upwards through the water column in pursuit of prey (Scott and Scott 1988). Small silver hake (less than 40 millimetres) on the Scotian Shelf feed mainly on invertebrates, especially krill and copepods (Koeller et al. 1989, DFO 1999b). Juvenile silver hake over 46 millimetres feed on other small silver hake to a significant amount. They do not feed on other juvenile commercial fish as there are few other species of commercial juvenile fish present when silver hake are at this developmental stage (Koeller et al. 1989).

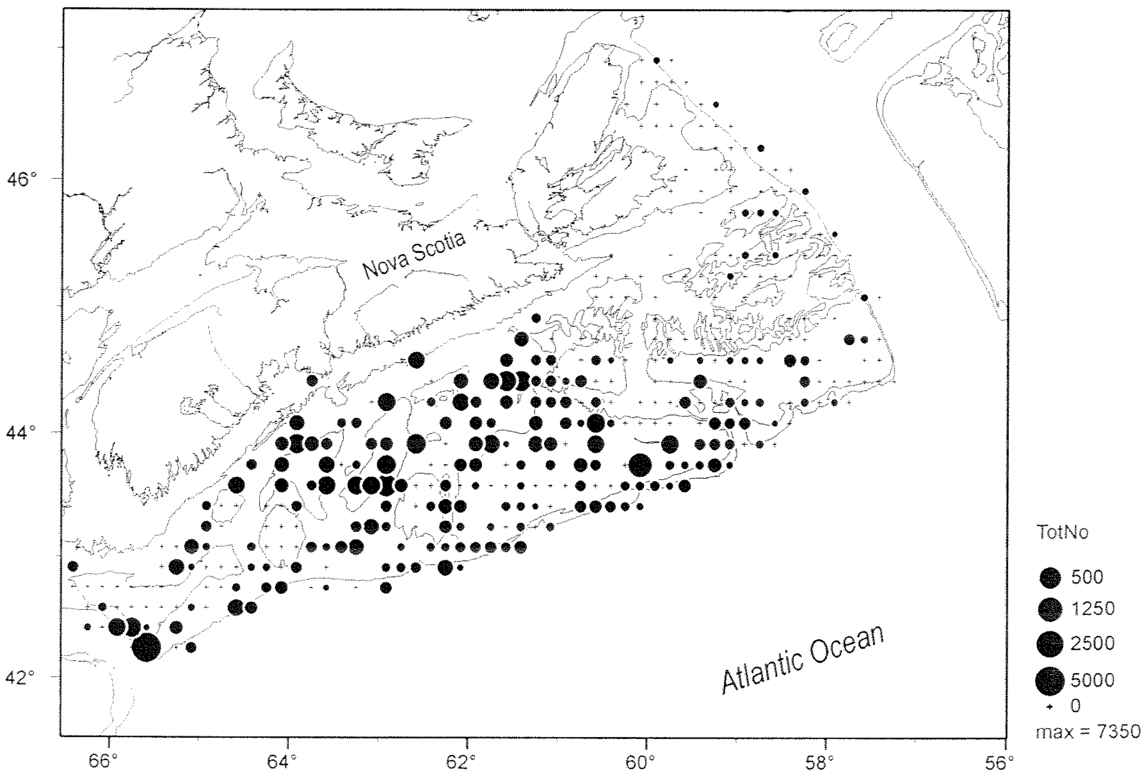


Figure 6-26. Location of silver hake caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

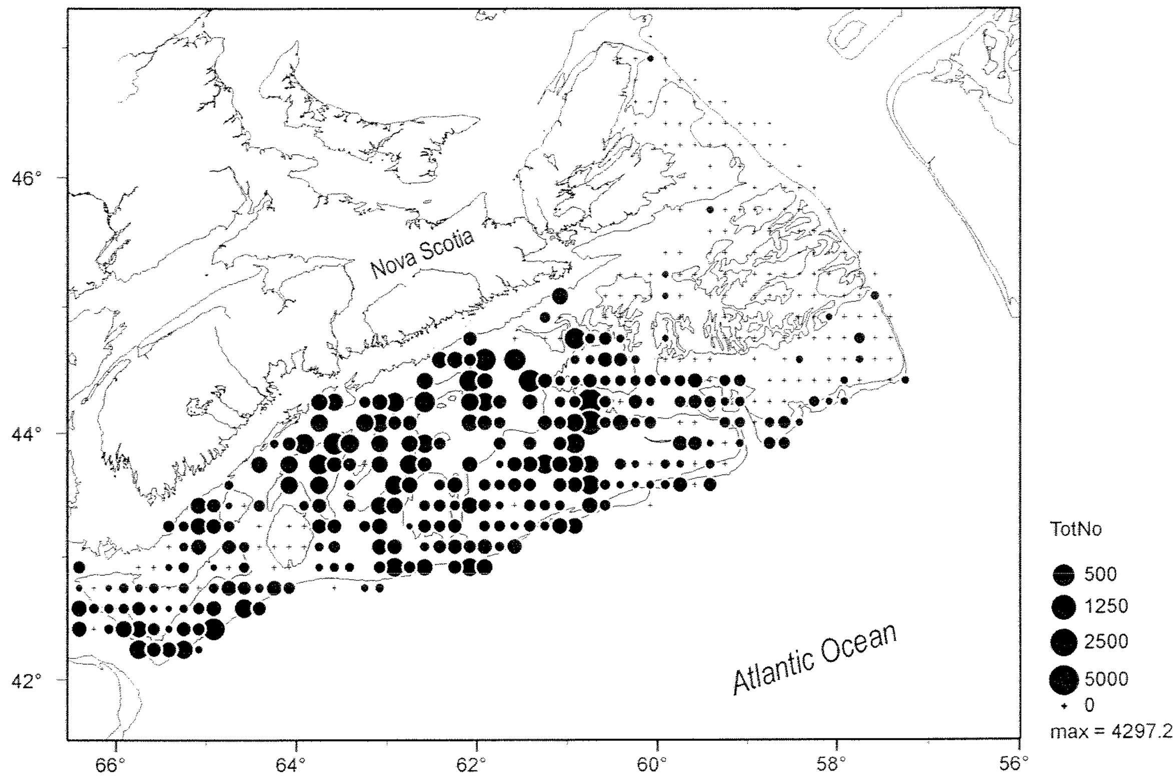


Figure 6-27. Location of silver hake caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

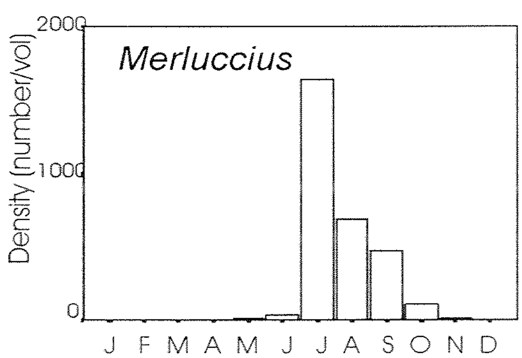


Figure 6-28. Concentrations of silver and offshore hake larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Silver hake spawn on Sable and Western Banks from June to September, with some spawning further east on Banquereau (DFO 1999b, Scott and Scott 1988). Peak spawning occurs in July and August on Western-Sable Island Banks. Figure 6-28 shows concentrations of silver hake and offshore hake larvae in the water column over the year (see also Appendix 2). Distribution of silver and offshore hake larvae, from the SSIP data, is shown in Figure 6-29 (the two species are not separated in the SSIP data). This figure shows a concentration of ichthyoplankton on Western-Sable Island banks. Fortier and Villeneuve (1996) sampled silver hake larvae in this area and Emerald Bank during a different sampling program. They found the densest concentrations of silver hake larvae in their study area were in shallow waters southwest of Sable Island. Sigaev (1996) found that spawning was most concentrated in areas near Sable Island during the first 10 days of July.

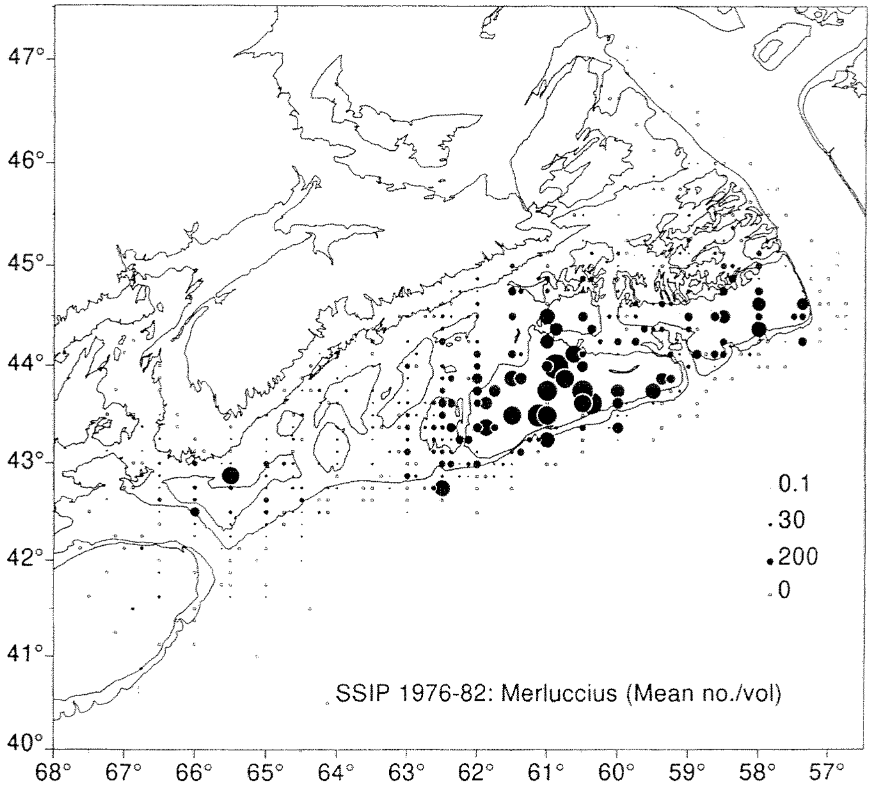


Figure 6-29. Locations where silver and offshore hake larvae were sampled by the SSIP (prepared by N. Shackell).

The population status of silver hake on the Scotian Shelf is not clear. There have been high rates of mortality and indicators of stock condition are at low levels; however, overall trends do not give clear indicators of overall population status (DFO 1999b). The fishery is restricted to a particular area seaward of 190 metres along the slope due to the small mesh gear used to catch silver hake (see Appendix 4 for boundaries of silver hake box).

Sand lances (Ammodytes spp.)

Two species of sand lance occur on the Scotian Shelf, the American sand lance (*Ammodytes americanus*) and the northern sand lance (*Ammodytes dubius).* It can be difficult to distinguish the two species and, as both play a similar role in the ecosystem, they are discussed together.

The American sand lance occurs in inshore waters from Hudson Bay and the Hudson Strait south to Virginia. It inhabits shallow waters. In the Gulf of Maine, the American sand lance was found in depths of 6 to 20 metres (Scott and Scott 1988). The northern sand lance occurs from Hudson Bay and Greenland south to the Scotian Shelf. It has a more offshore distribution than the American sand lance; however, the two species co-occur (Scott and Scott 1988). Scott (1982) considered 73 to 90 metres to be the preferred depth range of the northern sand lance. This may actually be the deepest part of its range on the Scotian Shelf. The highest concentrations of sand lance on the Scotian Shelf (species unidentified) were found in depths less than 50 metres (DFO 1996). Both species live on sandy bottoms and burrow in the sand to escape predators (Scott and Scott 1988, DFO 1996). They are found in a temperature range of 1 to 11°C in summer (DFO 1996). Substrate and depth may be more important factors than temperature in determining appropriate sand lance habitat (Scott 1982b).

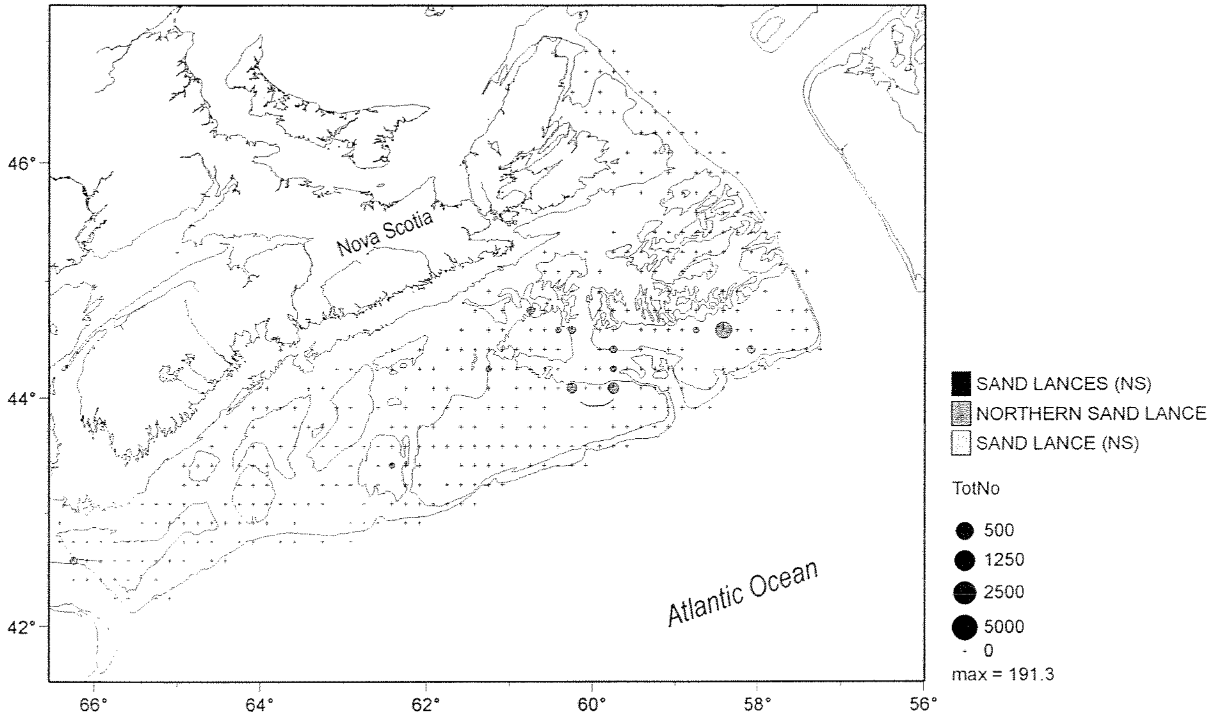


Figure 6-30. Location of sand lances caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

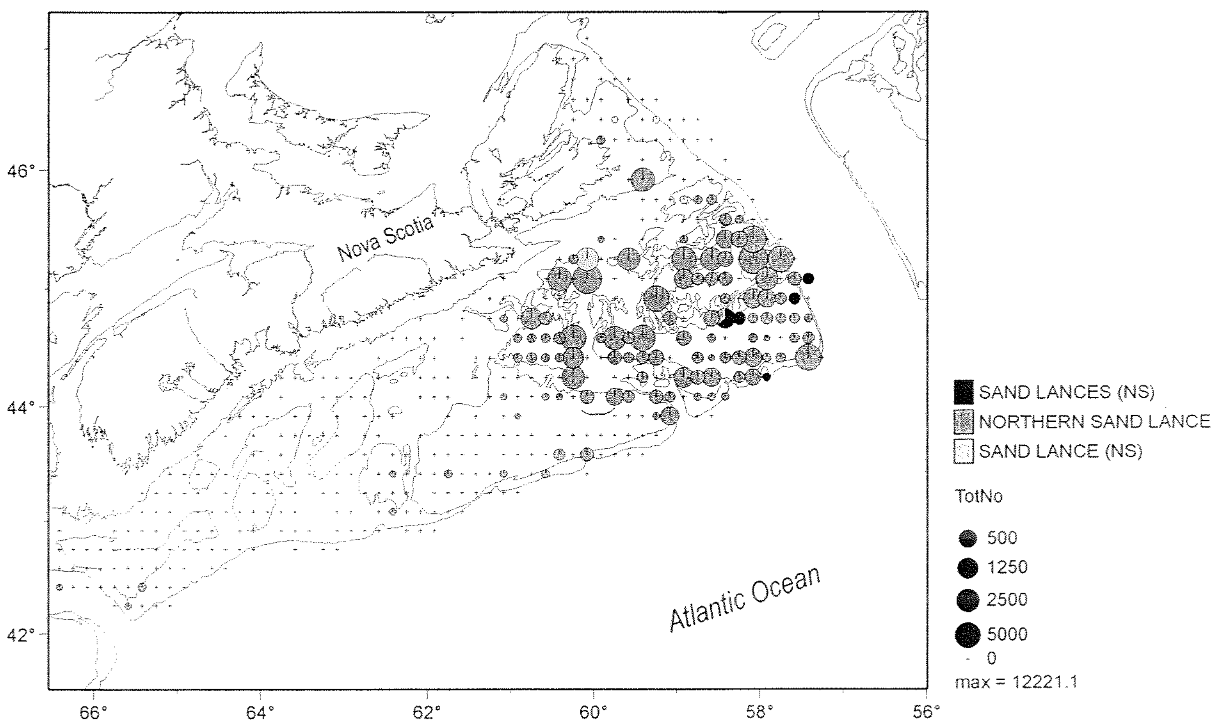


Figure 6-31. Location of sand lances caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Distribution of sand lances on the Scotian Shelf from demersal research trawl surveys is shown in Figures 6-30 and 6-31. The species of sand lances are not consistently distinguished from each other in the research surveys and there are three different species codes for sand lance in the research survey database. Because of the burrowing behaviour of sand lances, standard research trawls are generally not an effective way to sample for these species (DFO 1996). Earlier, non-standardized surveys have shown a broader distribution of sand lance on the outer banks (DFO 1996), not just the eastern shelf as shown in Figures 6-30 and 6-31.

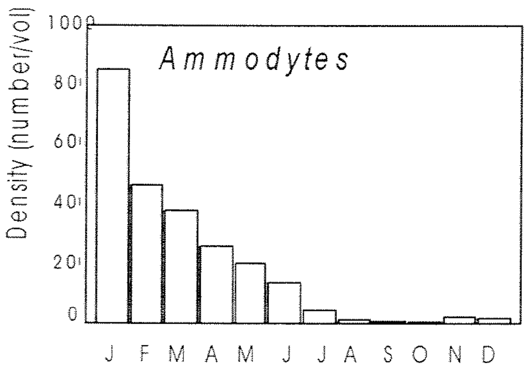


Figure 6-32. Concentrations of sand lance larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Sand lance feed on a variety of planktonic organisms. Their primary food is the copepod *Calanus finmarchicus*. They rise to surface waters at night to feed, returning to the bottom during the day to avoid predators (Scott and Scott 1988, DFO 1996).

Sand lance release demersal eggs that adhere to bottom sediments (Scott and Scott 1988). Larvae have been concentrated on Sable Island and Middle Banks and these are likely the major spawning sites on the shelf (DFO 1996). Peak spawning occurs in the winter months (Figure 6-32) (Scott and Scott 1988, see also Appendix 2). Figure 6-33 shows the distribution of eggs and larvae from SSIP data.

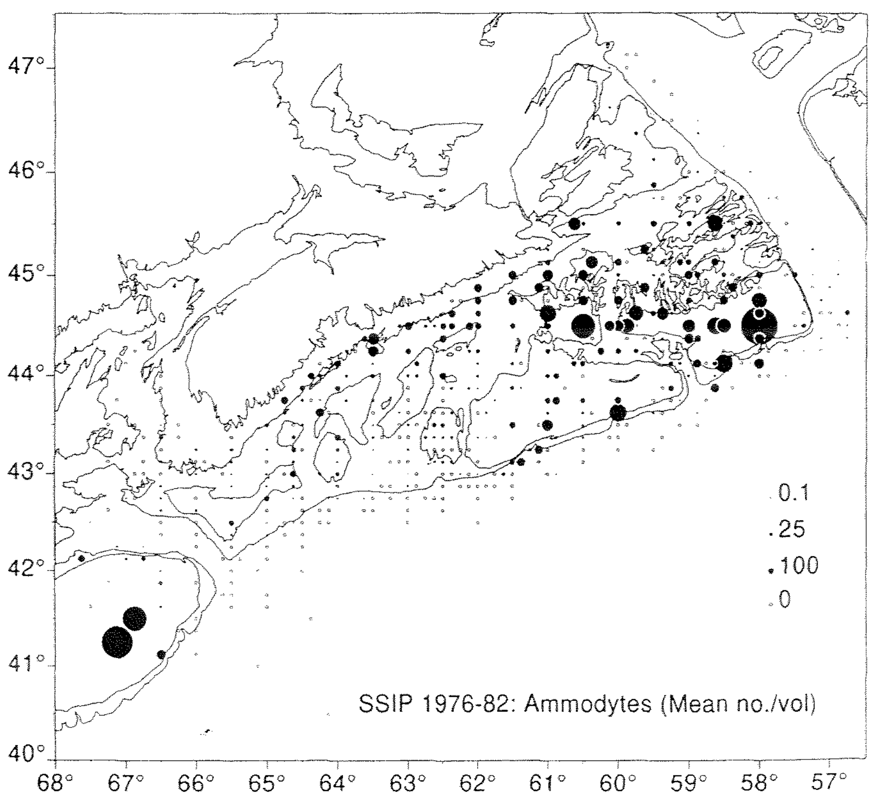


Figure 6-33. Locations where sand lance larvae were sampled by the SSIP (prepared by N. Shackell).

Sand lance are important prey for many species of fish, marine mammals, and seabirds and may attract predator species to areas where concentrations are high. Seabird reproductive success has been attributed to the availability of sand lance in some areas (Robards et al. 1999). Fishermen have reported high catch rates of haddock and cod when sand lance are plentiful (DFO 1996). Better definition of sand lance distributions could also provide information on the distribution of predator species.

*Atlantic mackerel (*Scomber scombrus)

Mackerel are highly migratory schooling fish which are distributed from southern Labrador to North Carolina. They are found in coastal waters from spring until fall, moving inshore as water temperatures warm up. They prefer temperatures between 9 and 12°C and move to waters offshore during the winter to stay in waters above 8°C, although they do occur in temperatures outside that range (Kulka and Stobo 1981, Scott and Scott 1988). They appear to overwinter along the shelf edge from Sable Island Bank south to Chesapeake Bay (Studholme et al. 1999).

Individual schools and fish range widely and are distributed according to temperature and other environmental preferences. Distribution of mackerel according to research trawl surveys can be found in Figures 6-34 and 6-35. The groundfish research trawl is not an effective way to sample for this pelagic species and these figures do not show complete distribution on the Scotian Shelf. Most of the mackerel caught by the trawl survey are young, immature fish (Grégoire, pers. communication). Mackerel are widely distributed in coastal areas in the summer, especially large bays. These inshore areas are not sampled by the summer research trawl survey. Their summer occurrence is strongly tied to temperature (DFO 2000d).

Mackerel filter feed on small planktonic organisms and also pursue individual prey, such as amphipods, euphausiids, shrimps, small squid, and fish eggs and larvae (Scott and Scott 1988). Larval mackerel over 5 millimetres in size prey on other larval fish, especially mackerel but also other species available at this time of year – yellowtail flounder, silver hake, and redfish (Fortier and Villeneuve 1996). Mackerel are prey for many species including whales, seals, sharks, bluefin tuna, cod, and swordfish.

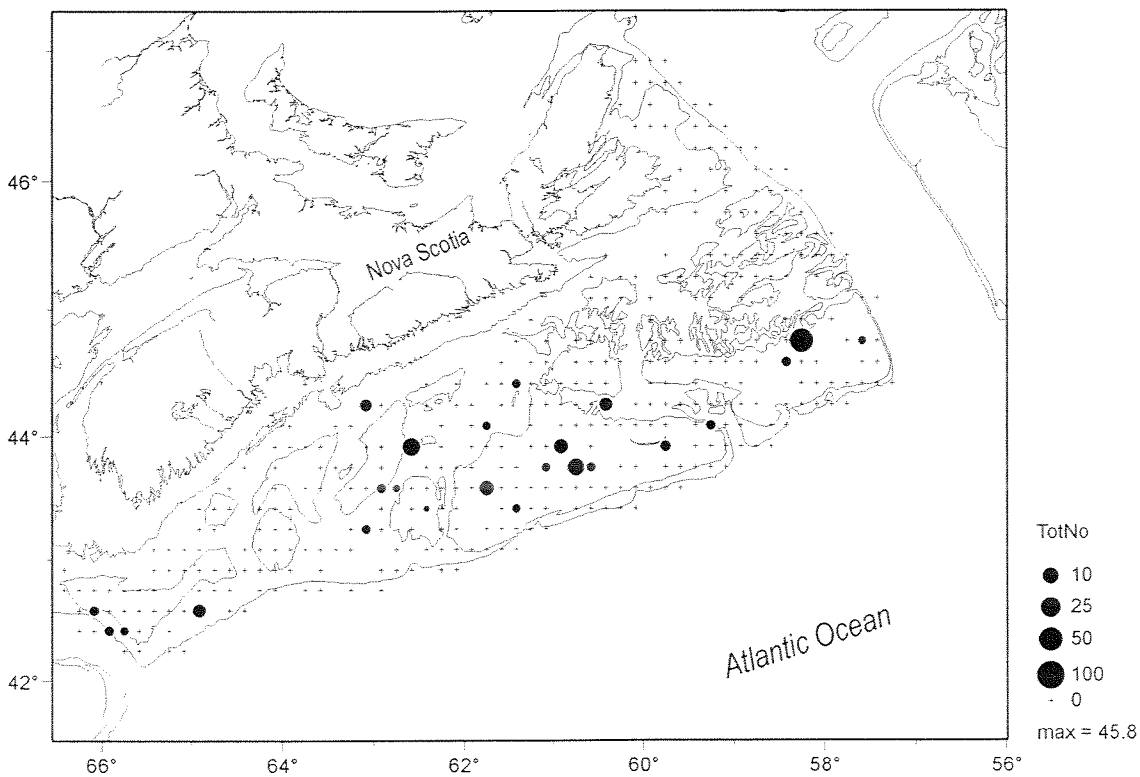


Figure 6-34. Location of mackerel caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

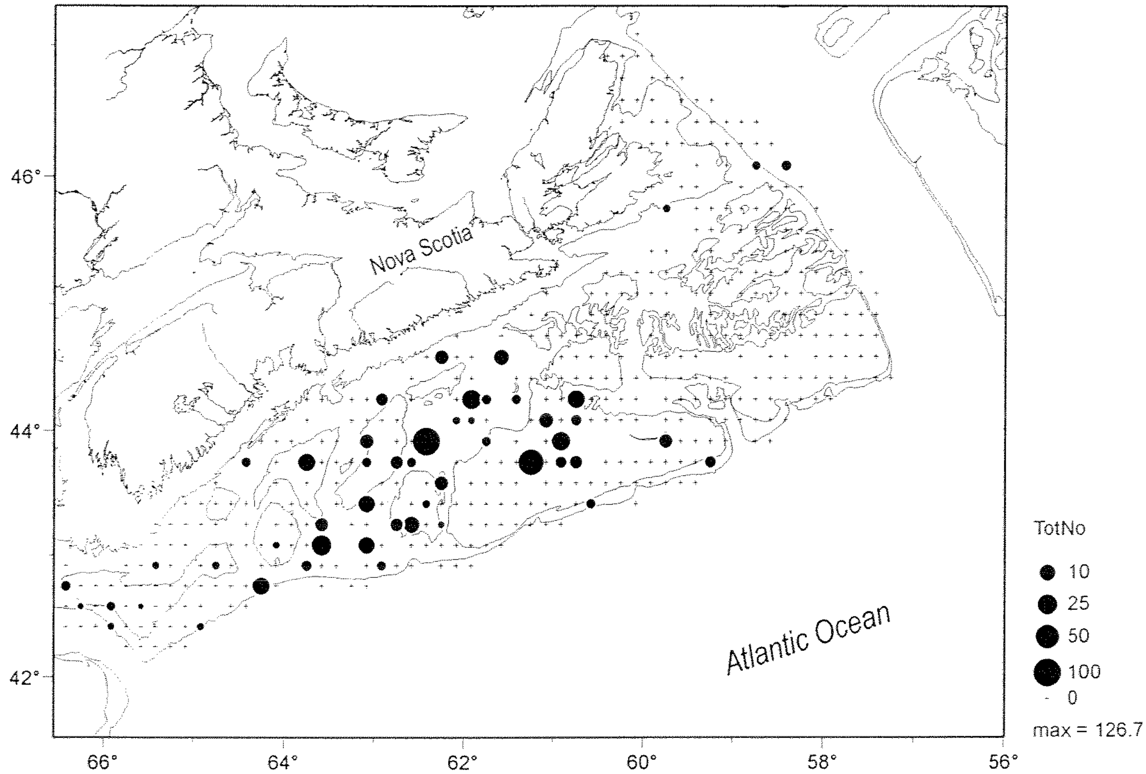


Figure 6-35. Location of mackerel caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

There are two main mackerel populations, a northern one that spawns in the Gulf of St. Lawrence and a southern one that spawns between Cape Cod and Cape Hatteras. Some spawning also occurs along the Atlantic coast of Nova Scotia and perhaps along Newfoundland's southeastern coast (DFO 2000d, Parsons and Hodder 1970). Spawning occurs from the end of May to mid-June along Nova Scotia's coast (Sette 1943). Mackerel eggs were sampled in significant numbers in St. Margaret's Bay, Nova Scotia, in June 1999, during an exploratory survey requested by mackerel fishermen (Bernier and Lévesque 2000). Mackerel larvae have also been sampled offshore on Emerald, Western, and Sable Island Bank (Fortier and Villeneuve 1996). The size and age of the larvae suggested that spawning occurs in shallow waters west of Sable Island in June or July.

In the Gulf of St. Lawrence, mackerel spawn from mid-June to mid-July (Scott and Scott 1988). Eggs are pelagic. When the juvenile fish reach about 5 centimetres in length, they begin to form schools (DFO 2000d). Some young mackerel from the Gulf of St. Lawrence stock appear to spend the first couple of years of their lives on the Scotian Shelf and shelf edge before migrating north to the Gulf to spawn (Grégoire, pers. communication). Kulka and Stobo (1981) sampled the shelf edge from The Gully to Cape Cod in winter. They found that mackerel in their first and second years (age groups 0 and 1) were found in much greater numbers than adult mackerel in samples taken along the edge of the Scotian Shelf. Significiant numbers of juvenile mackerel were sampled off Cape Cod; however, in those samples, age groups were mixed.

Localized abundance of mackerel is highly variable and temperature dependent (DFO 2000d). Populations as a whole are also variable. There are strong pulses of recruitment followed by years of very low recruitment to the stock (Anderson and Paciorkowski 1980, see also Runge et al. 1999).

Bluefin tuna (Thunnus thynnus)

Bluefin tuna are large, migratory pelagic fish. They travel from wintering areas in the Gulf of Mexico and off Florida north to the Scotian Shelf, the Gulf of St. Lawrence, and Newfoundland in summer. They are found on the Scotian Shelf from about June to October, when water temperatures warm (Scott and Scott 1988). Larger animals are believed to be able to better tolerate cool temperatures. Medium-sized animals are thought to be able to tolerate temperatures as low as 13°C (Rivas 1978 in Scott and Scott 1988). The smallest adult tuna are found off Nova Scotia only in late summer and early fall, when the water is warmest. Bluefin tuna are a pelagic schooling fish and are not sampled by the summer groundfish research survey. Scientists rely entirely on commercial catch, effort, and size data for assessments (Porter, pers. communication). Locations of landings from the Scotian Shelf for the period 1996-2000 can be found in Figure 6-36.[9] Figure 6-37 shows annual landings by weight since 1972.

Tuna feed on a variety of fish and invertebrates, including capelin, herring, mackerel, silver and white hake, barracudina, squid, and euphausiids (Scott and Scott 1988). Some sharks prey on tuna but in general, these large fish have few enemies.

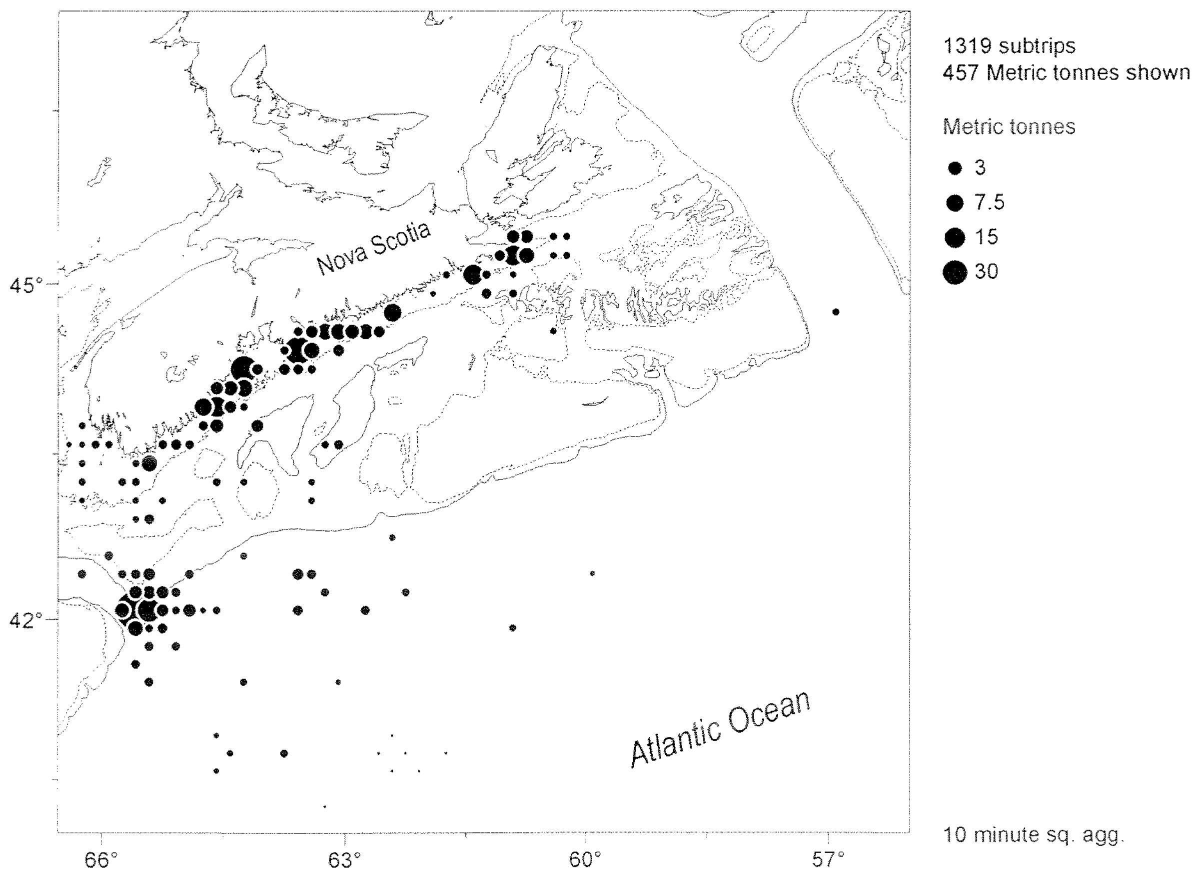


Figure 6-36. Location of bluefin tuna catches from commercial fisheries on the Scotian Shelf, 1996-2000, aggregated by 10 minute squares.

[9] Location data for the earlier period, 1978-1982, was not available.

Tuna found on the Scotian Shelf reproduce in more southerly areas: in the Gulf of Mexico, off Florida, or perhaps in the mid-Atlantic (Scott and Scott 1988, Lutcavage et al. 1999). There is uncertainty about the stock structure of bluefin in the Atlantic and evidence of mixing of assumed eastern and western Atlantic tuna stocks could mean that some tuna caught off Nova Scotia may have spawned in the Mediterranean (see e.g., Lutcavage et al. 1999).

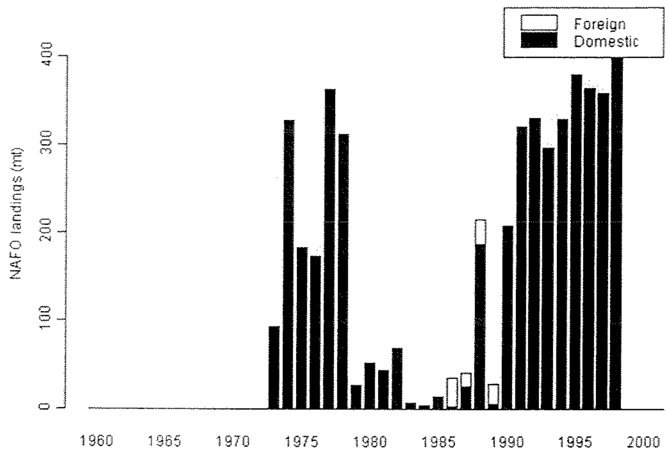


Figure 6-37. Landings (in metric tonnes) of bluefin tuna caught in NAFO Divisions 4V, 4W and 4X. Landings from 1960 to 1972 not available.

The status of bluefin tuna is assessed by ICCAT (International Commission for the Conservation of Atlantic Tunas). Estimates of the size of the Western Atlantic population have been dropping steadily since the mid-1970s for almost all age groups (Sissenwine et al. 1998). The spawning stock biomass according to the most recent ICCAT assessment is less than 20 percent of the spawning stock biomass in 1970 and is near historically low levels. There is, however, a great deal of uncertainty associated with the population estimates (Sissenwine et al. 1998).

Swordfish (Xiphias gladius)

Like bluefin tunas, swordfish are long-distance travellers that inhabit waters off Nova Scotia between June and October. The fish's distinctive sword makes it easy to identify, and dangerous – there are tales of animals attacking fishing boats (Scott and Scott 1988, Fitzgerald 2000). They are fast swimmers that move through the water column to depths greater than 600 metres (Carey and Robison 1981). Locations of swordfish landings on the Scotian Shelf are shown in Figure 6-38. Annual landings by weight are shown in Figure 6-39. During the summer, swordfish are concentrated on offshore fishing banks, along the shelf edge, and further offshore in waters above 15°C. Large fish appear to be able to better tolerate cooler waters (Fitzgerald 2000). They inhabit warm waters of the Gulf Stream during the winter (Beckett 1974).

Ninety percent of the swordfish caught in Canada are taken by longline. Before 1960, all of the swordfish were captured by harpoon. For instance, there used to be a prosperous swordfish fishery off Cape Breton in the first half of the twentieth century; however, swordfish stocks declined in the area in the late 1950s and early 1960s (Fitzgerald 2000). Since then, most landings have come from farther offshore, where the longliners fish on the shelf edge.

Swordfish feed on a variety of foods: fish such as mackerel, barracudinas, silver hake, redfish, and herring, and invertebrates such as squid and krill. They have even been known to attack whales (Scott and Scott 1988). Swordfish migrate to waters of the Scotian Shelf during summer to take advantage of abundant food. Young swordfish provide food for tuna and shark. Larger ones have few enemies except larger sharks (and even they may prefer to attack swordfish hooked on longlines) (Scott and Scott 1988).

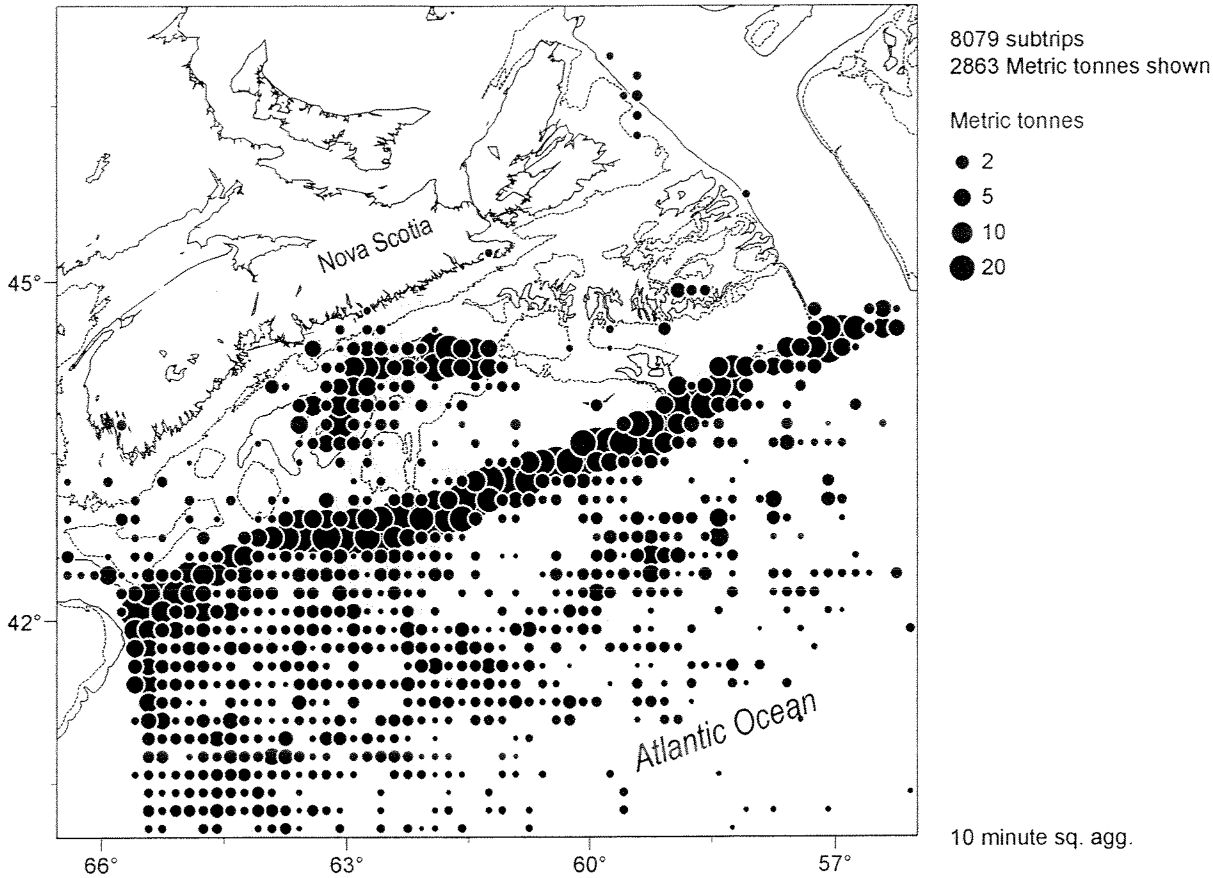


Figure 6-38. Location of swordfish catches from commercial fisheries on the Scotian Shelf, 1996-2000, aggregated by 10 minute squares.

Swordfish do not reproduce off Nova Scotia; however, a section of the Scotian Shelf is closed to swordfish fishing to protect swordfish broodstock (see Appendix 4 for closed areas). There is evidence that they spawn in all months of the year (Porter pers. communication). Their varied diet and presumed episodic spawning are features that make them especially resilient to fishing mortality and when given a chance, depressed stocks can quickly recover.

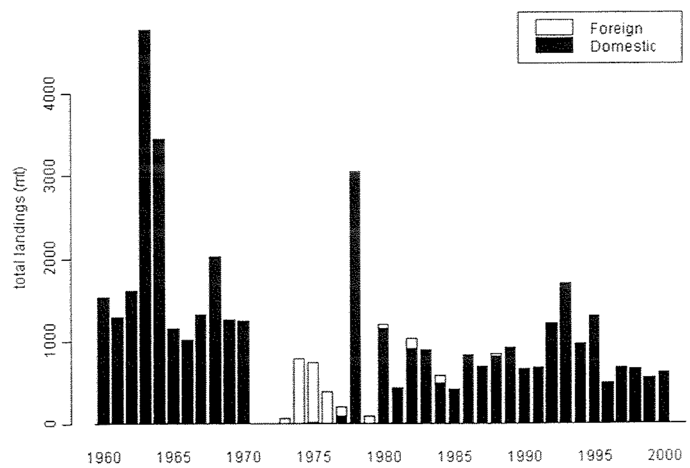


Figure 6-39. Landings (in metric tonnes) of swordfish caught in NAFO Divisions 4V, 4W and 4X.

Stocks are assessed and quotas are assigned to each country by ICCAT. Currently, fishing mortality for the North Atlantic stock is estimated to be above the maximum sustainable yield rate and ICCAT estimates of stock biomass have shown a steady decline since the 1950s. The biomass in 1999 was only 65 percent of that needed to produce maximum sustainable yield (ICCAT 1999). Like bluefin tuna, there is concern that swordfish are being harvested before they have the opportunity to spawn (ICCAT 1999, Fitzgerald 2000). Concerns have also been expressed about the removal of other species by the swordfish longline fishery, such as sharks, marine mammals, and turtles (Fitzgerald 2000, Smith 2001).

Redfishes (Sebastes spp.)

Two species of redfish occur regularly on the Scotian Shelf, *Sebastes fasciatus* (Acadian redfish) and *Sebastes mentella* (beaked redfish). Another species, *Sebastes marinus*, may be a rare visitor to the shelf. All three species are difficult to distinguish by appearance (DFO 2000e). They are generally not separated in research surveys or in fisheries landings, although they have different depth preferences and distributions. *Sebastes fasciatus* occurs from the Gulf of Maine to the Strait of Belle Isle (rare on the Labrador Shelf) from shallow waters to 592 metres in depth (Scott and Scott 1988). Its preferred depths and temperatures in the Gulf of Maine are 128 to 366 metres and 2.8 to 8.3°C. On the Scotian Shelf, it occurs generally in deep basins and at the shelf edge (DFO 2000f). In the western Atlantic, *Sebastes mentella* occurs from Baffin Island to the Scotian Shelf in deep waters (350 to 1100 metres) (Scott and Scott 1988). It is generally found in deeper slope waters than *S. fasciatus*. Off Nova Scotia, the major overlap of the two species occurs in the Laurentian Channel and on the eastern Scotian Shelf and slope (DFO 2000f). Distribution of redfish on the Scotian Shelf from research surveys can be found in Figures 6-40 and 6-41.

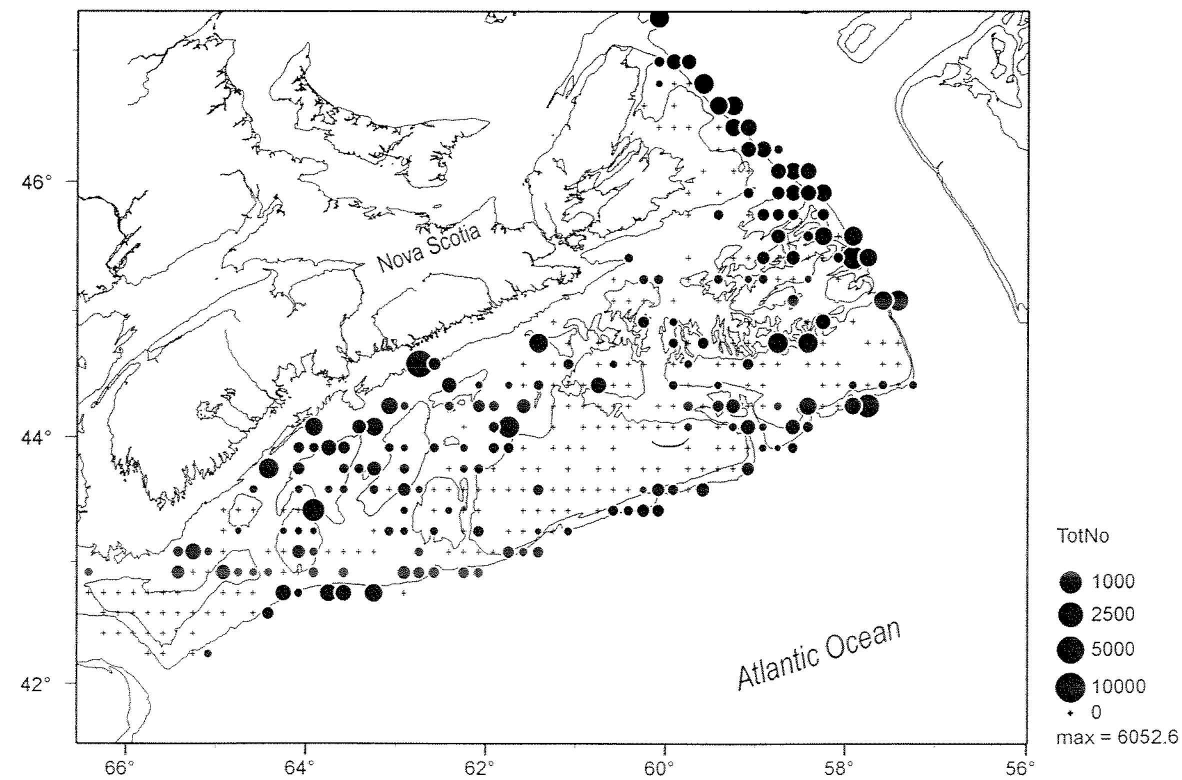


Figure 6-40. Location of redfish caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

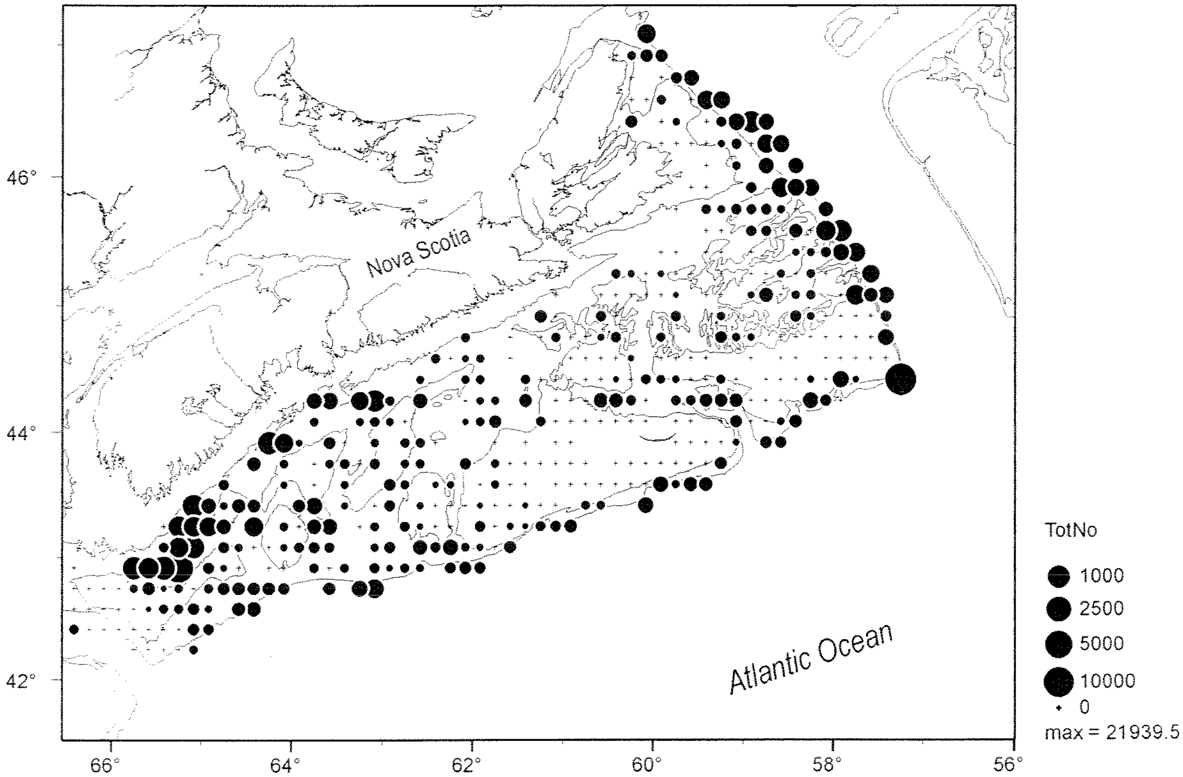


Figure 6-41. Location of redfish caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

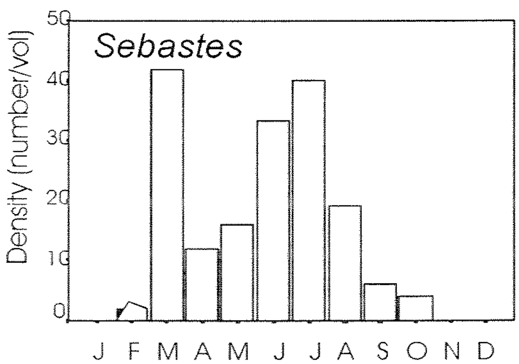


Figure 6-42. Concentrations of redfish larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Redfish rise to midwater depths at night to feed on pelagic crustaceans (amphipods, copepods, and euphausiids) and small fishes. Larger redfish feed on pelagic crustaceans and some pelagic fish (Methven 1999). Redfish are preyed on by cod, Atlantic and Greenland halibut, and swordfish (Scott and Scott 1988).

Redfish are ovoviviparous; in other words, eggs develop inside the female and live young are born. On the Scotian Shelf, young are released from March to July (DFO 2000e). Monthly concentrations of larvae in the water column are shown in Figure 6-42 and distribution of larvae sampled on the Scotian Shelf in Figure 6-43. Larvae were taken fairly widely over the shelf from March to October, with a peak in March and again in July (O'Boyle et al. 1984, see also Appendices 2 and 3). The young are pelagic until they reach about 25 millimetres in size, at which time they move to the ocean floor. An area north of Browns Bank known as the "bowtie" is closed to small mesh gear (less than 130 millimetres mesh size) to protect juvenile redfish (DFO 2000c, 2000f) (see Appendix 4 for closed areas).

With the decline of other groundfish stocks in the early 1990s, fishing pressure on redfish increased (DFO 2000e). The population on the western shelf is assessed separately from the eastern shelf and appears stable (DFO 2000f). On the eastern shelf and Laurentian Channel, larger fish are the primary targets of the fishery and stock status is somewhat less certain (DFO 2000e).

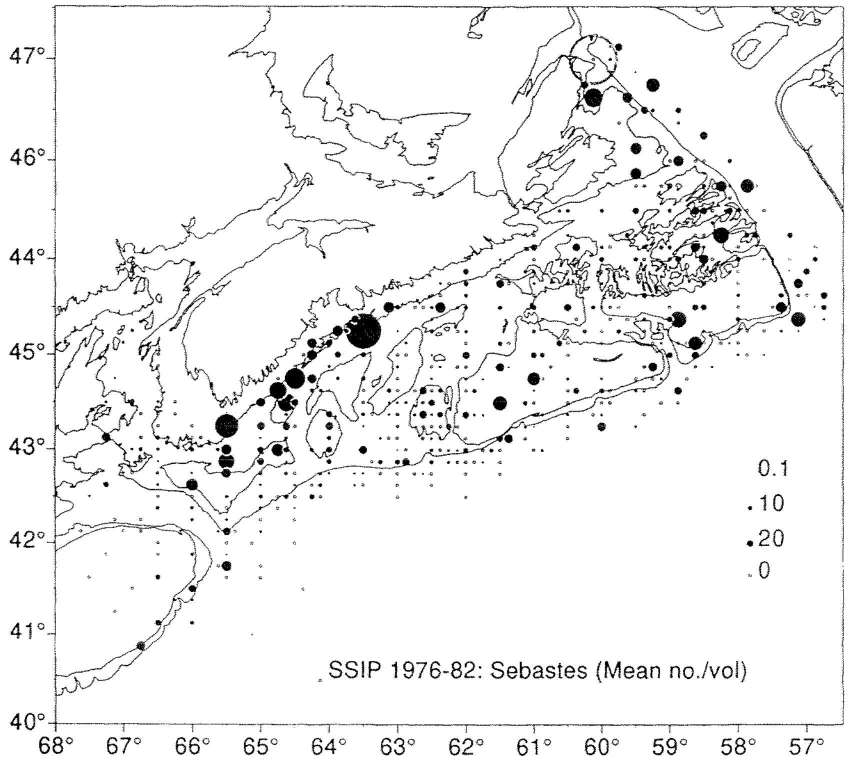


Figure 6-43. Locations where redfish larvae were sampled by the SSIP (prepared by N. Shackell).

American plaice (Hippoglossoides platessoides)

American plaice is a righteye flounder, one of a family of fishes uniquely adapted for life on the bottom. Plaice are flattened asymmetrically, with two eyes on the right side of their bodies. They live on fine sand or mud bottoms in depths of 36 to 274 metres (primarily at 73 to 274 metres). In the western Atlantic, they are distributed from Rhode Island to Baffin Island and off Greenland (Scott and Scott 1988). They occur in waters of –1.5 to 13°C but are generally thought to prefer temperatures just above 0°C (Pitt 1984). Distribution of American plaice on the Scotian Shelf from research trawl surveys is shown in Figures 6-44 and 6-45. Research in the southern Gulf of St. Lawrence showed that plaice occupy shallow, cool waters in summer and deeper, warmer waters in winter (Swain et al. 1998).

Plaice on the Scotian Shelf feed largely on bottom-dwelling invertebrates (Methven 1999). Off Newfoundland, fish plays a more important role in their diet (Methven 1999). Larvae feed on planktonic organisms, including diatoms and copepods (Johnson et al. 1999). Juvenile plaice less than 30 centimetres in length in the Gulf of St. Lawrence fed on mysids, amphipods, echinoderms (brittle stars), and polycheate worms during one study (Scott 1973). Larger animals feed on fish – capelin, sand lance, and sculpin – as well as brittle stars, sand dollars, sea urchins, and crustaceans. Food items appear to vary from place to place depending on availability (Scott and Scott 1988, Johnson et al. 1999).

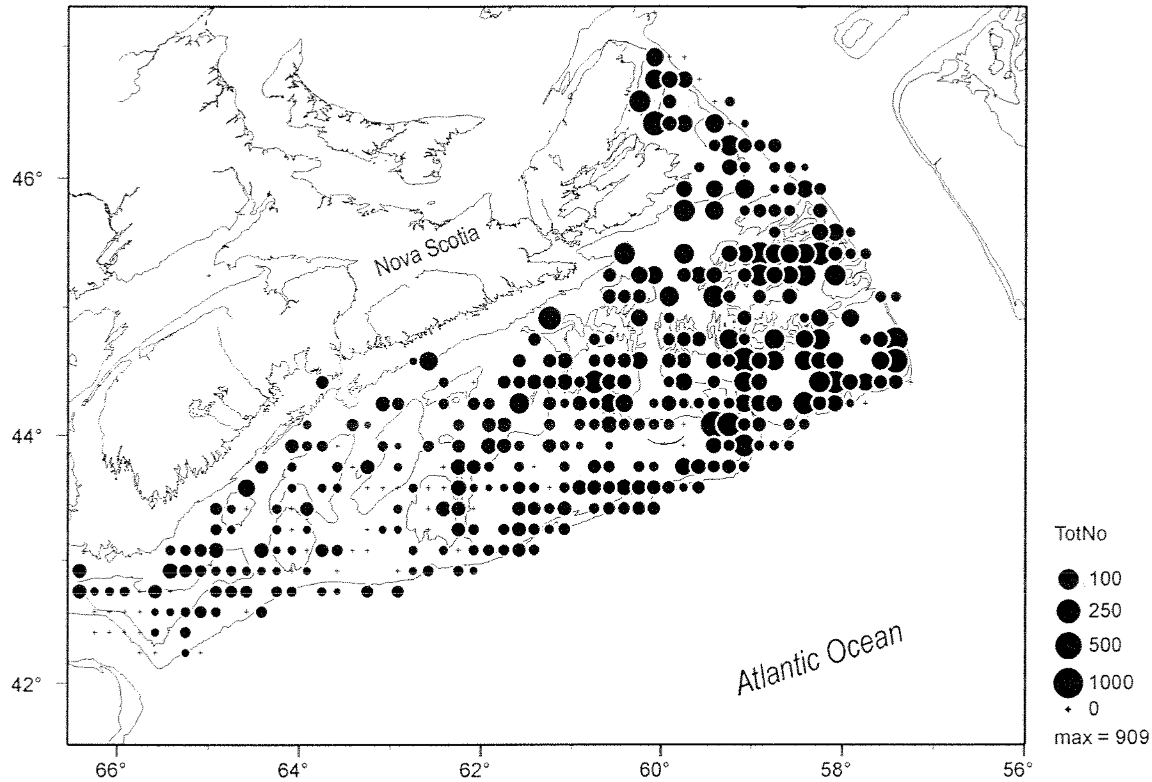


Figure 6-44. Location of American plaice caught during the summer stratified random research trawl survey, 1978-1982 (609 sets aggregated by 10 minute squares).

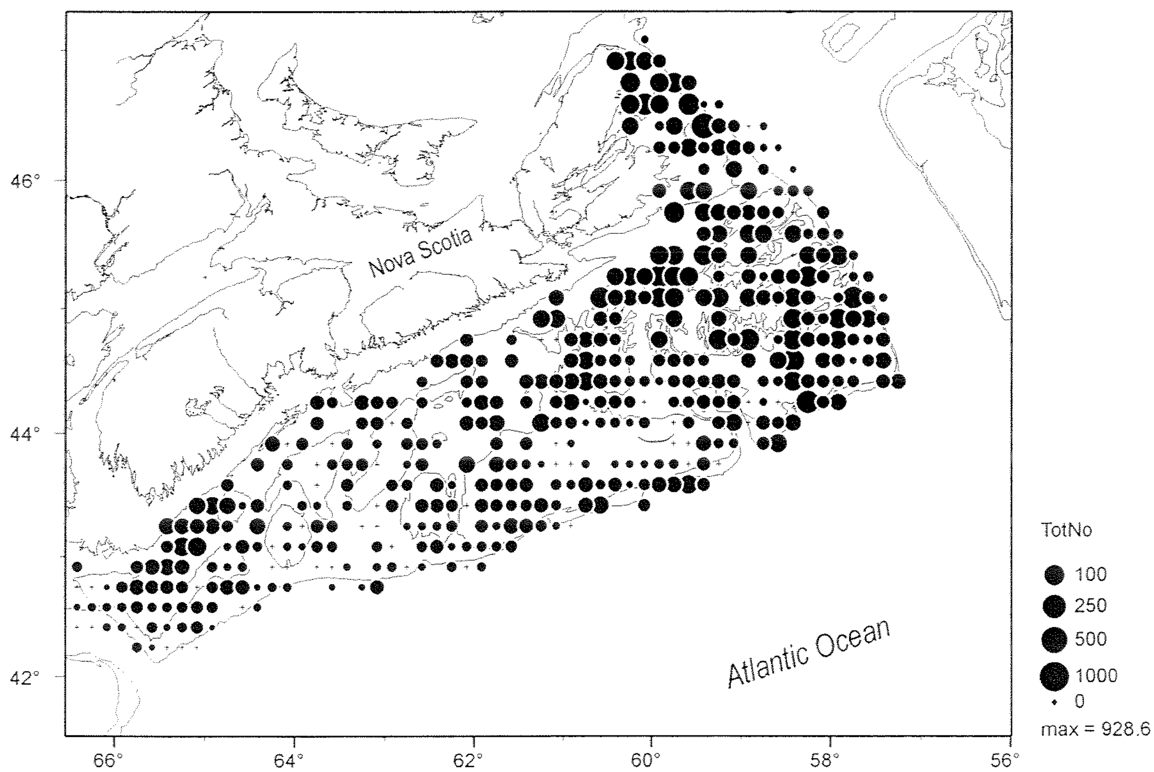


Figure 6-45. Location of American plaice caught during the summer stratified random research trawl survey, 1996-2000 (851 sets aggregated by 10 minute squares).

Female plaice reach sexual maturity between 3.6 years of age (Gulf of Maine) and 15.2 years (St. Mary's Bay, Newfoundland). Development rates are thought to be related to water temperature (Johnson et al. 1999). In the Gulf of Maine and Scotian Shelf, the peak spawning time is in the spring (Pitt 1984, Johnson et al. 1999, see also Appendix 2). Concentrations of plaice larvae in the water column by month is shown in Figure 6-46. Distribution of larvae from SSIP data is shown in Figure 6-47. Spawning occurs at depths of less than 90 metres (Johnson et al. 1999). Larval plaice are shaped like most other fish but develop a flat, asymmetrical shape as they grow.

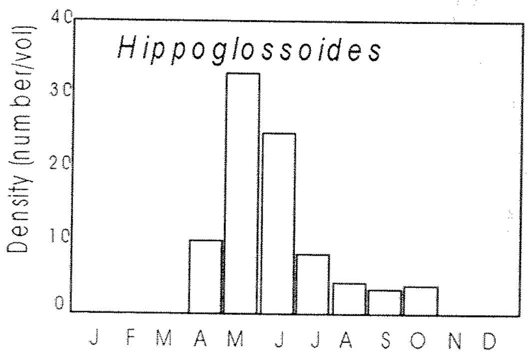


Figure 6-46. Concentrations of American plaice larvae in the water column by month, from SSIP data (prepared by N. Shackell).

Juvenile plaice are common to abundant in estuaries and bays along the American northeast coast, in both saline areas and in areas of mixing with freshwater (Jury et al. 1994). Plaice at other developmental stages – adults, spawning adults, larvae, and eggs – are also fairly common in estuaries and bays, concentrated in the saltwater areas. Juvenile plaice can also be found in numbers further offshore, along and within the 100 metre isobath (Johnson et al. 1999).

American plaice is assessed and managed with yellowtail flounder and winter flounder due to difficulties in reliably separating landings of the different species (DFO 2000f). Plaice populations on the eastern shelf declined from 1980 to the mid-1990s and have remained stable but low (DFO 2000g). On the western shelf, populations have improved after a decline and the stock has been stable in recent years (DFO 2000f).

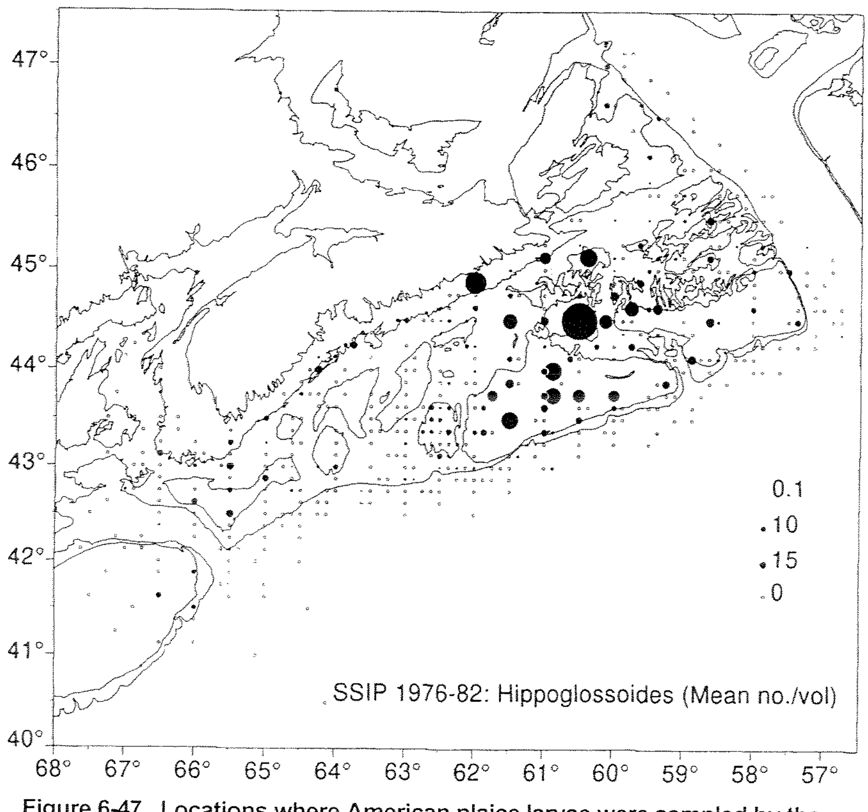


Figure 6-47. Locations where American plaice larvae were sampled by the SSIP (prepared by N. Shackell).

Atlantic halibut (Hippoglossus hippoglossus)

The Atlantic halibut is the largest flatfish. It ranges from Cape Chidley, Labrador to Virginia, and also occurs off Western Greenland (Scott and Scott 1988). Individuals roam extensively within that range. The halibut is a bottom-living fish found in depths of 50 to 2000 metres. They are most abundant between 200 and 500 metres on the Scotian Shelf and can be found in deep channels between banks and at the edge of the continental shelf (DFO 2000f). They prefer to remain in water temperatures within one or two degrees of 5°C. Large halibut move into deeper waters in the winter (DFO 2000f).

Halibut are not well-sampled by the research trawl survey (DFO 2000f, Zwanenburg and Wilson 2000). A longline survey for halibut started in 1998, carried out collaboratively by commercial fishermen and DFO (Zwanenburg and Wilson 2000). Sites on the Scotian Shelf and southern Grand Banks that are surveyed are shown in Figure 6-48. Locations selected for the random stratified phase of the survey are based on catch rates. Areas of low catch make up a lower proportion of the total sets in the survey than areas with medium and high catch rates, with a ratio of 5:7:10 corresponding to low:medium:high catch areas (Zwanenburg and Wilson 2000). During the commercial index fishery phase, fishermen select locations to fish based on their knowledge. The longline halibut survey is carried out in much deeper waters than groundfish research trawls, to depths of 800 metres and occasionally deeper as compared to 200 metres for the research trawl survey (Zwanenburg and Wilson 2000). For 1998 and 1999, catch rates estimated from the stratified survey and the commercial index phases are consistent and comparable (DFO 2000f). Catch rates from the 1999 commercial index survey are shown in Figure 6-49.

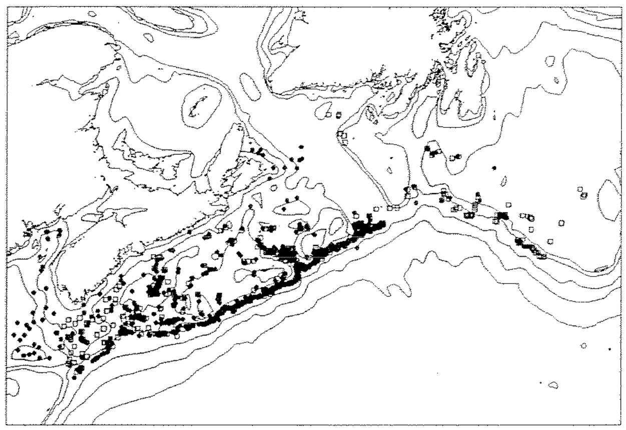


Figure 6-48. Location of random and commercial index surveys for halibut, 1998 and 1999 (from DFO 2000f).

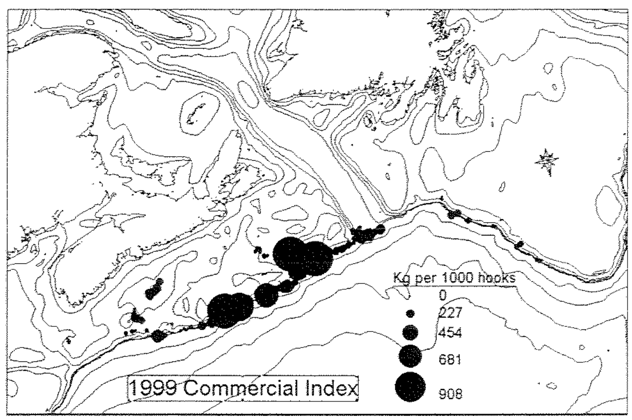


Figure 6-49. Catch rates from halibut longline commercial index survey, 1999 (from DFO 2000f).

Distribution of halibut landings from 1996-2000 is shown in Figure 6-50 (1978-1982 period not available). Like the rates from the commercial index survey, landings correspond to areas between banks, deep channels, and the edge and slope of the shelf.

Halibut feed mainly on other fishes, such as cod, haddock, sand lance, herring, and capelin, but also eat cephalopods, large crustaceans and other bottom-living invertebrates. Small halibut (less than 30 centimetres) feed mostly on invertebrates. As they grow larger, fish make up a greater proportion of their diet (Scott and Scott 1988).

Female halibut are able to ovulate several batches of eggs over a single reproductive period (Neilson et al. 1993, Cargnelli et al. 1999a). Spawning is thought to take place in deep water along the slope of banks and the continental slope during the late fall, winter, and early spring (Neilson et al. 1993, Scott and Scott 1988, Cargnelli et al. 1999a). Spawning activity peaks during November-December (Neilson et al. 1993). Spawning areas in the western Atlantic are not well understood. No halibut eggs and only three larvae were sampled by the SSIP, while only two larvae were caught during FEP cruises (Hurley pers. communication in Neilson et al. 1993). Eggs are suspended in the water column from 54 metres to 200 metres below the surface and are thought to develop near the seabed (Cargnelli et al. 1999a).

Neilson et al. (1993) suggested that Browns Bank could be a nursery area for juvenile halibut because of the small, immature halibut often caught there. Based on movements of halibut in tagging studies (Stobo et al. 1988), this could be the nursery area for halibut populating the Scotian Shelf and southern Grand Banks (Neilson et al. 1993). Stobo et al. (1988) suggested that The Gully could be near a spawning ground and serve as a nursery area for juvenile fish because of both fish in spawning condition and immature small fish caught there.

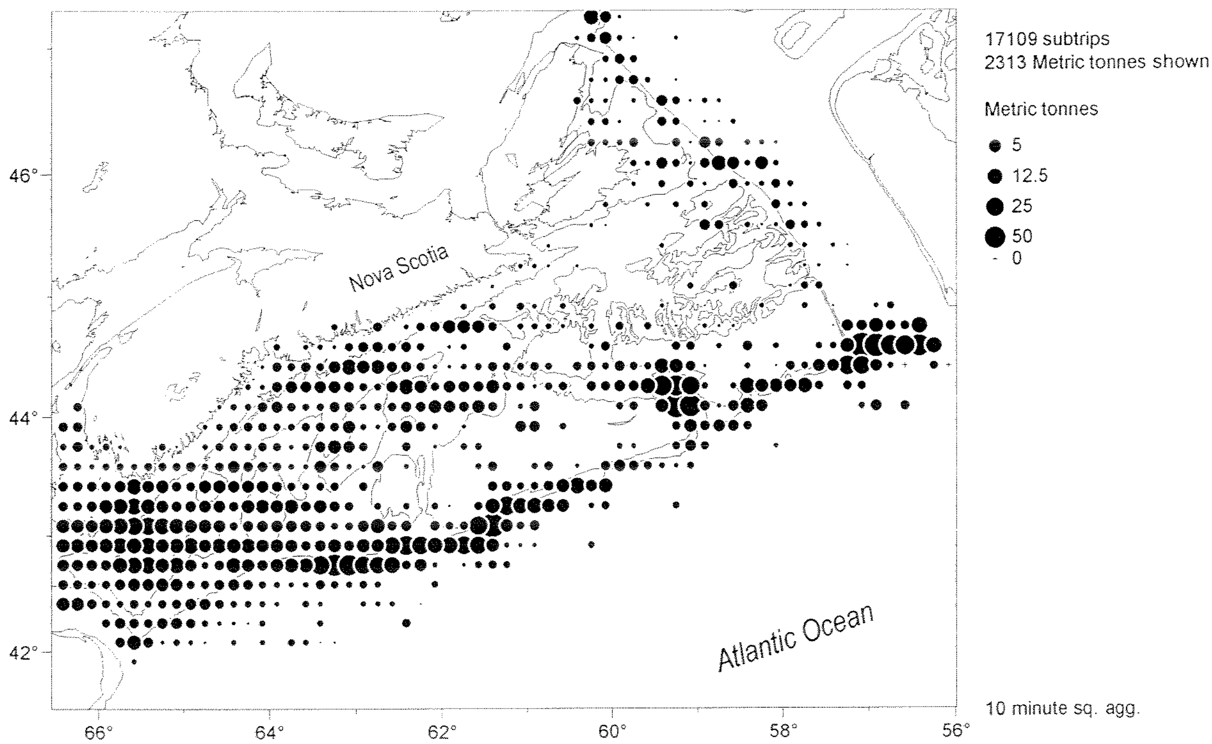


Figure 6-50. Location of halibut catches from commercial fisheries on the Scotian Shelf, 1996-2000, aggregated by 10 minute squares.

Important Areas

Successful spawning and survival of fish at early life stages are important for adult fish populations. Several broad areas of significance to commercial fish have been identified on the Scotian Shelf. The Western-Sable Island Bank area has high larval abundance and diversity year-round (Shackell and Frank 2000). Emerald Bank and Browns Bank had high diversity and relatively high abundance for the spring-summer and summer-fall periods. There were also periods of abundance and diversity on LaHave, Middle, Canso, Banquereau, and Misaine Banks.

Western-Sable Island Bank has a partial gyre that retains fish larvae and zooplankton over the bank. Its large size offers more heterogeneous habitat than other offshore banks and perhaps promotes larval diversity (Shackell and Frank 2000). Like Western-Sable Island Bank, Browns Bank also has a partial gyre that retains some larvae over the bank. The gravelly surficial sediments of the bank are the preferred habitat of juvenile haddock and larvae retained there appear to have a better chance of survival than those dispersed to other areas (Brickman 2001).

Cod eggs spawned on Browns Bank appear to move to coastal nursery areas. Inshore waters play an important role in the life cycle of pollock, cod, plaice, herring, and likely other species. More studies of coastal Nova Scotia should be carried out to determine important spawning and nursery areas for fish. Research is needed to determine the most important areas and the species found in inshore areas during those important early life stages. More research on the distribution of juveniles in offshore areas is also important.

Areas where spawning or juvenile commercial fish are known to be concentrated have been closed or face seasonal fishing restrictions (e.g., haddock spawning area on Browns Bank, the redfish "bowtie" north of Browns Bank, the haddock nursery area on Emerald-Western Banks, and the herring embayments). Not all spawning areas are well-defined. Surveys devoted to determining the locations of adult spawning fish would provide a better understanding.

Areas important for adult fish are difficult to determine and have generally not been included in this chapter. Healthy populations of forage fish species, such as sand lance and herring, are important for the entire ecosystem. Herring are highly concentrated in Chedabucto Bay and off Chebucto Head during the winter and these are major wintering areas for the Scotian Shelf stocks. 4Vn is an important wintering area for southern Gulf of St. Lawrence herring. Sand lance are concentrated in shallow areas with sandy sediments. Much of Sable Island Bank provides appropriate habitat for this species; however, other shallow sandy banks likely also provide suitable habitat.

More research is needed to gain a better understanding of interactions between fish species, including non-commercial species. Many non-commercial species have been impacted by commercial fisheries, either directly through being fished as bycatch or by changes in the population of targetted species. Greater knowledge of interactions between fish species and between fish and their habitats would assist in selecting appropriate management tools.

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7 MARINE MAMMALS[1]

Introduction

Two groups of marine mammals live in the waters of the Scotian Shelf: the cetaceans, a group that includes whales, dolphins, and porpoises, and the pinnipeds, a group that includes the seals found here and the sea lions and walruses found in other parts of the world. Cetaceans spend their entire lives in aquatic environments while the pinnipeds haul out on land to give birth and nurse their young. Like other mammals, marine mammals breathe air, are warm-blooded, bear live young, and suckle their young with milk produced from mammary glands. Mammals that live in the ocean are streamlined to aid movement through the water. A layer of subcutaneous fat, called blubber, contributes to this streamlining and serves as insulation against cool temperatures.

Marine mammals tend to be long-lived with low fecundity (Bowen and Siniff 1999). However, some populations can increase quickly if the appropriate conditions are present. The grey seal population of Sable Island was estimated to be increasing at a rate of about 12.6 percent annually between 1962 and 1993 (Mohn and Bowen 1996). In contrast, the annual rate of increase for the world sperm whale population has been estimated to be about 1 percent (Bowen and Siniff 1999). Most marine mammals have one young or less annually and some whales reproduce only once every five or six years.

Marine mammal population estimates are often imprecise and based on scant data, especially for the cetaceans because they spend their entire lives in the water, often in remote locations. Population trends may be as difficult to determine because of the imprecise nature of population estimates. The hundreds of thousands of animals taken by whalers decimated populations of the larger whales and may have resulted in permanent changes in marine ecosystems. For example, it has been speculated that minke whales became more abundant in the Southern Ocean due to decreased numbers of the larger baleen whales that were the preferred targets of whalers. As a result, minke whales had less competition for prey (Laws 1985). The overall impacts of whaling on marine ecosystems are generally not well-known.

Cetaceans (Whales, Dolphins, and Porpoises)

The order Cetacea is divided into two suborders. The Odontoceti (toothed whales) includes about 70 species of whales, dolphins, and porpoises, and the Mysticeti (baleen whales) includes about 12 species of whales that predominantly feed on pelagic euphausiids (krill), other plankton, and schooling fish. The odontocetes, or toothed cetaceans, feed mainly on squid, fish, and crustaceans. They are generally smaller than the baleen whales. Table 7-1 lists the cetaceans regularly occurring on the Scotian Shelf and includes a brief description of the species. Species that occur rarely are not included.

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Table 7-1. Whales, Dolphins, and Porpoises of the Scotian Shelf[2]

Common Name *Scientific Name*	Description and Social Behaviour	Habitat	Distribution and Movements	Food	Population and Conservation Status
Baleen Whales (Mysticeti)					
North Atlantic right whale *Eubalaena glacialis*[3]	• dark-coloured with light-coloured whale lice on growths called callosities • wide-bodied (rotund) • up to 15 metres long • usually seen as individuals (Roseway Basin) or individual females with calves (Bay of Fundy), occasionally groups of 100-200 where prey is dense	• calves and mothers found in nearshore areas • prefer waters of 100 to 150 metres, steep bottom slopes • prefer surface water temperatures of 8 to 15°C • thought to prefer to feed in frontal zones (areas with dense concentrations of prey)	• move from southern or offshore waters in the winter to northern feeding grounds • move between feeding areas in the Bay of Fundy and off New England to those on the Scotian Shelf (Roseway Basin and other basins)	• dense patches of copepods and other zooplankton	• about 300 to 350 whales in northwest Atlantic • endangered species (COSEWIC and NMFS)
Minke whale *Balaenoptera acutorostrata*[4]	• dark-coloured on top, lighter coloured undersides, white flipper patches • smallest baleen whale found off NS, up to 10 metres long • usually seen as individuals, occasionally small groups where prey is dense • may approach boats	• use continental shelf and coastal habitats, often seen along the coast • found in cool waters, even among ice floes	• widely distributed in the North Atlantic, as far north as Baffin Bay in the summer • most move south of NS in the winter; some may stay year-round • southward migration may occur offshore, northward migration in nearshore and pelagic waters	• opportunistic feeder, eats small schooling fish and zooplankton, e.g., sand lance, capelin, herring, and krill	• most recent best estimate of 3810 whales Canadian east coast population; world population in tens of thousands • status not evaluated (COSEWIC), not endangered or threatened (NMFS)
Sei whale *Balaenoptera borealis*[5]	• dark grey back and sides, lighter grey undersides • streamlined body • up to 15 metres long • seen as individuals or in groups of 2 to 10	• seen near shelf edge, bank edges and basins of the Scotian Shelf • sightings worldwide are from areas with waters deeper than 100 metres, there are occasional and well-known appearances inshore related to high copepod densities	• highly mobile, unpredictable appearances • there may be a separate population centred on the Scotian Shelf that feeds there from spring to fall and moves south in winter	• mostly copepods and krill, some small schooling fish (herring, mackerel, capelin)	• NS shelf population estimated at 1393 to 2248 (from 1965 to 1972 data) • no adequate current estimate of N. Atlantic population • status not evaluated (COSEWIC), endangered (NMFS)
Fin whale *Balaenoptera physalus*[6]	• dark-coloured back, light undersides, white right lower jaw, occasionally with pale chevrons on the back • prominent dorsal fin • slim, streamlined body • up to 24 metres long • commonly seen in small groups (2 to 8); single whales seen occasionally	• appear to prefer areas with high topographic variation, from 100 to 200 metres in depth (also commonly seen near the coast) • found in areas of upwelling and convergent fronts • found in waters with ice floes to temperate waters up to 15°C	• commonly seen along shelf edge, between Emerald and LaHave Banks, and shelf basins • seen in other areas of the shelf and in coastal areas, as well as far offshore (beyond 2000 metre isobath) • migrate between northern feeding grounds and southern wintering areas, but also seen off NS in winter	• young whales feed primarily on zooplankton, adults on zooplankton and small fish (krill, herring, capelin, etc.)	• estimates of population size vary: recent best estimate by NMFS was 2200 in NW Atlantic; IWC 1992 estimate was 10,800 for NS and NF population • species of special concern (COSEWIC), endangered (NMFS)

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[2] Most population estimates are from NMFS (Waring et al. 2000); conservation status is from COSEWIC (2001) and NMFS (Waring et al. 2000) (chapter 10 has more detail on conservatin designations); descriptions are from Leatherwood et al. (1976), Lien (1986), Katona et al. (1993), Reeves (1999); other references are with each species.

[3] Sources for this species: Mayo and Marx (1990), Reeves (1999), Right Whale Recovery Team (2000), and Waring et al. (2000).

[4] Sources for this species: Katona et al. (1993) and Stewart and Leatherwood (1985).

[5] Sources for this species: Gambell (1985b), Mitchell and Chapman (1977), Payne et al. (1990), Reeves (1999), and Waring et al. (2000).

[6] Sources for this species: Gambell (1985a), Katona et al. (1993), and P. Lane and Associates (1992).

Common Name *Scientific Name*	Description and Social Behaviour	Habitat	Distribution and Movements	Food	Population and Conservation Status
Blue whale *Balaenoptera musculus*[7]	• dark grey, broad, U-shaped head • body colour pale blue-grey to dark grey • the largest whale, up to 25 metres long in NW Atlantic • rarely observed	• widely distributed in the world's oceans, primarily along the edge of continental shelves and open ocean but also in inshore regions • in summer and fall, commonly occur in productive areas in temperate and polar oceans, especially where there are concentrations of euphausiids	• migrate from sub-tropical and tropical wintering/breeding grounds to feeding grounds in temperate and polar seas • some animals feed on the Scotian Shelf in summer; some move through to the Gulf of St. Lawrence and regions further north • sighted between Western and LaHave Banks, also in The Gully	• krill are main prey and most important food by far • occasionally consume copepods	• little known about population trends in NW Atlantic • at least 308 animals in NW Atlantic • species of special concern (COSEWIC), endangered (NMFS)
Humpback whale *Megaptera novaeangliae*[8]	• long white flippers, dark back, pale undersides • sensory knobs on the head • acrobatic • up to about 13 metres long • observed singly or in small groups (2 to 8) • may work together to herd fish • acrobatic	• feed in coastal and shelf areas, long-distant migrations may take them over deep ocean areas • found where prey is dense (e.g., sandy shoals where sand lance is found) • Scotian Shelf habitat preferences not well-known	• migrate between temperate summer feeding grounds and wintering grounds in the West Indies • some stay in northern areas year-round • relationship of Scotian Shelf whales with those from nearby feeding areas is not clear • distribution is related to availability of schooling fish	• euphausiids, schooling fish (herring, capelin, sand lance), and squid • occasionally corral prey through bubble feeding	• population of about 10,600 in North Atlantic, based on extensive survey • species of special concern (COSEWIC), endangered (NMFS)
Toothed Whales (Odontoceti)					
Sperm whale *Physeter macrocephalus*[9]	• distinctive large, blunt head • grey or brownish • largest toothed whale, up to 18 metres long • observed in small groups or as individuals, mostly males observed off NS	• prefers shelf edge and waters of 200 to 1500 metres on the Scotian Shelf, may be more common in submarine canyons (commonly sighted in The Gully) • females and calves prefer water temperatures above 15°C and are seen less frequently off NS	• most animals on Scotian Shelf are males which range more widely and to more northern latitudes than females • Some males may remain off NS year-round • females and juveniles generally found in tropical and sub-tropical waters, some sightings off NS	• squid is main prey, which they can pursue to great depths	• 1998 estimate of about 4700 whales from Gulf of St. Lawrence to Florida • not at risk (COSEWIC), endangered (NMFS)
Northern bottlenose whale *Hyperoodon ampullatus*[10]	• bulbous forehead, elongated jaw (beak) • brown to grey with dark flippers, flukes, and dorsal fin • up to 9 metres long • often seen in small groups, occasional sightings of individuals • curious nature, may approach slow-moving boats	• prefer areas greater than 1000 metres in depth; in The Gully area, they are never seen over depths less than 800 metres • found in cool waters • seem to prefer steep topography (submarine canyons and shelf edge)	• NS is the southern limit of areas regularly used by this species • one population is centred in The Gully and nearby waters year-round	• deep dives to catch main prey, squid, also eat deep-sea fish and invertebrates	• 130 animals estimated in Gully population, about 44 in Gully at a given time • no estimates of total North Atlantic population • species of special concern (COSEWIC), no status (NMFS)

[7] Sources for this species: Kawamura (1980), Reeves (1999), Reeves and Brown (1994), Whitehead et al. (1998), Yochem and Leatherwood (1985).
[8] Sources for this species: Payne et al. (1990), Reeves (1999), Smith et al. 1999, Waring et al. (2000), and Winn and Reichley (1985).
[9] Sources for this species: Lucas and Hooker (2000), Reeves and Whitehead (1997), Rice (1989), Whitehead et al. (1992).
[10] Sources for this species: Benjaminsen and Christensen (1979), Gowans et al. (2000), Hooker (1999), Mead (1989b), Whitehead et al. (1997a).

Common Name *Scientific Name*	Description and Social Behaviour	Habitat	Distribution and Movements	Food	Population and Conservation Status
Short-beaked common dolphin *Delphinus delphis*[11]	• dark grey back, pale sides and underbelly • V-shaped "saddle" mark under dorsal fin • up to 2.5 metres long • commonly occur in groups of 50 to 200, group size can be up to 2000 • will ride bows and play in ships' wakes	• found in waters above 5°C • prefer areas along shelf edge, where depths are 100 to 200 metres though found to depths of 2500 metres • prefer prominent underwater topography	• widely distributed throughout the world's oceans between 50°N latitude and 40°S latitude • common on Scotian Shelf during summer months	• eat a variety of fishes and squids	• approximately 30,000 in Northwest Atlantic (1998 estimate) • proportion using Scotian Shelf unknown • not at risk (COSEWIC), not endangered or threatened (NMFS)
Striped dolphin *Stenella coeruleoalba*[12]	• grey or brown back separated from paler undersides by a prominent black stripe • up to 2.7 metres long • often seen in groups of 20 or more; however group size in eastern Canada generally smaller than other areas • often seen in groups with other odontocetes	• prefer deep water along the shelf edge and further seaward • prefer waters influenced by warm currents (e.g., Gulf Stream) • in The Gully, appear when waters above 15°C	• NS is northern limit of range • considered uncommon in Canadian waters but regularly sighted in The Gully	• in general, eat small fish, squid and shrimp	• 1998 estimate of 61,500 animals in NW Atlantic • proportion using Scotian Shelf unknown • not at risk (COSEWIC), not endangered or threatened (NMFS)
White-beaked dolphin *Lagenorhynchus albiorostris*[13]	• black back with white or light grey on back below and behind dorsal fin • paler undersides • up to 3 metres long • seen in small groups (up to 25) and occasionally large groups • may be seen with other odontocetes	• cool waters (tends to prefer cooler waters and more coastal habitats than white-sided dolphin) • less common in the Gulf of Maine in the last few decades • uses areas with high concentrations of fish • occasionally trapped by ice off Newfoundland	• found from Cape Cod to Davis Strait • seasonal movements not well known, some appear to spend winters in cold waters near ice • often seen along NS coast in early summer	• squid, some fish (e.g., capelin, cod, herring, haddock), and crustaceans	• no recent population estimate by NMFS, North Atlantic population of perhaps high tens of thousands or low hundreds of thousands • not at risk (COSEWIC), not endangered or threatened (NMFS)
Atlantic white-sided dolphin *Lagenorhynchus acutus*[14]	• bright, well-defined white patch on flanks below dorsal fin, patch of yellow below white patch • black back and dorsal fin • up to 2.8 metres long • commonly seen in large groups of 50 to 500, sometimes in smaller groups or singly • often seen with other cetaceans • playful and acrobatic	• has become more abundant in the Gulf of Maine and on US continental shelf in the last few decades • prefer waters deeper than 50 metres • most sightings in waters cooler than 12°C	• found from Cape Cod to Davis Strait • probably shift southward and perhaps offshore in winter	• fish (e.g., herring and sand lance) and squid	• size of population using Scotian Shelf unknown – about 27,000 in Gulf of Maine and 12,000 in Gulf of St. Lawrence • NW Atlantic population in tens of thousands • not at risk (COSEWIC - 1991), not endangered or threatened (NMFS)

[11] Sources for this species: Evans (1994), Gowans and Whitehead (1995), Reeves (1999), Waring et al. (2000), and Whitehead et al. (1998).
[12] Sources for this species: Baird et al. (1997), Lucas and Hooker (2000), Perrin et al. (1994), Waring et al. (2000), and Whitehead et al. (1998).
[13] Sources for this species: Lien (1986), Reeves (1999), Reeves et al. (1999a).
[14] Sources for this species: Gowans and Whitehead (1995), Reeves (1999), Reeves et al. (1999b), Selzer and Payne (1988), and Waring et al. (2000).

Common Name *Scientific Name*	Description and Social Behaviour	Habitat	Distribution and Movements	Food	Population and Conservation Status
Long-finned pilot whale *Globicephala melas* [15]	• black except for a light-coloured patch on chest, large animals sometimes have a grey saddle • bulbous head and large, long dorsal fin • up to 6 metres long • seen in groups of 5 or more, commonly 20 to 50 • often seen with other whales • groups stay together even when threatened	• found in cool waters • sighted inshore in summer and offshore in winter • use coastal, shelf, shelf edge, and canyon habitats • appear to follow schools of squid	• distributed from North Carolina to Greenland • some proportion of population is present on Scotian Shelf year-round • may winter in offshore waters away from the shelf and shelf edge	• squid and fish (mackerel, herring, and silver hake)	• inadequate population estimates for number found in Canadian waters, perhaps between 15,000 and 25,000 in NW Atlantic • not at risk (COSEWIC), not endangered or threatened (NMFS)
Killer whale *Orcinus orca* [16]	• distinctive black body with white eye patch and white underbelly; white boomerang-shaped patch curves onto flank from underbelly • very large, tall dorsal fin • up to 10 metres long • seen in small groups (3 to 25 whales) • cooperate while hunting	• highly mobile, range widely in oceans • habitat preferences unknown off NS; in the Gulf of Maine, appearances may be associated with tuna	• distributed in all the world's oceans from arctic to subtropical waters • infrequent visitor to Scotian Shelf and eastern Canadian waters	• fish, squid, seals, other whales • different pods may have different food preferences; habits on Scotian Shelf not well known	• no population estimates for NW Atlantic • insufficient data to assess status (COSEWIC), not endangered or threatened (NMFS)
Harbour porpoise *Phocoena phocoena* [17]	• small, stocky body • no beak • dark grey back, pale grey flanks and undersides • one of the smallest cetaceans, about 1.5 metres long • seen singly or in small groups (up to 10 porpoises), occasionally in larger groups • shy and difficult to approach	• coastal areas • shallow waters of continental shelf (in Gulf of Maine, waters 92 to 183 metres deep) • follows schools of herring • found in cool waters in the range of 5 to 16°C	• range from Cape Hatteras to western Greenland • four populations in western North Atlantic: Bay of Fundy-Gulf of Maine, Gulf of St. Lawrence, Newfoundland and Labrador, Greenland • some evidence of a separate Scotian Shelf population • move to coastal areas in summer, offshore in winter	• herring is primary prey in Bay of Fundy, also eat mackerel, capelin, hake, cod, pollock, and squid and other invertebrates	• recent estimate of about 90,000 for Gulf of Maine/Bay of Fundy population • number using Scotian Shelf unknown • threatened (COSEWIC), no status (NMFS)

[15] Sources for this species: Bernard and Reilly (1999), Gannon et al. (1997), Nelson and Lien (1996), P. Lane (1992), Reeves (1999).
[16] Sources for this species: Dahlheim and Heyning (1999), Katona et al. (1993), Reeves (1999).
[17] Sources for this species: CWS (2000), Plaka (2000), Read (1999), Reeves (1999).

Whale observations on the Scotian Shelf

In general, whale distribution seems to correlate well with areas of high primary productivity. On the Scotian Shelf, whales have often been observed along the shelf break and in deep water basins. However, whales have not been systematically surveyed on the Scotian Shelf,[18] unlike in American waters. The University of Rhode Island was contracted by the U.S. Minerals Management Service to carry out the Cetacean and Turtle Assessment Program (CeTAP). Over a three-year period, this program surveyed the area from Cape Hatteras to Nova Scotia by air to determine the abundance and distribution of cetaceans and turtles (NFSC 2001). The Northeast and Southeast Fisheries Science Centers of the U.S. National Marine Fisheries Service (NMFS) continue to carry out air and ship surveys to assess populations of cetaceans and produce regular assessments of marine mammal populations. The NMFS assessments, especially the abundance estimates, were an important source for this chapter. Sighting and catch data found in reports prepared by Sutcliffe and Brodie (1977) and for the Canada-Nova Scotia Offshore Petroleum Board (Reeves 1999) were used to help create distribution maps. Whale distribution maps for the Scotian Shelf found in other reports have also been based on opportunistic sightings, whaling records, and inferred locations based on habitat or prey preferences (e.g., P. Lane 1992, Reeves and Brown 1994, MacLaren Plansearch 1996).

The observation data available for the Scotian Shelf has several limitations: they are biased towards particular parts of the shelf, in some cases species identifications are uncertain, and they are biased towards the late spring, summer, and fall. Sutcliffe and Brodie (1977) examined records of whales killed by vessels based in Blandford, Nova Scotia. These whalers focussed their efforts on the western Scotian Shelf and generally did not travel east of Sable Island Bank. The authors found that records of whale captures were grouped in areas along the shelf break, and in the Northeast Channel, Emerald Basin, and Roseway Basin. There were few records from the tops of banks. Observation records from other mariners are also biased towards the western half of the Scotian Shelf and the area around The Gully (see Kenney 1994). Whale observation records are included in the PIROP (Programme integré de recherches sur les oiseaux pélagiques) database compiled by the Canadian Wildlife Service; however the whale records have not been analyzed. Further information on the distribution of whales may be gained from examining this source (Huettmann pers. communication).

The figures of regional whale distribution found in this chapter are based on both catch and sighting records ("known regular occurrence") and occasional sightings and known food and habitat preferences ("probable regular occurrence"). Because there have been fewer observations on the eastern Scotian Shelf, due to less effort, the maps are likely biased towards the western Scotian Shelf. Nonetheless, they do provide some indication of where whales are likely to be more regularly encountered on the Scotian Shelf and slope. Whales could easily occur in areas other than indicated. The figures show distribution only within the Scotian Shelf study area, outlined on each map. Other than for the northern bottlenose whale, maps are for the late spring to early fall period because of the lack of information for the rest of the year.

At a finer scale, whale distributions have been linked with concentrations of zooplankton, herring, and other prey. For example, Woodley and Gaskin (1996) found that concentrations of the copepod *Calanus finmarchicus* were high in areas of the lower Bay of

[18] Due to their endangered status, the movements of North Atlantic right whales are better known than other species. However, their use of the Scotian Shelf is still not completely known.

Fundy where right whales were present. When fin whales were present, the authors observed relatively high densities of herring and euphausiids.

Whales and seabirds are often observed in the same areas (Pierotti 1988). A study in the Barents Sea commented that most sightings of whales were heralded by an increased number of fulmars and kittiwakes circling and feeding in the area (Joiris et al. 1996, statistical significance was not measured). While this may be because these areas are highly productive and thus attractive to seabirds, it may also be because whales drive small fish to the surface, making it easier for seabirds to capture their prey (Stewart and Leatherwood 1985). Another Barents Sea study positively correlated the abundance of thick-billed murres with observations of cetaceans (Mehlum et al. 1998). Both the murres and the whales were feeding on capelin and the authors suggested that the birds used the presence of cetaceans as an indicator of high prey concentrations.

Mysticetes (Baleen Whales)

The baleen whales are the largest animals in the world and among the longest-lived. Most have very low reproductive rates. The largest animal on earth, the blue whale, is estimated to reach sexual maturity at around age 10 with females producing a calf about every two or three years. Blue whales are thought to live to about 75 years. Minke whales, the smallest baleen whales in the North Atlantic, reach sexual maturity between six and eight years old and can reproduce annually. Their lifespan is estimated at 30 to 40 years (Stewart and Leatherwood 1985).

The baleen whales strain sea water through baleen plates in their mouths to capture planktonic creatures such as copepods, euphausiids, and amphipods. Some species also consume small schooling fish such as herring and capelin. The rorqual whales – the minke, fin, blue, and humpback whales – gulp large mouthfuls of water and filter it against the baleen, expelling the water and keeping the prey. The "skimmers" – the bowhead and right whales – feed by swimming steadily and continuously straining food from the water. The sei whale is a rorqual whale that both skims and gulp feeds (Katona et al. 1993).

Most of the baleen whales seen on the Scotian Shelf migrate seasonally from tropical or sub-tropical calving grounds to summer feeding grounds in cooler temperate or polar waters (Bowen and Siniff 1999). By migrating, baleen whales take advantage of areas of high productivity in cool water areas. It is thought that calving in warm waters may in some way improves the survival prospects of calves.

Some baleen whales may stay in cool temperate waters during autumn and winter months to take advantage of the higher productivity. Winter distributions on the Scotian Shelf and adjacent waters are little known as few whale surveys have been carried out on the Scotian Shelf during the late autumn, winter, and early spring. Whales may be found in Gulf Stream influenced waters far offshore and rarely seen during the winter. Fin whales have been regularly observed on the shelf in winter (Whitehead, pers. communication).

North Atlantic right whale (Eubalaena glacialis)

The North Atlantic right whale is one of the most endangered marine mammals in the world. In 1998, the population of North Atlantic right whales was estimated to be between 300 and

350 individuals (Right Whale Recovery Team 2000). Individuals have been identified based on a photo-census of the whales (Kraus et al. 1998 cited in Waring et al. 2000). It is uncertain if the population is slowly recovering from years of whaling or if it is actually declining (Waring et al. 2000). The average intervals between calves for right whale mothers has increased from an average of 3.67 years in 1992 to 5 years in 1998, and may reflect environmental and other stresses on the population (Kraus et al. 1998 cited in Waring et al. 2000). However, after several years of few calves, the winter of 2000-2001 saw 30 calves born, an event characterized by the United States National Marine Fisheries Service (NMFS) as a "baby boom" (NMFS 2001).

The NMFS has identified five known habitats of importance for right whales (Waring et al. 2000). The five areas are:

1) the coastal waters of Georgia and Florida (only known calving area),
2) the Great South Channel (feeding and socializing area),
3) Massachusetts and Cape Cod Bays (feeding and socializing area),
4) the Bay of Fundy (feeding, nursery, and socializing area), and
5) the Scotian Shelf (feeding and socializing area).

There may be important habitats that are less well-known. For example, individual right whales and mother and calf pairs have been sighted occasionally in the Gulf of St. Lawrence (Conway pers. communication).

In New England waters, the whales feed extensively on copepods and look for dense patches to allow them to feed efficiently (Mayo and Marx 1990). Some feeding areas are more highly used in certain years, depending on oceanographic conditions. Right whales also may move between feeding areas fairly frequently and make long excursions offshore (Waring et al. 2000). Roseway Basin between Browns and Baccaro Banks was highly used in the late 1980s and was designated a whale conservation area (now called a whale sanctuary) (Figure 7-1). However, in the 1990s, the whales made greater use of the lower Bay of Fundy (Reeves 1999). Several whales were sighted in Emerald Basin in 1997 and 1998, suggesting that they may use central and eastern parts of the Scotian Shelf more extensively than currently known (Reeves 1999, Right Whale Recovery Team 2000). Whales tagged with radio transmitters travel widely and in varying depths of water (Mate et al. 1997). They may leave known feeding areas and travel hundreds of kilometres within a few weeks (Waring et al. 2000, Right Whale Recovery Team 2000).

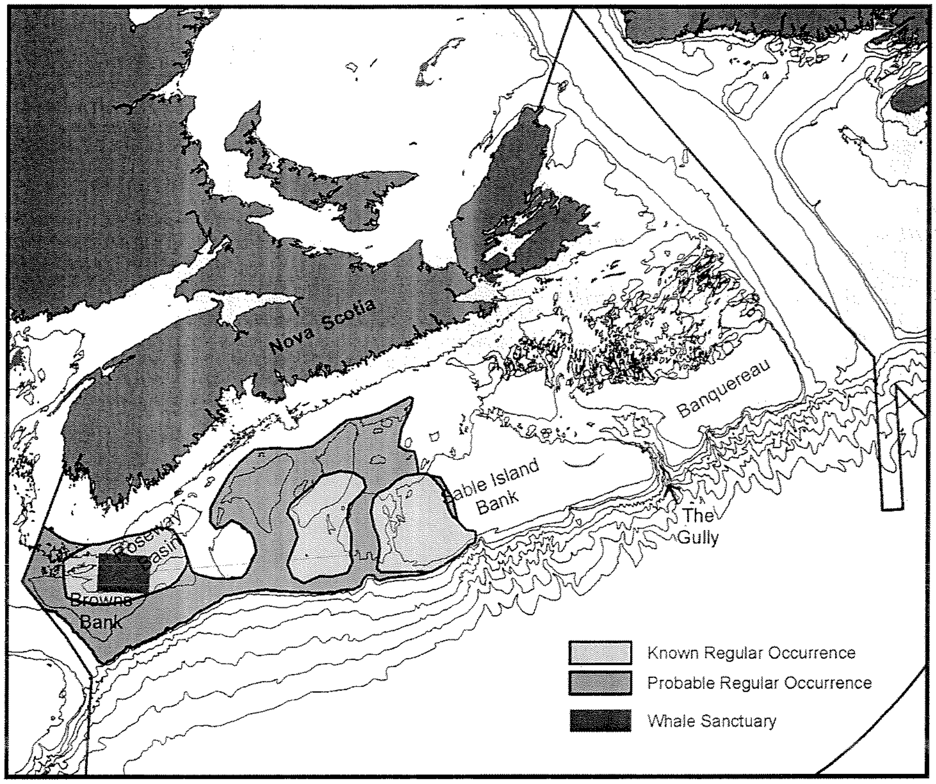

Figure 7-1. Known and probable regular occurrence of the North Atlantic right whale on the Scotian Shelf, late spring to fall. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Minke whale (Balaenoptera acutorostrata)

The minke whale is the smallest baleen whale found on the Scotian Shelf, with a maximum length of about 10 metres (Stewart and Leatherwood 1985). These whales are widely distributed in the North Atlantic and range north to Baffin Bay during the summer months. Some stay in waters off Nova Scotia throughout the year, while others migrate south during the winter months. Southward migrations are thought to occur offshore; northward migrations are both offshore and coastal (Stewart and Leatherwood 1985). They use continental shelf and coastal habitats and are often seen in near-shore areas (Figure 7-2).

Fish make up a greater proportion of the diet of minke whales as compared to the other baleen whales. Minkes feed on species such as sand lance, capelin, herring, cod, mackerel, and salmon as well as squid and zooplankton (krill and copepods) (Stewart and Leatherwood 1985, Katona et al. 1993).

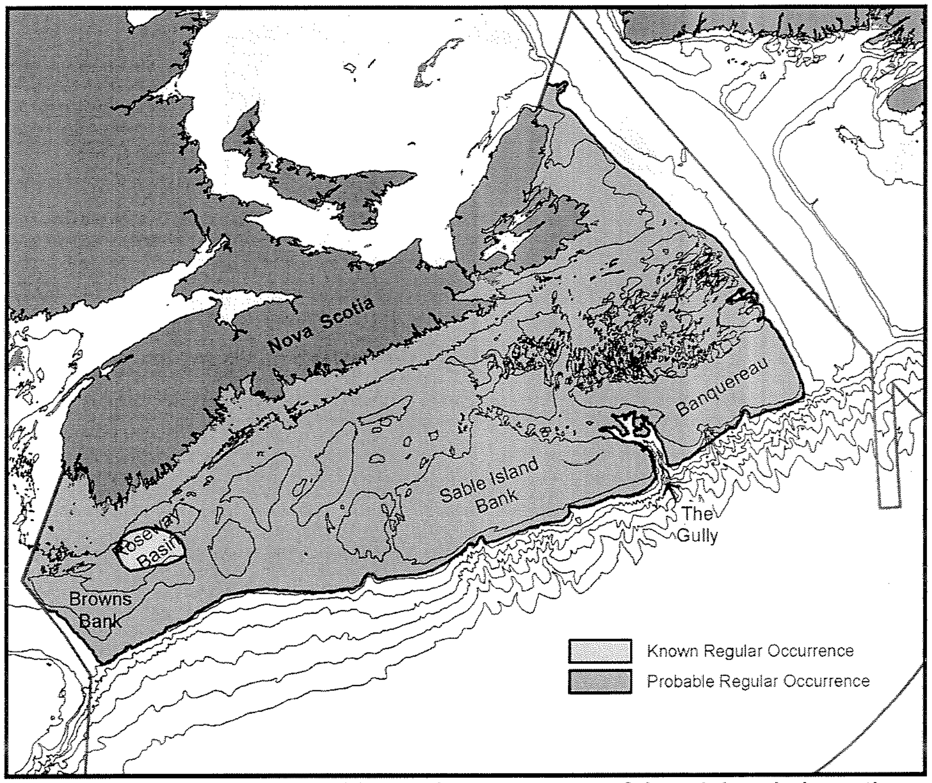

Figure 7-2. Known and probable regular occurrence of the minke whale on the Scotian Shelf, late spring to fall. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Sei whale (Balaenoptera borealis)

Sei whales are widely distributed around the world, preferring temperate waters. They migrate north in summer months but do not appear to use polar areas to the same extent as other baleen whales (Gambell 1985b). They feed extensively on copepods and also eat other zooplankton (euphausiids and amphipods) and small schooling fish such as herring (Gambell 1985b). The stomach contents of 88 sei whales[19] were examined on the Scotian Shelf in the early 1970s (Mitchell et al. 1986). Most had fed on copepods and many had fed on krill. Only two had traces of other prey items in their stomachs – a fish and a squid.

Mitchell and Chapman (1977) suggest that the Scotian Shelf population of sei whales make up a separate stock. Further evidence to confirm or deny this has not been forthcoming (Waring et al. 2000). Whitehead et al. (1998) suggest that records of sei whales in sighting databases are underrepresented, since they are difficult to identify definitively. Records from the Scotian Shelf show a preference for the shelf edge and the edges of banks, including the area between Browns and Baccaro Bank (Reeves 1999, Figure 7-3). In general, sei whales are thought to prefer depths characteristic of the edge of continental shelves, although they move into shallower waters to take advantage of prey concentrations (Waring et al. 2000).

Mitchell et al. (1986) found that the occurrence of right whales and sei whales in Roseway Basin was related. They suggested that these species associated closely and regularly during

[19] Number does not include those examined with no food in their stomachs.

feeding season since they both preferred to feed on copepods. This observation has been made in other areas. For example, the occurrence of sei whales in the Gulf of Maine was found to be strongly correlated with that of right whales and related to the abundance of copepods in the area (Payne et al. 1990).

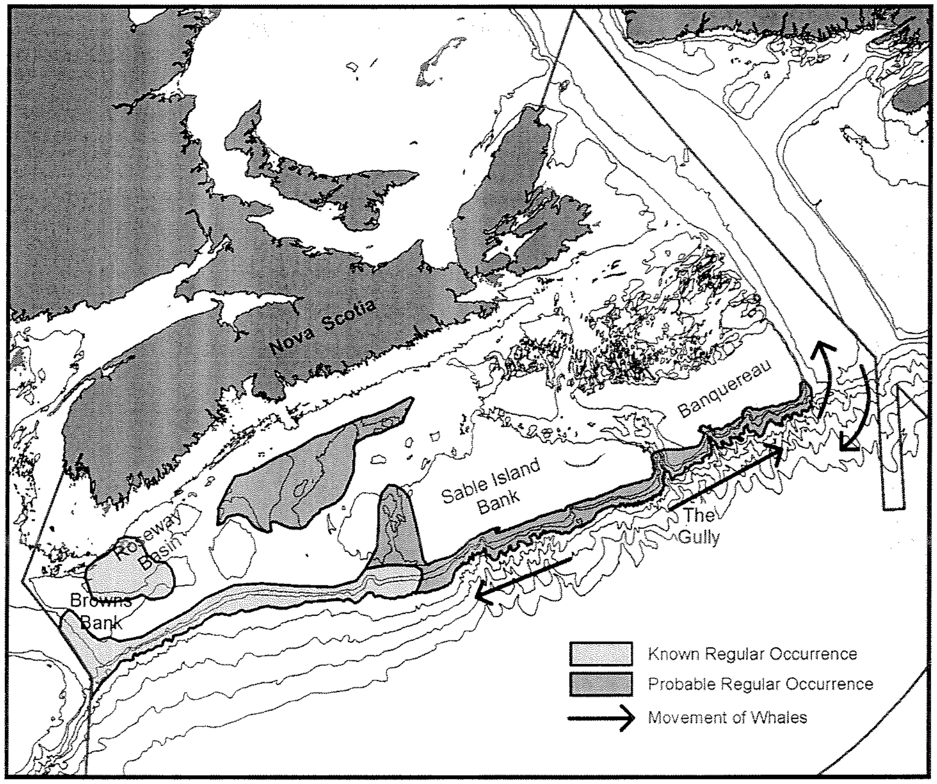

Figure 7-3. Known and probable regular occurrence of the sei whale on the Scotian Shelf, late spring to fall. Arrows indicate movement of whales to other regions. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

The sei whale is considered an endangered species by the United States National Marine Fisheries Service; however, the status of the current population and population trends are not well-known (Waring et al. 2000). Waring et al. (2000) suggests that the Scotian Shelf could be the centre for a major portion of the sei whale population during the summer months. There has been little effort to document sei whale use of the Scotian Shelf and the major evidence for their use of the shelf are the records of whalers. They caught a substantial number of sei whales on the shelf from 1966 to 1972 (Mitchell and Chapman 1977).

Fin whale (Balaenoptera physalus)

Fin whales are broadly distributed in continental shelf and offshore areas around the world. There is evidence of seasonal migrations between wintering areas to temperate and polar feeding areas in the summer. In the North Atlantic, wintering areas extend from the edge of pack ice south to the Caribbean and Gulf of Mexico (Gambell 1985a). Fin whales appear frequently on the Scotian Shelf during the summer months and are also seen occasionally during the winter (spring to fall distribution, Figure 7-4). They are fairly abundant compared to other large baleen whales with an estimated population of several thousand animals in eastern Canadian waters; however, they have been listed as a species of "special concern" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

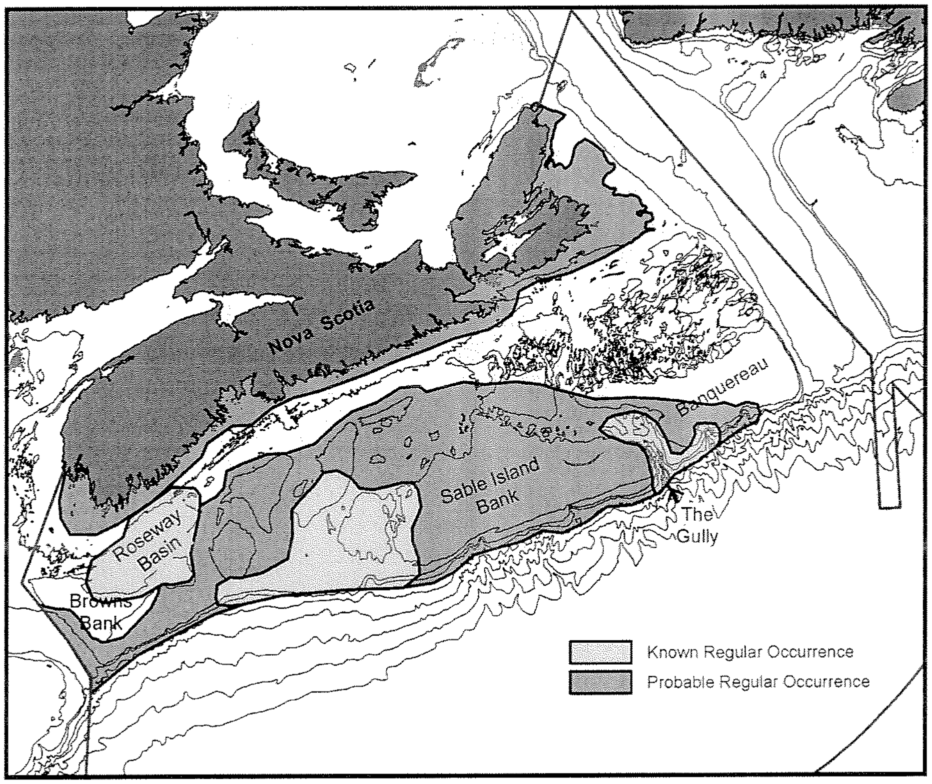

Figure 7-4. Known and probable regular occurrence of the fin whale on the Scotian Shelf, late spring to fall. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

In the northern hemisphere, fin whales feed more often on small fish than they do in other parts of their range, where euphausiids make up a large proportion of prey (Gambell 1985a). Katona et al. (1993) states that young whales feed mostly on zooplankton. In the northwest Atlantic, adults appear to feed mostly on krill and on small fish such as herring, mackerel, and capelin (Mitchell et al. 1986, Katona et al. 1993). The whales appear to switch prey depending on availability. Concentrations of fin whales can be found in Chedabucto Bay during the winter months, when herring school there close to the coast (P. Lane 1992). Some winters they can also be found off Chebucto Head and occasionally in the mouth of Halifax Harbour when herring are present (Whitehead et al. 1988 cited in P. Lane and Associates 1992). During the summer, they are commonly seen off St. Margaret's Bay (Whitehead, pers. communication).

Blue whale (Balaenoptera musculus)

Blue whales can be found in oceans around the world, primarily in open ocean areas although they are regularly seen in the Gulf of St. Lawrence and other continental shelf areas. Their distribution and seasonal movements are related to concentrations of euphausiids, their main prey (Yochem and Leatherwood 1985, Bowen and Siniff 1999). Blue whales in the southern oceans can reach a size of 30 metres and 180 tonnes. Those seen in the northwest Atlantic have been smaller, up to about 25 metres in length (Yochem and Leatherwood 1985, Whitehead et al. 1998).

Blue whales are slow-moving when feeding. They feed almost solely on krill and consume between two and four tonnes of food per day (Yochem and Leatherwood 1985). In the North Atlantic, copepods are also part of their diet and they occasionally eat herring and capelin, probably accidentally (Yochem and Leatherwood 1985). Fin whales and minke whales are often seen with blue whales in the Gulf of St. Lawrence.

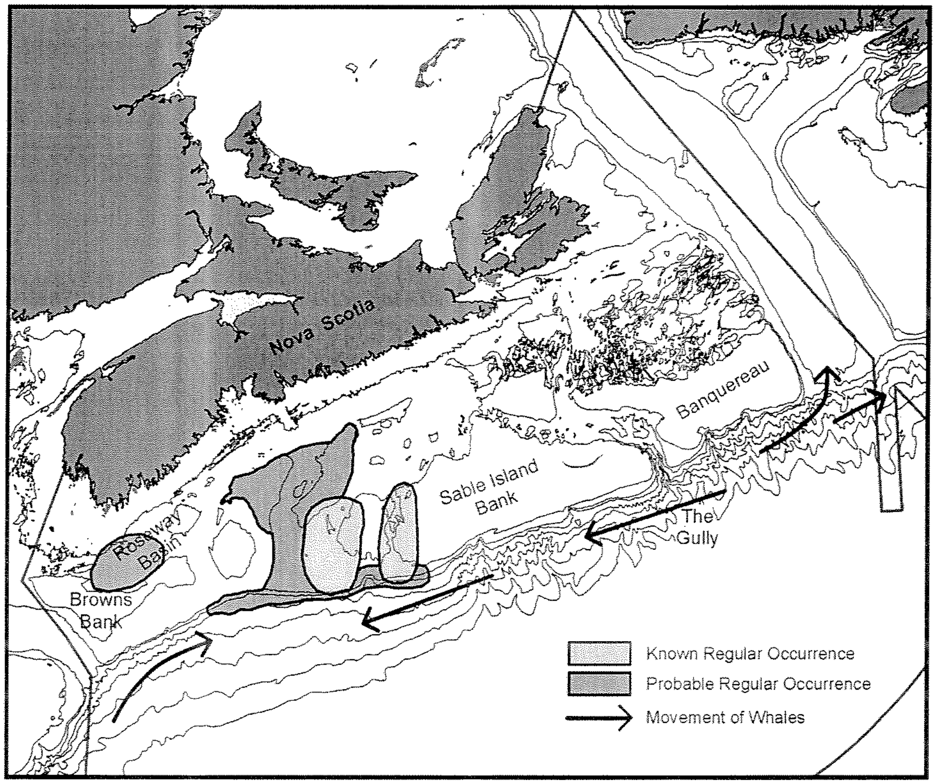

Figure 7-5. Known and probable regular occurrence of the blue whale on the Scotian Shelf, late spring to fall. Arrows indicate movement of whales to other regions. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Blue whales have been sighted on the Scotian Shelf from May to October (Figure 7-5). Most observations were in the vicinity of Emerald Bank and the area between Emerald and LaHave Banks (Reeves 1999). Whitehead et al. (1998) reported observations of blue whales in the vicinity of The Gully in the late summer. There has been little effort to document blue whale use of the Scotian Shelf and most records are observations made by whalers in the 1966 to 1972 period (see Sutcliffe and Brodie 1977). It is expected that blue whales could be found in any areas of high primary productivity on the Scotian Shelf in the summer and fall (Reeves 1999).

It is estimated that a few hundred blue whales can be found in Canadian waters (Reeves and Brown 1994). A 1988 photo census identified 308 individuals in the Gulf of St. Lawrence – not the entire population, although population trends are not well-known (Waring et al. 2000). The number of animals using the Scotian Shelf is not known.

Humpback whale (Megaptera novaeangliae)

Humpbacks migrate from southern latitudes to summer feeding grounds in the North Atlantic. There are believed to be three eastern Canadian feeding aggregations, one centred off Newfoundland, one in the Gulf of St. Lawrence, and one centred in the Gulf of Maine. They have been sighted in both offshore and inshore areas of eastern Canada (Leatherwood and Reeves 1983). Photographs have confirmed that whales from both the Newfoundland and Gulf of Maine groups migrate across the Scotian Shelf and slope and visit the Scotian Shelf during the summer (P. Lane 1992, Whitehead et al. 1998, Reeves 1999, Waring et al. 2000). There is increasing evidence that some whales regularly use the Scotian Shelf as a feeding area in summer and fall (Waring et al. 2000, Reeves pers. communication, see Figure 7-6). There have also been sightings of humpbacks on the Scotian Shelf during the winter (Reeves 1999).

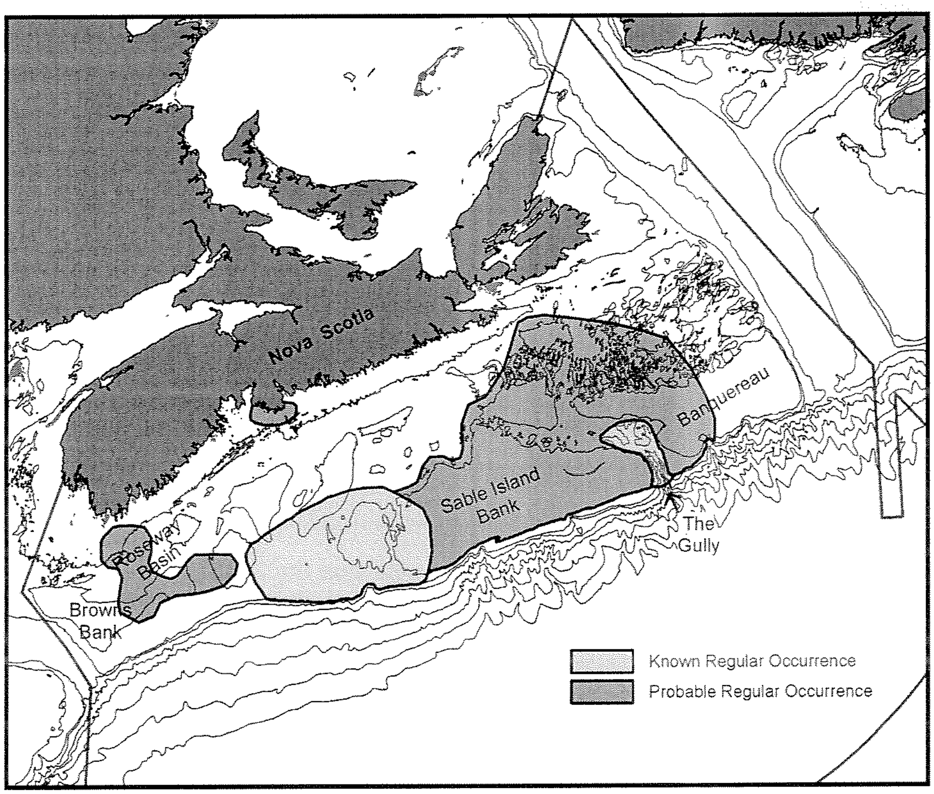

Figure 7-6. Known and probable regular occurrence of the humpback whale on the Scotian Shelf, late spring to fall. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Humpback whales feed on euphausiids; schooling fish such as sand lance, herring, and capelin; and less frequently, squid. They can herd or group fish and krill using their flukes.

They also feed by blowing bubbles under or around their prey, forming a temporary "bubble net" around the fish or krill before swimming through the net, mouth open (Winn and Reichley 1985, Katona et al. 1993). In the Gulf of Maine, their distribution was found to be largely correlated with that of abundant prey species. A decrease in the herring and mackerel stocks in the Gulf of Maine resulted in high concentrations of humpbacks in areas with abundant sand lance. When herring and mackerel began to recover, humpback distribution shifted to areas preferred by those species (Payne et al. 1990, Waring et al. 2000).

The North Atlantic humpback population is estimated at 10,600 (Smith et al. 1999, Waring et al. 2000). The number of animals that regularly use the Scotian Shelf is not known. The humpback is listed by COSEWIC as a species of special concern.

Odontocetes (Toothed Whales)

The odontocetes all have teeth, although the number and arrangement of them vary. For example, some species have teeth only in the lower jaw. They capture and grasp their prey, primarily fish and squids, using their teeth. The toothed whales use echolocation to navigate and find prey. Except for the sperm whale, the heads of toothed whales are smaller in proportion to their body than the baleen whales that need to be able to filter massive amounts of water. Most odontocentes are under nine metres in length; however, male sperm whales may be twice that length (Katona et al. 1993).

Distribution of toothed whales found off Nova Scotia varies by season. There have been few observations of whales on the Scotian Shelf from late fall to early spring, reflecting the lack of effort to observe or catch whales during this time of year. Some toothed whale species are definitely or probably found on the shelf or slope year-round (e.g, northern bottlenose whale, white-beaked dolphin, and long-finned pilot whale).

Sperm whale (Physeter macrocephalus)

The sperm whale has an extensive distribution, ranging widely throughout the world's oceans (Rice 1989). Females have a more restricted range than males and generally prefer waters above 15°C (Reeves and Whitehead 1997). The sperm whale is the largest toothed whale with a huge head that makes up between one-quarter and one-third of its body length (Rice 1989). Male sperm whales are significantly larger than females, 1.3 to 1.5 times longer and up to three times the weight of female whales (Rice 1989).

In general, sperm whales are most often found in areas where waters mix to create zones of high productivity, such as the edges of continental shelves, large islands, and offshore banks, and in areas of submarine canyons (Reeves and Whitehead 1997, see Figure 7-7). Griffin (1999) observed sperm whales much more frequently on the eastern boundary of a warm core ring on the slope of the Scotian Shelf than in adjacent water masses. He suggested that these frontal regions were important sperm whale habitat. They feed mostly on medium- and large-sized squids throughout much of their range (Rice 1989). Adult males may eat more than a tonne of squid per day (Katona et al. 1993). Sperm whales may be the deepest diving mammal. They are able to hunt squid at depths below 1000 metres (Reeves and Whitehead 1997).

Whitehead et al. (1992) monitored mature male sperm whales acoustically over several years in a limited area of the Scotian Shelf. Their records indicated that sperm whales could be found in depths of 63 to 2000 metres, and could most often be found in depths of 200 to 1500 metres on the eastern Scotian Shelf. They recorded high densities of sperm whales along the edge of the Shelf, especially in The Gully and nearby Shortland canyon. Female sperm whales and calves have also been sighted in Nova Scotia waters; however, this area likely represents the northern limit of their range (Reeves and Whitehead 1997). Strandings of sperm whales in December and January suggest that the Scotian Shelf provides year-round whale habitat for some male sperm whales (Lucas and Hooker 2000).

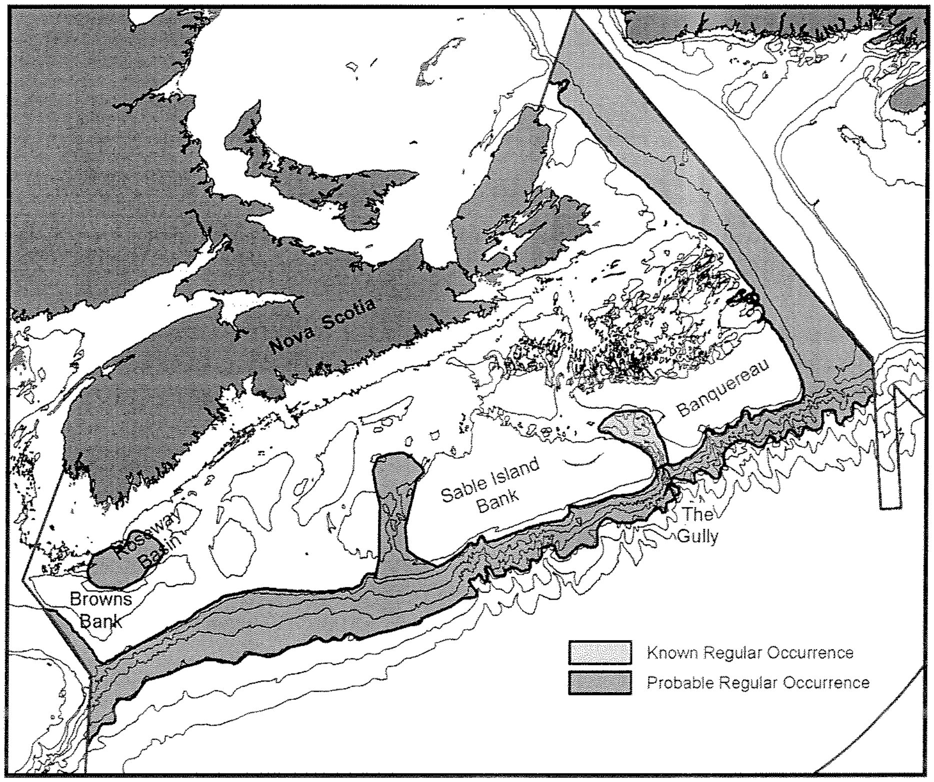

Figure 7-7. Known and probable regular occurrence of the sperm whale on the Scotian Shelf, late spring to fall. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Northern bottlenose whale (Hyperoodon ampullatus)

The beaked whales (Ziphiidae) are relatively small, deep-diving whales with prominent beaks. Several species occur or are thought to occur off Nova Scotia; the northern bottlenose whale is the best known of these. Northern bottlenose whales are found only in the North Atlantic, from Nova Scotia to the Davis Strait and east to Europe. A small population of bottlenose whales lives year-round in and near The Gully and has been the focus of scientific research by Dalhousie University biologists (see e.g., Whitehead et al. 1997a, Whitehead et al. 1997b, Hooker et al. 1998, Gowans et al. 2000, Dalebout et al. 2001). It is the only long-term study of a beaked whale population (Whitehead et al. 1997a). Bottlenose whales dive deeper than 1000 metres in search of their prey, mainly deep water squid from the genus *Gonatus* and deep-sea fish (Benjaminsen and Christensen 1979, Hooker et al. 2001). They may remain submerged for one to two hours (Mead 1989b). Whales observed in The Gully dived to depths over 800 metres to a maximum of 1453 metres and remained submerged for up to 70 minutes (Hooker 1999).

The Gully and an area off northern Labrador are the two centres for the whale in the Northwest Atlantic. The Gully population appears to be distinct from the Labrador population and its population has been monitored for over a decade using photo-identification techniques (Whitehead et al. 1997, Gowans et al. 2000). About 44 whales are in The Gully at any given time (Gowans et al. 2000). The entire population using The Gully was recently estimated to be about 130 animals (Gowans et al. 2000).[20] Besides The Gully, the whales use nearby areas that are deeper than 1000 metres in depth, such as Shortland canyon, and have never been seen in waters less than 800 metres in depth (Whitehead et al. 1997a, see Figure 7-8). Globally, they are rarely found in waters less than 1800 metres deep (Mead 1989b). They seem to prefer the steep topography of submarine canyons and the shelf edge. The Gully population is centred on a 20 kilometre x 8 kilometre core area at the entrance of the canyon (Whitehead et al. 1997a). This area is currently a whale sanctuary (see Figure 7-2) and an Area of Interest for DFO's marine protected area program.

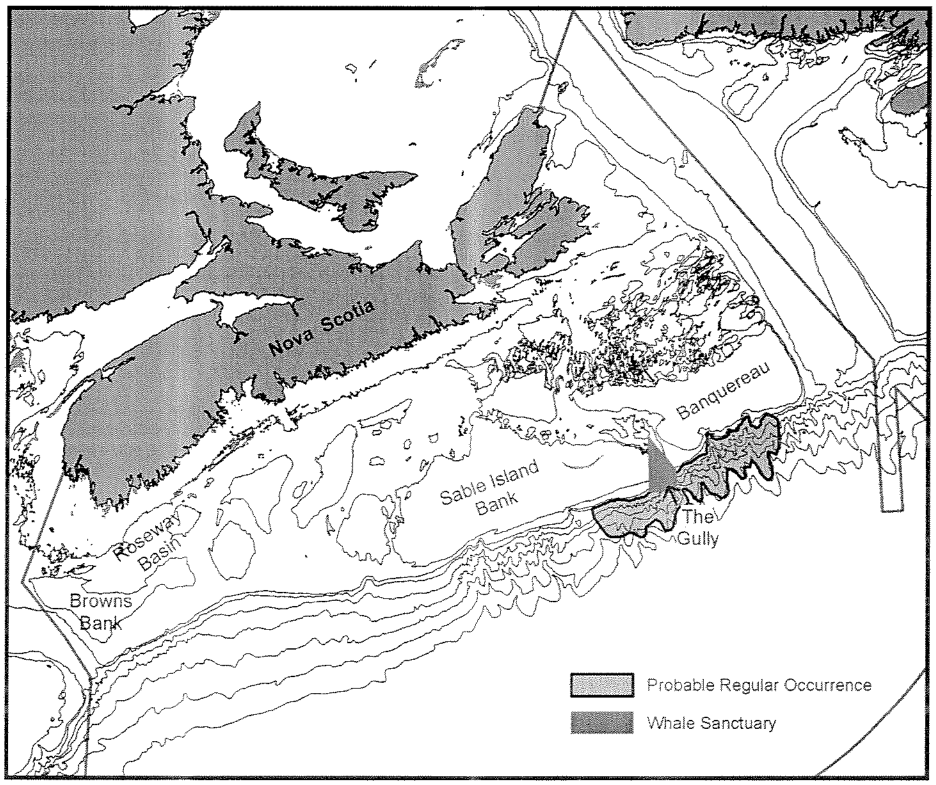

Figure 7-8. Known and probable regular occurrence of the northern bottlenose whale on the Scotian Shelf, year-round. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

[20] The estimate of 230 whales found in Whitehead et al. (1997a) was judged to be less precise by the authors of the later estimate, two of whom were authors of the earlier paper.

COSEWIC has listed The Gully population of the northern bottlenose whale as a species of special concern. The small size of this population makes it particularly vulnerable, as does its proximity to human activities occurring in the area: shipping, petroleum exploration, and fishing.

Short-beaked common dolphin (Delphinus delphis)

The short-beaked common dolphin is found worldwide in temperate, sub-tropical, and tropical waters between the latitudes of 50°N and 40°S (Waring et al. 2000). They are most common on the Scotian Shelf and slope from mid-summer to autumn, when water temperatures increase to above 11°C (Gowans and Whitehead 1995). Their distribution generally has been related to water temperature and bottom topography (Evans 1994). Gowans and Whitehead (1995) found common dolphins in waters of 60 to 2500 metres in depth. They appear to prefer areas of the continental slope from 100 to 200 metres, with steep topographical features (Selzer and Payne 1988, Whitehead et al. 1998, see Figure 7-9). They are abundant in The Gully (Whitehead et al. 1998). Common dolphins have occasionally been seen close to shore in Nova Scotia (P. Lane 1992). They prey on mackerel and squid and can be found in areas where those species are abundant. Common dolphins are often taken as bycatch in American mid-water trawl fisheries off the U.S. northeast coast; however, the bycatch from Canadian fisheries is not known (Reeves 1999, Waring et al. 2000).

*Striped dolphin (*Stenella coeruleoalba)

Striped dolphins are found around the world in warm temperate to tropical waters. They are found in Nova Scotia waters when the water temperatures reach above 15°C and some stay into the winter months well after the water has cooled (Whitehead et al. 1998, Lucas and Hooker 2000). They are considered uncommon in Canadian waters (Waring et al. 2000) and no distribution map is provided; however, they have been sighted frequently in The Gully area (Whitehead et al. 1998). Most stranding records in Canadian waters have come from Sable Island (Waring et al. 2000, see Lucas and Hooker 2000). Striped dolphins generally feed on fish, squids, and crustaceans (Perrin et al. 1994).

They are often seen in groups in 20 or more in other areas but in Canadian waters group size tends to be smaller than elsewhere in their range (Baird et al. 1997).

White-beaked dolphin (Lagenorhynchus albiorostris)

White-beaked dolphins are found throughout cool temperate and subarctic waters. In the Northwest Atlantic they occur from Cape Cod to the Davis Strait; however, seasonal movements in Canadian waters are not well-known (Reeves 1999, Reeves et al. 1999a). There are records of white-beaked dolphins off Newfoundland in autumn, winter, and spring, both in coastal areas and offshore (Lien 1986, Reeves et al. 1999a). They are regularly seen off Peggy's Cove and in nearby waters in early summer (Whitehead, pers. communication). No distribution map is provided due to the few published sightings on the Scotian Shelf, although they are probably fairly common.

White-beaked dolphins eat cod and other gadids, herring, hake, as well as squid, mackerel, and capelin in some areas (Lien et al. 1997, Reeves et al. 1999a). Animals examined off Newfoundland in March had eaten cod (Dong et al. 1996). Large groups of dolphins have been spotted in areas with high concentrations of fish. The dolphins will cooperate to herd fish together for more efficient feeding (Reeves et al. 1999a).

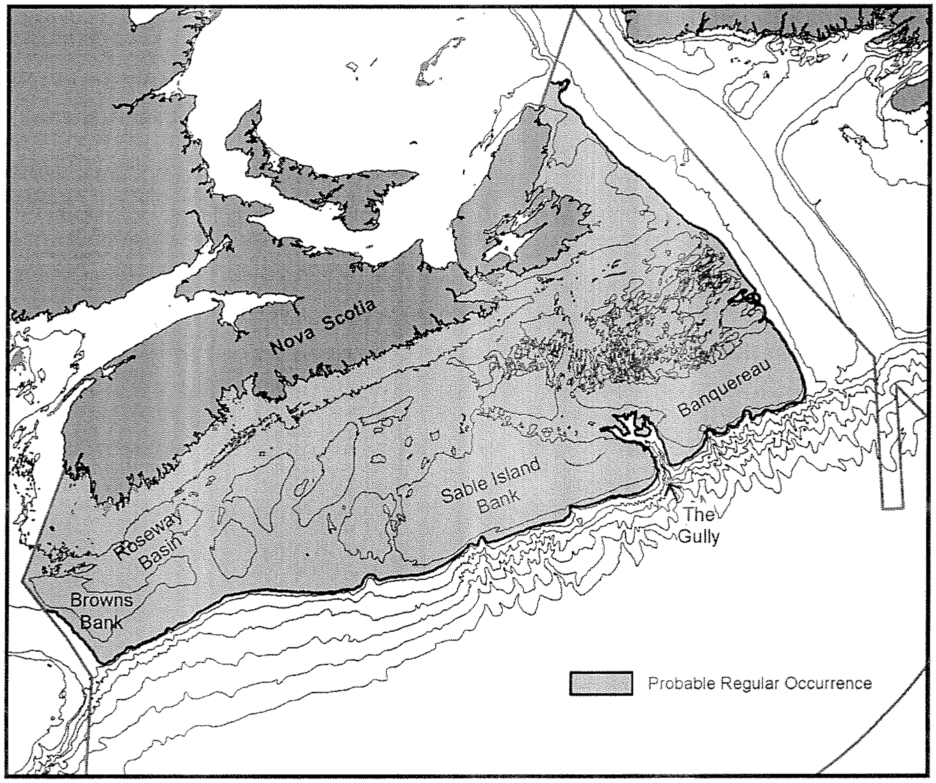

Figure 7-9. Probable regular occurrence of the short-beaked common dolphin, Atlantic white-sided dolphin, and long-finned pilot whale on the Scotian Shelf. Observations of these species have been fairly wide-spread across the shelf. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Atlantic white-sided dolphin (Lagenorhynchus acutus)

Like the white-beaked dolphin, the white-sided dolphin is found in cool temperate and subarctic waters. They are found along the continental shelf and slope in both shallow and deep waters (Reeves et al. 1999b), appearing to prefer depths of less than 100 metres (Waring et al. 2000, see Figure 7-9). They are most often seen on the Scotian Shelf in the summer and early autumn although they are not common (Reeves et al. 1999b). Palka et al. (1997 in Waring et al. 2000) suggested that there are three stocks in the Northwest Atlantic, with the Scotian Shelf lying between the ranges of the Gulf of Maine and Gulf of St. Lawrence stocks. In winter and spring they appear to move south from Newfoundland along the continental shelf edge. They appear to be more common on the eastern Scotian Shelf (Reeves 1999) and are frequently sighted in The Gully. Gowans and Whitehead (1995) suggest that some may overwinter in that area.

Sand lance is an important prey for the Atlantic white-sided dolphin and their movements off the northeastern United States have been linked to the seasonal distribution of the fish (Selzer and Payne 1988). They also prey on mackerel, herring, and squid and can be found in areas where these species are concentrated. Other fish are also eaten, for example, silver hake and smelt (Reeves et al. 1999b).

Long-finned pilot whale (Globicephala melas)

The long-finned pilot whale occurs on the Scotian shelf and further offshore in all months of the year (Reeves 1999). They are frequently sighted in inshore waters off Cape Breton during summer months and appear to move further offshore during the winter (P. Lane 1992). Most sightings have occurred along the shelf edge in spring and early summer, although there are sighting records from the shelf, shelf edge, and submarine canyons (Reeves 1999, see Figure 7-9). Pilot whales appear to occupy areas of various depths and bottom topography and prey concentrations are of importance. There is noticeable seasonal variation in distribution at the northern and southern limits of the range, with whales more abundant off Newfoundland during the summer and more abundant south of Georges Bank in winter (Nelson and Lien 1996). The offshore is important wintering habitat (Nelson and Lien 1996).

Studies of pilot whales from different areas and carried out at different times have found somewhat different prey consumption by the animals. A recent study using whales caught incidentally along the northeastern United States shelf edge, south of the Gulf of Maine, found mackerel, long- and short-finned squid, herring, and silver hake in the whales' stomach contents (Gannon et al. 1997). The authors concluded that long-finned squids were a primary prey item, with schooling fishes such as mackerel eaten opportunistically. Off Newfoundland, short-finned squid are a primary prey item (Sergeant 1962 cited in Reeves 1999) and the occurrence of pilot whales there in summer is related to spawning squid (Bernard and Reilly 1999). Payne and Heinemann (1993) found that distribution and movements of pilot whales off the northeastern United States were closely related to the abundance of long-finned squid and mackerel.

Killer whale (Orcinus orca)

Killer whales are the most widely distributed marine mammal, occurring in all the oceans at almost all latitudes. They are most common in temperate waters in coastal areas (Dahlheim and Heyning 1999). They are considered uncommon on the Scotian Shelf (Reeves 1999) and there are few records of them from this area (Mitchell and Reeves 1988 cited in Reeves 1999). They are widely distributed in the North Atlantic and highly mobile (Dahlheim and Heyning 1999).

Killer whales are the only cetaceans that regularly eat other mammals, generally baleen whales and dolphins as well as seals and other pinnipeds. The whales also eat herring and other fish. Their diet varies widely and throughout their range they have been known to eat birds, reptiles, squid, and even a moose (Dahlheim and Heyning 1999). Different pods may have different food preferences (Katona et al. 1993). Their feeding habits on the Scotian Shelf are not known.

Harbour porpoise (Phocoena phocoena)

The harbour porpoise is one of the smallest cetaceans, about 1.5 metres long and weighing 50 kilograms. They are distributed throughout temperate waters of continental shelves in the northern hemisphere (Read 1999). The Scotian Shelf is an important part of the harbour porpoise's range in the Western North Atlantic (Reeves 1999), although the four discrete populations generally agreed on do not include the Scotian Shelf as a focal point (Bay of Fundy-Gulf of Maine, Gulf of St. Lawrence, Newfoundland and Labrador, and Greenland) (Read 1999). There is some evidence of a separate population along Nova Scotia's Atlantic coast (Reeves 1999). Porpoises appear to inhabit coastal and nearshore regions from spring until fall and move offshore to fishing banks during the winter, although records are generally from waters less than 125 metres deep (Reeves 1999). The few records from the offshore may be because of difficulty in sighting the small animals (Reeves 1999). Harbour porpoises are seldom found in waters warmer than 17°C (Read 1999), preferring temperatures of 5 to 16°C (CWS 2000).

Porpoises are frequently found in areas where their prey are concentrated. The main prey species are small schooling fish such as herring and capelin, as well as silver hake and cod (Read 1999, Reeves 1999). Their appearance in the Bay of Fundy is closely tied to congregations of herring. Although COSEWIC lists the Northwest Atlantic population as a threatened species, it is the Gulf of Maine-Bay of Fundy population that is of most concern (Reeves 1999, CWS 2000). The most recent estimate for the Gulf of Maine-Bay of Fundy population is about 90,000 animals (Plaka 2000). No estimate is available for animals that use the Scotian Shelf. Although harbour porpoise populations appear relatively high when compared to other species of cetaceans, they have a high rate of incidental mortality (Caswell et al. 1998). Their tendency to frequent areas heavily used by gillnet fishers makes them vulnerable to entrapment by fishing gear.

Other toothed whales

Several other whales have been sighted on the Scotian Shelf. Their use of the shelf is not well-known or is thought to be infrequent. The distributions of the pygmy sperm whale (*Kogia breviceps*) and the dwarf sperm whale (*Kogia simus*) are generally not well-known. There are records of both from the Scotian Shelf and their hypothesized distribution is along the shelf edge and further seaward (Baird et al. 1996, Reeves 1999, Lucas and Hooker 2000).

Cuvier's beaked whale is a widespread deep water species that is known to occur along the United States east coast. Most records are from strandings (Heyning 1989). Reeves (1999) could not confirm reports of its occurrence off Nova Scotia; however, he noted that the lack of sightings does not rule out its presence in deep waters offshore. If Cuvier's beaked whale occurs in Canadian waters, it will likely be in similar areas as those sighted off the northeastern United States. Sightings of undifferentiated beaked whales off the northeast U.S., including the Cuvier's beaked whale and the mesoplodonts discussed below, have been concentrated in the deep waters of the Georges Bank region and in association with the Gulf Stream and related warm-core rings (Waring et al. 2000). Bycatch of beaked whales from northeastern U.S. fisheries have come from the continental shelf slope and canyons along Georges Bank (Waring et al. 2000).

The small beaked whales from the genus *Mesoplodon* are generally not well-known. There are records of three species from the genus on the Scotian Shelf: Sowerby's beaked whale

(*M. bidens*), Blainville's beaked whale (*M. densirostris*), and True's beaked whale (*M. mirus*) (Mead 1989a). Both Blainville's and True's beaked whale are believed to generally occur further south, while the range of Sowerby's beaked whale extends further north to Labrador and south to the northeastern United States (Mead 1989a, Reeves 1999). Whitehead (pers. communication) observes that mesoplodonts appear to be quite common along the edge of the Scotian Shelf (see Figure 7-10). The mesoplodonts are difficult to identify to the species level at sea and most records of them are from strandings (Waring et al. 2000).

The bottlenose dolphin (*Tursiops truncatus*) and Risso's dolphin (*Grampus griseus*) have both been observed a few times off Nova Scotia but are not regularly present on the shelf (Reeves 1999, Lucas and Hooker 2000). The bottlenose dolphin has been observed occasionally in The Gully during late summer (Whitehead et al. 1998). Its main range is further south. Risso's dolphin is a deep water species that may occur regularly seaward of the shelf (Reeves 1999). Globally, it is patchily distributed in the open ocean seaward of the continental shelf slope and occurs frequently in areas of steep bottom topography (Kruse et al. 1999). Reeves (1999) suggests that it may be associated with waters influenced by the Gulf Stream.

Two unconfirmed sightings of Fraser's dolphin, a tropical species, were made in The Gully (Whitehead et al. 1998). No other species of cetaceans are confirmed or hypothesized for Scotian Shelf waters.

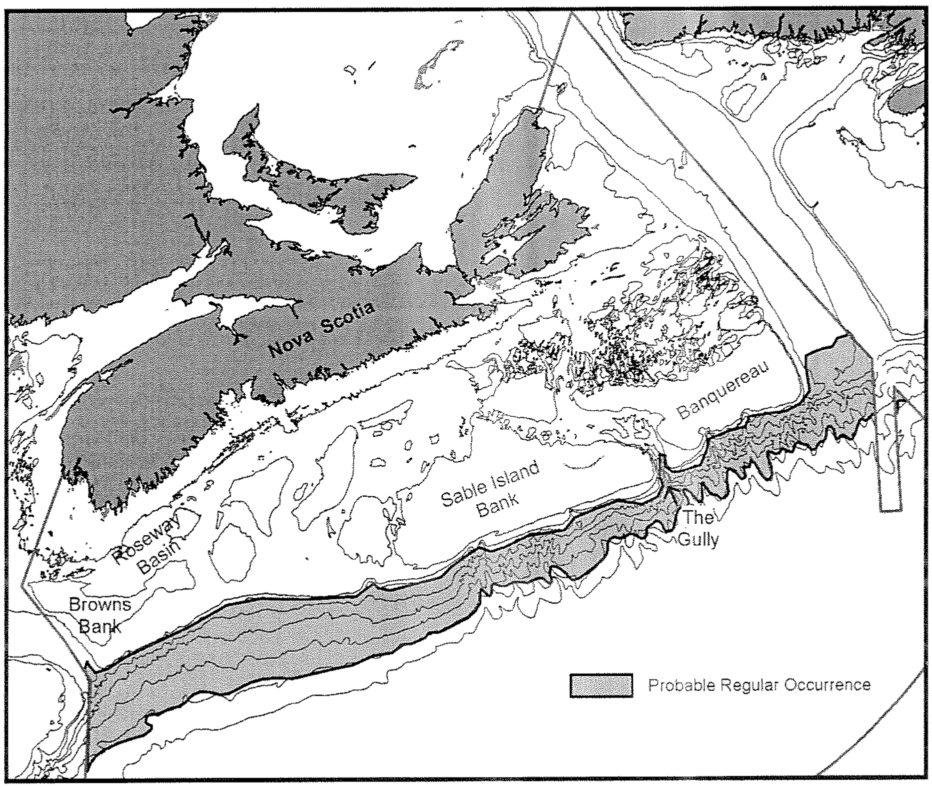

Figure 7-10. Probable regular occurrence of beaked whales from the genus *Mesoplodon*. See *Whale Observations* (p. 182) for details on the creation of the distribution maps.

Pinnipeds (Seals, Sea lions and Walruses)

Seals are the only group of pinnipeds that occur on the Scotian Shelf. They are awkward on land but graceful swimmers that are well adapted to the marine environment. They have streamlined bodies with an insulating layer of blubber to protect them from cold waters. Unlike whales, pinnipeds generally are covered with a well-developed pelage consisting of short, somewhat stiff hairs in the case of seals and fur in the case of sea lions and fur seals. The pinnipeds haul out on land or ice to give birth and suckle their young, with the exception of walruses that nurse aquatically.

Seals generally have a higher rate of reproduction than whales, with mature females giving birth each year to one pup (on rare occasions, two). Only two species of seals breed on the Scotian Shelf, the harbour seal and the grey seal. Seals are vulnerable to disturbance during pupping. Response to the disturbance varies by species and according to the nature and duration of the disturbance.

Seals eat a wide variety of fish, crustaceans, and cephalopods (Bowen and Siniff 1999). They appear to vary their diets by season and area to take advantage of prey that are plentiful. Many studies have shown that although seals will eat a variety of species, two to five species will make up the bulk of their diet at any one time (Bowen and Siniff 1999). Most of the fish eaten are relatively small and fall within a range of 10 to 35 centimetres (Bowen and Siniff 1999).

The harp and hooded seals have been sighted more frequently on the eastern Scotian Shelf in recent years. Whitehead et al. (1998) speculated that increased sightings on the shelf may be due to increased population size or may be related to changes in the oceanic environment. Ringed seals are also occasionally seen on Sable Island (Bowen, pers. communication). Table 7-2 lists and briefly describes the seals occurring on the Scotian Shelf.

Harbour seal (Phoca vitulina)

Harbour seals are non-migratory seals that seem to stay near areas where they haul out (Bowen and Siniff 1999). Juveniles disperse farther from their birth location before settling in a home range; however, studies in Europe have found that most pups stay within 50 kilometres or even 20 kilometres of sites where they were tagged (Thompson and Härkönen cited in Bowen and Siniff 1999). Occasionally, groups of adults and juveniles may move to new foraging grounds. There are seasonal changes in movements. For example, some populations move to take advantage of foraging areas that are seasonally productive, such as spawning concentrations of fish. Animals congregate seasonally in breeding and moulting areas but disperse more widely at other times of the year (Whitehead et al. 1998).

Thousands of harbour seals breed along the Atlantic coast of Nova Scotia and less than 50 breed on Sable Island, the only offshore breeding location in eastern Canada. The Sable Island population has been declining since the early 1990s likely due to several factors, such as increased shark predation on juveniles and reduced female fertility (Bowen cited in Whitehead et al. 1998). When disturbed, harbour seal mothers are likely to enter the sea, usually with their pup. Although harbour seal pups are accomplished swimmers within hours of birth, repeated and extended disturbances may increase the risk of shark predation. As well, pups that are forced into rough seas are placed at risk of drowning (Bowen, pers. communication).

Table 7-2. Seals of the Scotian Shelf[21]

Common Name *Scientific Name*	**Description and Social Behaviour**	**Habitat**	**Distribution and Movements**	**Food**	**Population and Conservation Status**
Harbour seal *Phoca vitulina*[22]	• small, spaniel-like nose • coat is light to dark grey-brown, paler belly • pups are silvery-grey • about 1.7 metres long • bask on exposed rocks and ledges and coastal areas at low tide, often in small groups • individuals or small groups at sea	• coastal areas, stay near areas where they haul out • temperate waters • take advantage of seasonal foraging areas	• in West Atlantic, breed from New Hampshire to Baffin Island and Hudson Bay • juveniles disperse before settling in a home range • distributed along Atlantic coast of NS and Sable Island • in NS waters year-round	• fish such as herring, mackerel, cod, and pollock; short-finned squid, crustaceans • sand lance near Sable Island • diet varies with prey availability	• thousands along Atlantic coast • less than one hundred on Sable Island (only offshore breeding population in Canada, perhaps the world) • status has not been evaluated by COSEWIC
Grey seal *Halichoerus grypus*[23]	• distinctive long nose • coat varies in colour from dark grey (males) to pale brown (females); obvious patterns • pups are white at birth • 2 to 3 metres long • seen in small groups or as individuals • sociable, will haul out in large groups	• offshore, dispersed widely over shelf when not breeding • some found in coastal areas • prefer exposed haul out sites	• breed from Nova Scotia to Gulf of St. Lawrence • breed on Sable Island • dispersed over Scotian Shelf and throughout eastern Canada when not breeding • in NS waters year-round	• fish, mainly sand lance, flatfishes, and cod, and squid • typically shallow divers (50 to 100 metres) with most foraging on offshore banks	• 1994 estimate of 150,000 in Sable Island population • not at risk (COSEWIC)
Hooded seal *Crystophora cristata*[24]	• silvery grey coat with large, black blotches • males have an inflatable nasal sac • pups have bluish-grey coats, white bellies • 1.5 to 2.6 metres long • individuals seen on Scotian Shelf	• generally associate with pack ice in winter, Scotian Shelf near southern limit of normal range	• generally found further north where they follow advancing and retreating pack ice • juveniles and some adults occasionally seen on Scotian Shelf in spring after whelping	• deep divers (to 500 metres), feed on bottom-dwelling fish, squid, and herring	• 1997 estimate of about 500,000 in NW Atlantic • not at risk (COSEWIC)
Harp seal *Pagophilus groendlandica*[25]	• coat white to grey or tan, with dark head and darker harp-shaped pattern on back • juveniles have grey coats with dark spots, harp pattern emerges in early adulthood • about 1.8 metres long • individuals seen on Scotian Shelf	• generally associate with pack ice in winter, Scotian Shelf near southern limit of normal range	• generally found further north where they follow advancing and retreating pack ice • juveniles and adults occasionally seen south of Gulf of St. Lawrence in spring (February to May)	• capelin, also herring, sand lance and crustaceans • diet changes with age and availability of prey	• 2000 estimate of about 5.2 million in NW Atlantic • status has not been evaluated by COSEWIC

[21] Descriptions are from Hannah (1998), Katona et al. (1993), and Whitehead et al. (1998); conservation status is from COSEWIC (2000); other references are with each species.
[22] Sources for this species: Bowen and Harrison (1996), Bowen and Siniff (1999), Katona et al. (1993), and Whitehead et al. (1998).
[23] Sources for this species: Beson (1998), Bowen and Harrison (1994), Bowen and Siniff (1999), Mohn and Bowen (1996), and Whitehead et al. (1998).
[24] Sources for this species: Bowen and Siniff (1999), Stenson et al. (1997), and Whitehead et al. (1998).
[25] Sources for this species: DFO (2000), Katona et al. (1993), and Whitehead et al. (1998).

A study comparing harbour seal diets in two areas, the Bay of Fundy and the Eastern Shore, found that Atlantic herring, cod, pollock, and short-finned squid made up more than 80 percent of the total amount consumed (Bowen and Harrison 1996). Eastern shore harbour seals also consumed small amounts of mackerel and capelin. Diets varied from year to year, with some prey species playing a more important role some years. An earlier study of harbour seal diet, using seals from Nova Scotia's Atlantic coast and Sable Island, found herring, squid, flounders, alewife, and hake to be the most important prey foods (Boulva and McLaren 1979). Around Sable Island, sand lance is thought to be the most important species (Bowen cited in Whitehead et al. 1998). These findings suggest that prey availability plays an important role in food selection (Bowen and Harrison 1996). Most of the seals used in the studies were collected during the summer and fall and diets during the spring and winter may be different.

Grey seal (Halichoerus grypus)

Sable Island is home to the world's single largest breeding population of grey seals, representing more than half the entire eastern Canadian population (Whitehead et al. 1998). Grey seals also whelp on Camp, White, and Hay Islands along the eastern shore and off Cape Breton (Hannah 1998, Bowen and Siniff 1999). Whelping occurs between mid-December and mid-January. The grey seal is the longest-lived of the seals found on the Scotian shelf, with a lifespan of about 45 years. Their population has been increasing rapidly, at a rate of about 13 percent a year over the last three decades (Beson 1998, Bowen and Siniff 1999). The animals disperse widely over the Scotian Shelf during the non-breeding season.

Grey seals are sociable onshore, hauling out near other grey seals and occasionally near harbour seals. At sea, they can be found in small groups or alone. Grey seal mothers will tolerate brief disturbances with little effect, usually defending their pup quite vigorously (Bowen, pers. communication). Sand lance, flatfishes, and cod make up the main part of grey seal diets (Bowen and Harrison 1994).

Hooded seal (Cystophora cristata)

Hooded seals are migratory seals that are seen on the eastern Scotian Shelf off Cape Breton and occasionally further south. Formerly considered rare on the Scotian Shelf, many juveniles were observed on Sable Island in the mid and late 1990s (Whitehead et al. 1998). Hooded seals travel from the Arctic to whelp on pack ice in the Gulf of St. Lawrence and further north in February and March. Pups are weaned in just four days. After the breeding and pupping period, juvenile and adult seals disperse widely to feed on the continental shelf off Newfoundland (Bowen and Siniff 1999) and apparently in areas further south. They return north as the pack ice retreats in the spring. Hooded seals feed on redfish and other bottom-dwelling fish, squid and herring (Katona et al. 1993).

Harp seal (Pagophilus groenlandicus)

Harp seals were formerly considered rare on the Scotian Shelf but have been seen regularly on the eastern shelf in recent years. The animals found on the Scotian Shelf breed further north, likely in the Gulf of St. Lawrence. Dozens of juveniles were observed on Sable Island in the mid and late 1990s and they have also been observed more frequently south of the

Scotian Shelf (Whitehead et al. 1998). Capelin and Arctic cod are the most important prey of harp seals off Newfoundland (DFO 2000). They also feed on herring, sand lance and crustaceans (Katona et al. 1993). Their diet appears to vary according to availability of prey and by age.

Other species

Besides the species listed, the ringed seal (*Phoca hipsida*) is an occasional visitor to Sable Island (Whitehead et al. 1998). These sightings represent the farthest south it generally strays.

The Atlantic walrus (*Odobenus rosmarus*) formerly bred on Sable Island and probably along the Atlantic coast of Nova Scotia but has been extirpated from the Northwest Atlantic. There are rare observations of strays from the Arctic population off Nova Scotia (Katona et al. 1993).

Important Areas

Sable Island, The Gully, and surrounding waters have been identified as an important area for marine mammals (Amirault 1995, Whitehead et al. 1998). A report prepared for Parks Canada suggested that the entrance of The Gully could be of "global cetacean significance" (P. Lane 1992: 2-52). Fisheries and Oceans Canada established the deep canyon area of The Gully as a whale conservation area (now called whale sanctuary) in 1994 and in 1997 initiated the Sable Gully Conservation Strategy to address growing conservation interest. The Conservation Strategy document was released in 1998 and included conservation objectives, goals, and recommendations for planning and management (DFO 1998). It is currently an "Area of Interest" under DFO's marine protected areas program and its features, including whale use of the area, have been described in Harrison and Fenton (1998).

Sable Island is the most important breeding area for grey seals in eastern Canada and is also a breeding area for harbour seals. Its important features have been documented in many reports, including Beson (1998).

The right whale feeding area at Roseway Basin has been proposed as a site of "global cetacean significance" (P. Lane 1992: 2-52). Brown et al. (1995) have suggested that it be protected as a conservation zone with no industrial activity. In 1994, it was established by DFO as a seasonal (July-November) whale conservation area (now called whale sanctuary); however, this designation serves only to alert mariners to the possible presence of whales and offers no legal protection for the animals. This area was heavily used by right whales in the early 1980s followed by diminished use in the 1990s. Greater numbers of whales have been seen in that area during more recent seasons. The shift in whale distribution suggests that changes in the ocean environment can trigger a quick response from whales. In the future, the population could shift to other historically or potentially attractive feeding areas on the Scotian Shelf, such as Emerald or LaHave Basin and other areas on the edges of banks. An area encompassing parts of Emerald and Western Banks, including the channel between them (the Western Gully), also appears to be important for baleen whales (see e.g., Mitchell et al. 1986).

Whales are commonly observed at the shelf edge, where there are high levels of primary productivity. That area may be important both for animals that stay in the region and those migrating north or south.

In general, whales use the Scotian Shelf as a feeding area and a migratory route to other feeding areas further north. Whales need vast amounts of food to fuel their large bodies. In the summer, many whales tend to feed in areas with high concentrations of prey where feeding is efficient. As shown by the figures in this chapter, different whale species are often found in the same area. Their prey are often concentrated in areas where two water masses meet, where currents form eddies (for example around a land mass or where currents collide), or where waters are mixed through upwelling. Those areas will be highly productive for phytoplankton or will concentrate planktonic organisms through eddies. Small, schooling fish – prey for many whale species – will also be attracted to areas where zooplankton are plentiful. Highly productive areas will be attractive for whales, seals, and many of the other organisms of the Scotian Shelf.

The seasonal movements of prey species influence the distribution of many marine mammals. Whales and seals may be attracted to high concentrations of small, schooling fish and follow them close to shore. Marine mammals will feed in areas where large aggregations of schooling fish appear on a seasonal basis, such as Chedabucto Bay.

The best way to gain a better understanding of important areas for the marine mammals of the Scotian Shelf would be to carry out systematic surveys. There also exists a vast amount of sighting data that has not yet been analysed, from fisheries observers, petroleum companies, and the PIROP program. By examining existing data, we may develop a better picture of whale distribution on the Scotian Shelf.

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8 MARINE-ASSOCIATED BIRDS[1]

Introduction

The bird species included in this chapter regularly use marine habitats during some part of their life histories. Seabird distributions on the Scotian Shelf and along Nova Scotia's Atlantic coast reflect oceanographic conditions and habitat availability. Gulls, terns, and cormorants breed along Nova Scotia's coast and some species remain year-round in coastal areas. Several species of waterfowl nest in the province's salt marshes and others pass through on migration; some species winter along the southwestern coast. The offshore provides habitat for the "true" seabirds, the pelagic birds which remain at sea for most of the year. Most of these birds breed in other areas; however the shallow banks and the continental shelf edge are important feeding areas for pelagic birds year-round. Besides species occurring regularly on the shelf, tropical and European species may be blown into Atlantic Canadian waters during storms or otherwise stray north or west.

Many of the birds found on the Scotian Shelf and along Nova Scotia's coast are world-class travellers. Shorebirds winter in tropical and semi-tropical climates, and breed in the Arctic and near-Arctic. Shearwaters breed in southern latitudes and come north to their summer habitat offshore. Migration periods, especially fall migration, finds a diversity of avifauna in Nova Scotia's coastal waters and offshore. Some species of migratory birds stay along Nova Scotia's Atlantic coast into late fall or early winter (Tufts 1986).

In other works on the Scotian Shelf, especially the environmental assessments (see e.g., Mobil Oil 1983, MacLaren Plansearch 1996, CNSOPB 1998), sections on marine birds have focussed on pelagic birds because they are most vulnerable to the effects of oil spills. Their vulnerability is due to their relatively low rates of reproduction, the concentration of huge nesting colonies in few areas, and their tendency to spend much time on or in the water. The vulnerable species include the auks, gannets, shearwaters, fulmars, and kittiwakes. Lock et al. (1994) described the distribution and habitat for many Atlantic Canadian sea birds, including birds found along the coast, and explained their relative vulnerability to oil-caused mortality. P. Lane and Associates (1992) provided a good overview of pelagic and coastal birds of Nova Scotia.

All bird species are vulnerable to the effects of changes in habitat. Brown (1991) described some of the possible repercussions of global warming on the marine birds of the northwest Atlantic. His paper, although speculative, provided a quick summary of the linkages between the marine environment and the life history of birds. Besides changes in climate, seabirds are vulnerable to changes in the population of prey species. Species that are highly dependent or show marked preferences for particular prey are most vulnerable to changes in prey species populations (see e.g., Tasker et al. 1999a).

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Coastal Birds

Coastal breeding birds

At various times of the year, loons, grebes, sea ducks, dabbling ducks, cormorants, gulls, terns, and shorebirds can be found along the Atlantic coast. Erskine (1992) mapped the distribution of all species known to breed in the Maritime provinces. Species of breeding birds found along the Atlantic coast are fewer in number than non-breeding birds that pass through on migration or come to feed after nesting further inland. The species that breed in coastal areas are listed in Table 8-1. There are other birds, such as sparrows, thrushes, and warblers, that nest in coastal areas. However, marine habitats are considered more important for the species listed in Table 8-1. Seabird colonies of Nova Scotia's Atlantic coast are listed later in the chapter (Figure 8-3).

Included in Table 8-1 are four pelagic birds found in offshore areas for much of the year:

- a small number of Atlantic Puffins,[2] which breed on the Bird Islands off Cape Breton, Pearl Island in Lunenburg County, and other sites in southwestern Nova Scotia;
- a small number of Razorbills, which breed on Pearl and the Bird Islands;
- numerous Leach's Storm-petrels, which breed on Pearl Island and many other coastal islands; and
- Black-legged Kittiwakes, which breed on the Bird Islands and other islands off Cape Breton (Lock 1987).

Puffins and Razorbills can be seen in the vicinity of their colonies during breeding season and spend the rest of the year farther offshore. Razorbills are generally found closer to the coast during the winter than puffins which prefer open ocean habitats (Terres 1982, see e.g., Huettmann 1999). Leach's Storm-petrels breed on many of the coastal islands and range far offshore to forage for food, even during breeding season. Puffins, razorbills, and storm-petrels have small clutch sizes with only a single egg produced each breeding season. The Black-legged Kittiwake is a pelagic gull that nests in rocky coastal areas. Each breeding pair lays three to four eggs each breeding season (Tufts 1986, Lock et al. 1994). Other pelagic birds found on the Scotian Shelf do not breed in Nova Scotia.

Historically, Atlantic Puffins and Razorbills nested on other coastal islands along Nova Scotia's Atlantic coast, including islands off Yarmouth (Tufts 1986). A few other pelagic seabirds formerly nested in the province, for example, the Common Murre was known to nest on Green Island and Gannet Rock off Yarmouth, and the Bird Islands in Cape Breton (Tufts 1986). The Northern Gannet formerly nested on Gannet Rock and likely nearby islets (Tufts 1986). Breeding colonies of the extinct Great Auk may have existed on coastal islands. Populations of colonial nesting birds decreased in number from intense hunting and egging. The number of Leach's Storm-petrels have been reduced all along the Atlantic coast due to predation by gulls (Lock, pers. communication). However, breeding populations of many birds have recovered and are increasing (Chardine et al. 1999). Although the number of puffin colonies has declined from historic highs, the number of new nesting sites has increased in recent years (Chardine 1999). The first Nova Scotia kittiwake colony was observed in Cape Breton in 1971, although it was believed to be long-established (Tufts 1986,

[2] Common names of birds are capitalized throughout this chapter, as is standard practice in ornithological literature. The common names of other species are not capitalized, unless they include a proper name, again following standard practice.

Lock 1987). Kittiwakes have since expanded to other sites along the Atlantic Coast and Bay of Fundy (Kehoe 1994, Lock 1998).

Table 8-1. Marine-associated birds that breed along Nova Scotia's Atlantic Coast*

Common Name	Latin Name	Habitat Use/Time of Year
Storm-Petrels		
Leach's Storm-petrel	*Oceanodroma leucorhoa*	Breeds on numerous coastal islands along Atlantic coast. Seen offshore from April to October.
Cormorants		
Great Cormorant	*Phalacrocorax carbo*	Breeds in coastal and island colonies along eastern Cape Breton. Some winter along Atlantic coast.
Double-crested Cormorant	*Phalacrocorax auritus*	Breeds along the Atlantic coast. A small number overwinter.
Herons		
Great Blue Heron	*Ardea herodias*	Breeds in coastal areas and on islands; some breed inland. Regularly feeds in shallow coastal waters (P. Lane and Associates 1992).
Black-crowned Night Heron	*Nycticorax nycticorax*	Established a breeding colony on Bon Portage Island, Shelburne County, in the 1970s.
Waterfowl		
Green-winged Teal	*Anas crecca*	Nests in fresh and salt water marshes.
American Black Duck	*Anas rubripes*	Breeds in/near various wetland habitats. Concentrations along southwest coast in winter.
Northern Pintail	*Anas acuta*	Seen during fall and winter migrations. Nests (uncommon) throughout NS in salt and freshwater marshes. Has nested on Sable Island.
Common Eider	*Somateria mollisima*	Nests along the Atlantic coast in summer. Large numbers winter along the coast.
Red-breasted Merganser	*Mergus serrator*	Common along the coast in autumn through spring. Small numbers nest, a few on coastal islands (P. Lane and Associates 1992).
Shorebirds		
Semi-palmated Plover	*Charadrius semipalmatus*	Breeds in small numbers on coastal beaches in southwestern NS and Sable Island.
Piping Plover	*Charadrius melodus*	Breeds on a few beaches in southwestern NS. Endangered.
Willet	*Catoptrophus semipalmatus*	Breeds along Atlantic coast, usually near salt marshes. Has become more common in last 30 years. Regularly seen on beaches during spring/fall migration.
Least Sandpiper	*Calidris minutilla*	A few nest regularly on Sable Island and in small numbers along the Atlantic coast.
Gulls and Terns		
Herring Gull	*Larus argentatus*	Common in summer; some overwinter. Large breeding colonies along the coast.
Great Black-backed Gull	*Larus marinus*	Commonly nests in colonies along the coast, also singly in inland lakes. Some overwinter. Often seen offshore.
Black-legged Kittiwake	*Rissa tridactyla*	Breeds on the Bird Islands and other islands off Cape Breton. Winters offshore.
Roseate Tern	*Sterna dougallii*	Breeds in small numbers on Sable Island and coastal islands, with colonies of other terns. Endangered.
Common Tern	*Sterna hirundo*	Breeds in colonies along eastern and south shores and Sable Island.
Arctic Tern	*Sterna paradisaea*	Breeds in colonies along eastern and south shores and Sable Island.
Alcids		
Razorbill	*Alca torda*	One breeding colony off Cape Breton and one on southwestern coast. Winters in waters of the continental shelf.
Black Guillemot	*Cepphus grylle*	Breeds in small numbers on coastal islands. Present along coast year-round.
Atlantic Puffin	*Fratercula arctica*	One breeding colony off Cape Breton and a few on southwestern coast. Winters offshore.

*Information in table compiled from Tufts (1986) and Lock et al. (1994) unless otherwise referenced.

The Common Eider is the only sea duck that regularly breeds in Nova Scotia, nesting on islands along the coast. Eiders dive for sea urchins, crustaceans, and molluscs in coastal areas. The other marine-associated breeding ducks are three dabbling ducks that usually breed in fresh water wetlands but also nest in salt water marshes, and a diving duck that occasionally nests on coastal islands. The dabbling ducks eat aquatic plants, small crustaceans and insects in coastal salt marshes. The Red-breasted Merganser dives for fish, molluscs, and crustaceans.

Although most shorebirds seen in Nova Scotia are migratory transients, some nest on coastal beaches, the most significant species being the endangered Piping Plover which nests at several beaches in southwestern Nova Scotia (see Chapter 10 for more information). The plovers feed on small marine invertebrates along sandy beaches. Gulls and terns nest on islands along the coast as well as on Sable Island. Many gulls are opportunistic feeders, feeding on fish, molluscs, and crustaceans, the eggs and young of other birds, as well as discards and garbage from fishing vessels. Black-legged Kittiwakes feed largely on fish they pluck from surface waters. The terns hover and plunge from the air to pick fish from surface and near-surface waters.

About 70 percent of the North American population of Great Cormorants breeds along Nova Scotia's coast (Bird Studies Canada 2001a). Double-crested Cormorants also nest along the coast, as do Black Guillemots, the only coastal alcid species. The cormorants and guillemots dive to catch fish. Guillemots also consume crustaceans.

Herons breed on islands along the Atlantic coast. The Great Blue Heron nests in both coastal and inland areas of the province, with most colonies in coastal areas. In coastal areas, they eat fish, insects, and more rarely, small birds.

Coastal non-breeding birds

Table 8-2 lists the birds that occur regularly along Nova Scotia's Atlantic coast but do not nest there, as well as the time of year they frequent coastal areas. Many migratory bird species visit Nova Scotia's coast in spring and fall. Some species breed in the province but further inland, coming to the coast to feed. This list does not include the pelagic birds that spend most of their lives in offshore areas.

Nova Scotia is an important staging area for shorebirds during fall migration. Most forage for minute molluscs and crustaceans in the mudflats of the Bay of Fundy before attempting their long journey to South America. A fair number can also be found on the beaches of Nova Scotia's Atlantic coast; however, these number in the hundreds rather than the hundreds of thousands that use the upper Bay of Fundy.

Waterfowl that breed in more northerly areas migrate and winter along the Atlantic coast. Key gathering places include Lingan Bay, Cape Breton; Martinique, Chezzetcook, Grand Desert, and Cole Harbour, Halifax Regional Municipality; Port Joli, Queen's County; Cape Sable, Shelburne County; and Pinkney's Point, Yarmouth County (P. Lane and Associates 1992). Those areas have rich feeding grounds and remain free of ice for most or all of the year (P. Lane and Associates 1992).

Table 8-2. Non-Breeding birds occurring regularly along Nova Scotia's Atlantic coast*		
Common Name	**Latin Name**	**Habitat Use/Time of Year**
Loons and Grebes		
Red-throated Loon	*Gavia stellata*	In coastal areas during spring and fall migration; uncommon in winter.
Common Loon	*Gavia immer*	Winters on salt water; breeds inland on freshwater.
Pied-billed Grebe	*Podylimbus podiceps*	Occasionally seen in estuaries and sheltered saltwater coves in winter. Nests by freshwater ponds.
Horned Grebe	*Podiceps auritus*	In coastal areas during spring and fall migration; uncommon in winter.
Red-necked Grebe	*Podiceps grisegena*	In coastal areas during spring and fall migration; uncommon in winter.
Waterfowl		
Brant	*Branta bernicla*	Small numbers in coastal areas in southwest NS during spring and fall migration.
Canada Goose	*Branta canadensis*	In coastal areas during spring and fall migration. Large numbers overwinter at Port Joli and Cole Harbour.
Greater Scaup	*Aythya marila*	In coastal areas during spring and fall migration (may be abundant to January); uncommon later in winter.
Harlequin Duck	*Histrionicus histrionicus*	Rare winter resident along the Atlantic coast, more common on southwest coast than eastern shore. Migratory transient in fall and spring.
Long-tailed Duck**	*Clangula hyemalis*	Common in winter along the coast.
Black Scoter	*Melanitta nigra*	Common along the coast during fall and spring migration; small numbers (uncommon) in winter.
Surf Scoter	*Melanitta perspicillata*	Common along the coast during fall and spring migration; fairly common in winter.
White-winged Scoter	*Melanitta fusca*	Common along the coast during fall and spring migration; fairly common in winter.
Common Goldeneye	*Bucephala clangula*	Common along the coast during fall and spring migration; fairly common in winter. Breeds inland in small numbers.
Bufflehead	*Bucephala albeola*	Common along the coast during fall and spring migration; small numbers (uncommon) in winter.
Shorebirds		
Black-bellied Plover	*Pluvialis squatarola*	Common along the coast during fall and spring migration. Occasionally, a few overwinter around Cape Sable Island.
Lesser Golden Plover	*Pluvialis dominica*	Uncommon (but occasionally numerous) during fall migration; rare during spring migration.
Lesser Yellowlegs	*Tringa flavipes*	Uncommon during spring migration; more common during fall migration.
Ruddy Turnstone	*Arenaria interpres*	Uncommon during spring migration; common during fall migration. Occasionally overwinter near Louisbourg, and perhaps Sable and Cape Sable Islands.
Red Knot	*Calidris canutus*	Uncommon during spring migration; more common during fall migration. May occasionally overwinter on southwest coast.
Sanderling	*Calidris alba*	Uncommon during spring migration; common during fall migration. Some overwinter on southwest coast.
Semipalmated Sandpiper	*Calidris pusilla*	Uncommon during spring migration; common during fall migration. Small numbers of non-breeders in summer.
White-rumped Sandpiper	*Calidris fuscicollis*	Uncommon during spring migration; common during fall migration.
Pectoral Sandpiper	*Calidris melanotos*	Uncommon during spring migration; common during fall migration.
Purple Sandpiper	*Calidris maritima*	Common in some areas during winter (November – April), usually on rocky shores.
Dunlin	*Calidris alpina*	Uncommon during spring migration; common during fall migration. Occasionally, a few overwinter on the south and eastern shores.
Short-billed Dowitcher	*Limnodromus griseus*	Uncommon during spring migration; common during fall migration.
Gulls and terns		
Common Black-headed Gull	*Larus ridibundus*	Fairly common along the Atlantic coast in winter.
Bonaparte's Gull	*Larus philadelphia*	Uncommon during spring migration; more common along south shore during fall migration.
Ring-billed Gull	*Larus delawarensis*	Common during spring and fall migration; small numbers during winter. Formerly considered rare.
Iceland Gull	*Larus glaucoides*	Fairly common in winter, especially Halifax and Sydney harbours.

*Some of these birds breed in the province but inland. Information in table compiled from Tufts (1986) and Lock et al. (1994) unless otherwise referenced.

**Long-tailed duck was formerly known as Oldsquaw (see American Ornithologists' Union 1998).

Migratory birds often stopover on the Tusket Islands and Seal Island, off southwestern Nova Scotia. These islands also support large breeding populations of birds. Remote Seal Island is at the crossroads of the Bay of Fundy and open Atlantic and is the last Nova Scotia landfall for migratory birds heading south. The number of bird species sighted there is comparable to the number seen in all of Atlantic Canada (ACWERN 2001). The Atlantic Bird Observatory, which monitors migratory birds, operates a station there and on nearby Bon Portage Island.

Waterfowl, coastal seabirds, and shorebirds other than those species listed in Table 8-2 are occasional or rare visitors to the Scotian Shelf and Nova Scotia's coastal waters. The Laughing Gull formerly nested in Nova Scotia and is now only an occasional, rare visitor. The endangered (and perhaps extinct) Eskimo Curlew formerly used Nova Scotia's coasts as a staging ground on its fall migration, although less extensively then the coasts of Labrador and Newfoundland. The last Nova Scotia record of this species is from the nineteenth century (Tufts 1986). As well as the diminution of ranges, some birds are expanding their ranges to include Nova Scotia. Snowy Egrets have been seen regularly on Bon Portage Island since the 1980s and may soon establish a breeding population (Tufts 1986). Summer sightings of Common Black-headed Gulls, a European species, increased in the 1980s and their nests may soon be discovered in the province (Tufts 1986).

Important Coastal Bird Areas

Coastal islands, especially along the eastern shore of Nova Scotia, are important nesting sites for sea birds, waterfowl, and shorebirds. There are many different provincial, national, and international programs to identify and designate important areas for birds. Internationally, Bird Life International[3] identifies sites important to conserving the world's birds through its Important Bird Areas (IBA) program. The Ramsar program identifies wetlands of international importance, with an emphasis on those used as waterfowl habitat. The Canadian government has established Migratory Bird Sanctuaries, largely to protect migratory game birds. National Wildlife Areas also protect migratory bird habitat and National Parks may include important coastal habitat for seabirds. Wildlife management areas have been set up by the Nova Scotia government to protect important habitat for wildlife. Provincial Parks, Wilderness Areas, and Wildlife Sanctuaries are provincial designations that also protect some important areas for birds. The following areas along the Atlantic coast of Nova Scotia have been identified as ecologically important sites for coastal or marine birds (Lock et al. 1994, Bird Studies Canada 2001b). The areas are not discrete – parts or all of some provincially, nationally, or NGO-designated sites are incorporated into IBAs and the Ramsar site. Figure 8-1 shows the locations of these important bird areas along the Atlantic coast and one offshore area.

Migratory Bird Sanctuaries (Canadian government):

- Big Glace Bay Lake (also identified as an IBA)
- Port Hebert (part of South Shore – Port Joli Sector IBA)
- Port Joli (part of South Shore – Port Joli Sector IBA)
- Sable Island (also identified as an IBA)
- Sable River (part of South Shore – Port Joli Sector IBA)

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[3] Bird Life International's Canadian partners are Bird Studies Canada and the Canadian Nature Federation.

National Park (Canadian government):

- Kejimkujik Seaside Adjunct (part of South Shore – Port Joli Sector IBA)

Wildlife Management Areas (Nova Scotia government):

- Pearl Island
- Eastern Shore Islands (also identified as an IBA)

Wildlife Sanctuaries (Nova Scotia government):

- Martinique Beach (part of Musquodoboit Harbour Outer Estuary Ramsar site and Musquodoboit IBA)

Wilderness Areas (Nova Scotia government):

- Scatarie Island (also identified as an IBA)

Provincial Park (Nova Scotia government):

- Cole Harbour Heritage Park
- Martinique Beach (part of Musquodoboit Harbour Outer Estuary Ramsar site and Musquodoboit IBA)
- Point Michaud Beach (part of Basque Islands and Michaud Point IBA)
- Risser's Beach (part of South Shore – East Queens Co. Sector IBA)
- Summerville Beach (part of South Shore – Port Joli Sector IBA)
- Thomas H. Raddall (Queen's County) (also part of Port Joli Important Bird Area)

Ramsar site:

- Musquodoboit Harbour Outer Estuary (includes Martinique Beach Wildlife sanctuary and Martinique Beach Provincial Park)

Nova Scotia Bird Society Sanctuaries:

- Indian Island
- Hertford Island (part of Bird Islands IBA)
- Tusket Island Group, including Outer Bald Island

Research Stations:

- Bon Portage Island (owned by Acadia University)
- Seal Island (used by the Atlantic Bird Observatory but privately owned and for sale)

Important Bird Areas (no legal designation unless otherwise indicated):

- Basque Islands and Michaud Point (includes Point Michaud Provincial Park)
- Big Glace Bay Lake (also a Migratory Bird Sanctuary)
- Bird Islands (Hertford and Ciboux) (includes a NS Bird Society Sanctuary)
- Bon Portage Island (also a Research Station owned by Acadia University)
- Cape North
- Country Island Complex
- Eastern Cape Sable Island
- Eastern Shore Islands (also a Wildlife Management Area)
- Harbour Rocks (part of Gabarus Wilderness Area)
- Ingonish Island

- Musquodoboit (includes Martinique Beach Provincial Park and Martinique Beach Wildlife Sanctuary, also a Ramsar site)
- Northern Head (Cape Percé) and South Head (Cape Morien)
- Portnova Islands
- Rocks off Fourchu Head
- Sable Island, Nova Scotia (also a Migratory Bird Sanctuary)
- Scatarie Island (also a Wilderness Area)
- South Shore - Barrington Bay Sector
- South Shore - Port Joli sector (includes parts of Kejimkujik National Park Seaside Adjunct; Port Hebert, Port Joli and Sable River Migratory Bird Sanctuaries; and Summerville Beach and Thomas Raddall Provincial Parks, as well as unprotected areas)
- South Shore - Roseway to Baccaro
- South Shore - East Queens Co. Sector (includes Risser's Beach Provincial Park)
- St. Paul Island

Although all these sites have been identified as important, they have varying levels of protection. Several of the IBAs have no legal designation. Another site, the Brothers Islands, has been acquired by the province with the intention of establishing the tiny islands as a Wildlife Management Area (Boates, pers. communication). The site is the most important breeding colony in Canada of the endangered Roseate Tern (Lock et al. 1994).

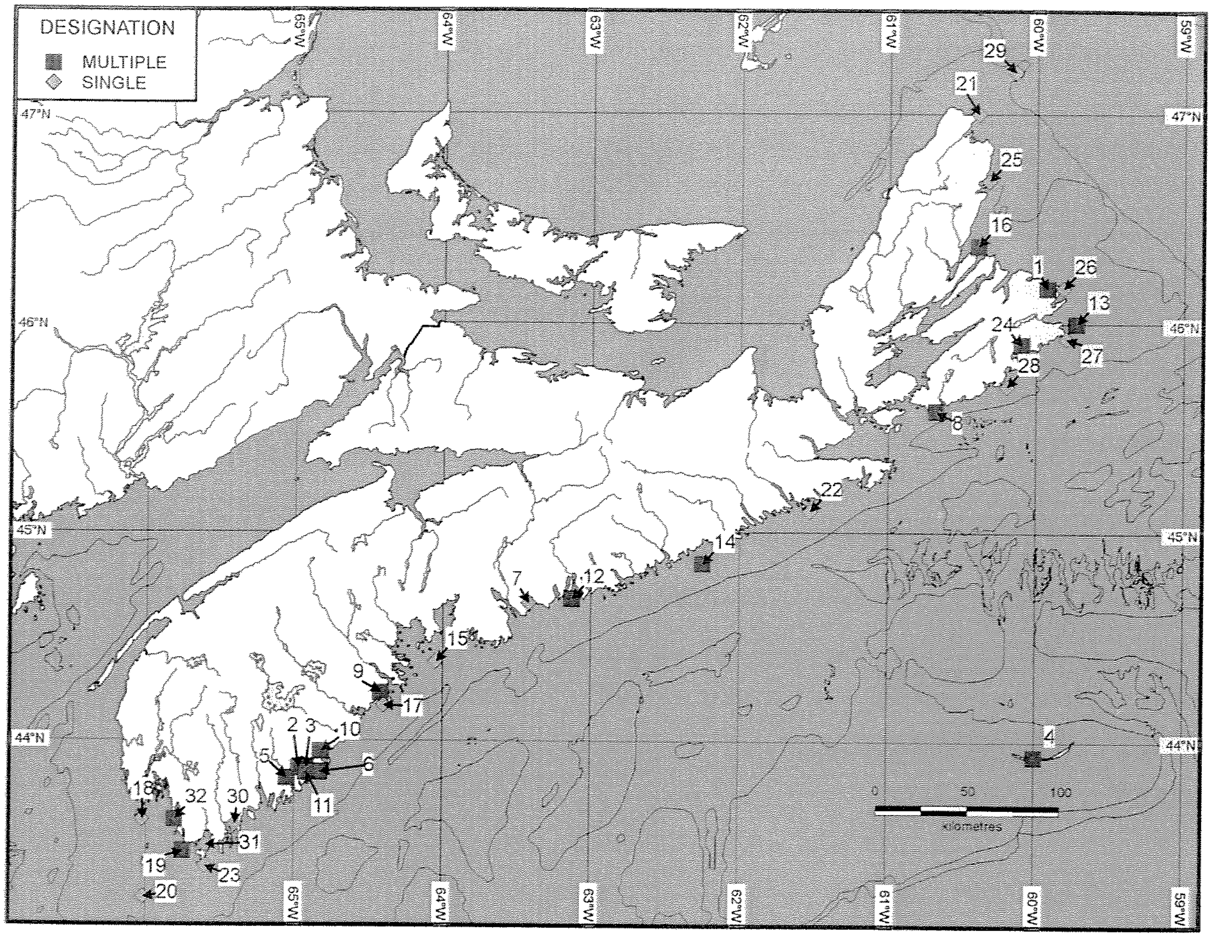
The presence of upwellings appears to significantly influence winter distributions of shorebirds (Morrison 1984). The few shorebirds that overwinter in Nova Scotia prefer specific sites, including Cape Sable Island, an area of significant upwelling. The presence of shorebirds in winter may be an indication of the occurrence of regular coastal upwelling events in those areas.

Pelagic Birds

Pelagic seabirds spend most of the year at sea, coming to shore only to breed. Most nest on island colonies or at inaccessible sites on the mainland to protect themselves from terrestrial predators. Pelagic birds are relatively long-lived and have low fecundity. For most species, each breeding pair only produces one egg each year (Lock et al. 1994). They are vulnerable to disturbances at their breeding colonies and years of egging and hunting by humans have significantly impacted many populations.

The pelagic birds of the Scotian Shelf are listed in Table 8-3 with the time of year they can be found in offshore areas. Auks, fulmars, gannets, shearwaters, storm-petrels, and Black-legged Kittiwakes are some of the offshore species. The offshore communities of seabirds have a different make-up in the summer and winter; however, similar areas are used all year by the various species (Lock et al. 1994).

Nearly all the pelagic birds found on the Scotian Shelf do not breed in the province. The four exceptions – Leach's Storm-petrel, Black-legged Kittiwake, Razorbill, and Atlantic Puffin – are discussed in the section on coastal breeding birds. Islands off Newfoundland and southern Labrador offer better habitat for nesting pelagic birds, which breed in the millions in less than 100 colonies in that region. Successful colonies are near highly productive ocean areas with abundant food and are isolated from predators – few areas of coastal Nova Scotia meet those criteria (P. Lane and Associates 1992).



Index of areas (some numbers refer to more than one area, see text for more information)

1. Big Glace Bay Lake
2. Port Hebert
3. Port Joli
4. Sable Island
5. Sable River
6. Kejimkujik Seaside Adjunct
7. Cole Harbour
8. Point Michaud Beach
   Basque Islands and Michaud Point
9. Risser's Beach
   South Shore (East Queens County Sector)
10. Summerville Beach
11. Thomas Raddall
12. Martinique Beach Provincial Park
    Martinique Beach Wildlife Sanctuary
    Musquodoboit Harbour Outer Estuary Ramsar site
    Musquodoboit Important Bird Area
13. Scatarie Island
14. Eastern Shore Islands
15. Pearl Island
16. Bird Islands (Hertford and Ciboux)
17. Indian Island
18. Tusket Island Group (including Outer Bald Island)
19. Bon Portage Island
20. Seal Island
21. Cape North
22. Country Island Complex
23. Eastern Cape Sable Island
24. Harbour Rocks
25. Ingonish Island
26. Northern Head and South Head
27. Portnova Island
28. Rocks off Fourchu Head
29. St. Paul Island
30. South Shore - Roseway to Baccaro Sector
31. South Shore - Barrington Bay Sector
32. Brothers Islands

South Shore - Port Joli Sector (not shown) includes 2,3,5,6,10,11

Figure 8-1. Coastal and offshore areas that have been identified as important to birds. Multiple designation means areas that have a designation from more than one agency or organization; single designation means areas that have a designation from one agency or organization.

Most pelagic birds feed on small fish. Sand lance, capelin, and herring are important prey species for seabirds in eastern Canada; however, other small fish are also eaten when available. Phalaropes, shorebirds that are pelagic during non-breeding seasons, feed on planktonic crustaceans and amphipods at upwellings (Brown 1986). Dovekies eat crustaceans and zooplankton, while puffins will eat crustaceans and squid as well as small fish. Jaegers and skuas feed on fish from the ocean surface. They will also steal food from other birds and occasionally catch and eat small seabirds. Oceanic areas that are productive and have concentrations of preferred prey will likely be highly used by seabirds, for example, areas of tidal- or wind-induced upwellings and fronts where water masses meet and concentrate plankton.

Table 8-3. Birds occurring regularly in offshore areas, Scotian Shelf*		
Common Name	**Latin Name**	**Time of Year**
Fulmars, Shearwaters, Storm-petrels		
Northern Fulmar	*Fulmarus glacialis*	Most common in winter, some records throughout the year.
Cory's Shearwater	*Calonectris diomeda*	Uncommon, regular summer sightings.
Greater Shearwater	*Puffinus gravis*	Regular summer resident offshore.
Sooty Shearwater	*Puffinus griseus*	Regular summer resident offshore.
Manx Shearwater	*Puffinus puffinus*	Uncommon, regular summer sightings.
Wilson's Storm-petrel	*Oceanites oceanicus*	Regular summer resident offshore.
Leach's Storm-petrel	*Oceanodroma leucorhoa*	Breeds on coastal islands but ranges widely offshore during summer.
Gannets		
Northern Gannet	*Sula bassana*	Common during spring and fall migration along Atlantic coast and offshore
Phalaropes		
Red-necked Phalarope	*Phalaropus lobatus*	Southwest Scotian Shelf during spring and fall migration.
Red Phalarope	*Phalaropus fulicarius*	Common during spring and fall migration.
Skuas and Jaegers		
Pomarine Jaeger	*Stercorarius pomarinus*	Present during spring and fall migration, rare in summer.
Parasitic Jaeger	*Stercorarius parasiticus*	Present during spring and fall migration, rare in summer.
Long-tailed Jaeger	*Stercorarius longicaudus*	Rare during spring and fall migration.
Great Skua	*Stercorarius skua*	Regular sightings during the summer offshore.
South Polar Skua	*Stercorarius maccormicki*	Rare sightings during the summer.
Gulls, terns		
Black-legged Kittiwake	*Rissa tridactyla*	Common in winter, uncommon in summer. Breeds in small numbers along the coast (see below).
Alcids		
Dovekie	*Alle alle*	Common and widespread in winter, especially on the Scotian Shelf southwest of Sable Island.
Common Murre	*Uria aalge*	Common in winter. Formerly bred on coastal islands off Nova Scotia.
Thick-billed Murre	*Uria lomvia*	Common in winter.
Razorbill	*Alca torda*	Offshore in winter and during spring and fall migration. Breeds in Nova Scotia in small numbers (see below).
Atlantic Puffin	*Fratercula arctica*	Winters offshore. Breeds in Nova Scotia in small numbers (see below).

*Information in table compiled from Tufts (1986) and Lock et al. (1994) unless otherwise referenced.

Monaghan et al. (1996) examined changes in the activities of Black-legged Kittiwakes and Common Murres in the Shetland Islands after a dramatic decrease in sand lance (*Ammodytes marinus*[4]), their primary prey, over a two-year period. They found little difference in breeding success in the birds, despite changes in time spent foraging and attending chicks; however, they could not tell how many birds had not bred because of lack of prey availability. Earlier studies in the Shetlands had shown that breeding failures in kittiwakes and other surface feeding birds had followed a collapse in sand lance stocks (see Tasker et al. 1999a for an overview). Diving birds were little affected by the collapse. In Norway, the decrease of capelin stocks in the 1980s resulted in reduced breeding success for seabirds in that area (Tasker et al. 1999a). In Canada, the reduction of fishing activity on the east coast has resulted in fewer fish discarded at sea and changes in the diets of gulls, especially great black-backed and herring gulls (Tasker et al. 1999b). Great Black-backed Gulls in Newfoundland have started to prey more heavily on Black-legged Kittiwakes and Atlantic Puffins, affecting their breeding success (Tasker et al. 1999b).

The distribution maps in this section are from the *Gazetteer of Marine Birds in Atlantic Canada* (Lock et al. 1994). They are based on data collected for PIROP (Programme Intégré

[4] This sand lance is also commonly known as sandeel.

de Recherches sur les Oiseaux Pélagiques), a program that ran from 1966 to 1992 (Huettmann 1997). Coverage of ocean areas, both spatially and temporally, is uneven. There are large areas of the Scotian Shelf for which no data are available or are available only for certain times of year. The eastern Scotian Shelf has especially poor coverage at all times of the year, while the months of December to March have low coverage for the entire Shelf (Lock et al. 1994, Huettmann 1997). After 1979, there was less effort (and fewer observations) on the Scotian Shelf (Huettmann 1997). This makes it difficult to link changes in seabird populations and distributions with changes in oceanographic features, since the scale of oceanographic data is different than that of the seabird data (Huettmann 1997). Figures 8-2 to 8-5 present a composite picture that does not take into account trends over the years. The seabirds that are considered "vulnerable" and mapped here are the auks, gannets, shearwaters, fulmars, and kittiwakes (Lock et al. 1994). "Vulnerable" refers to vulnerability to oil pollution.

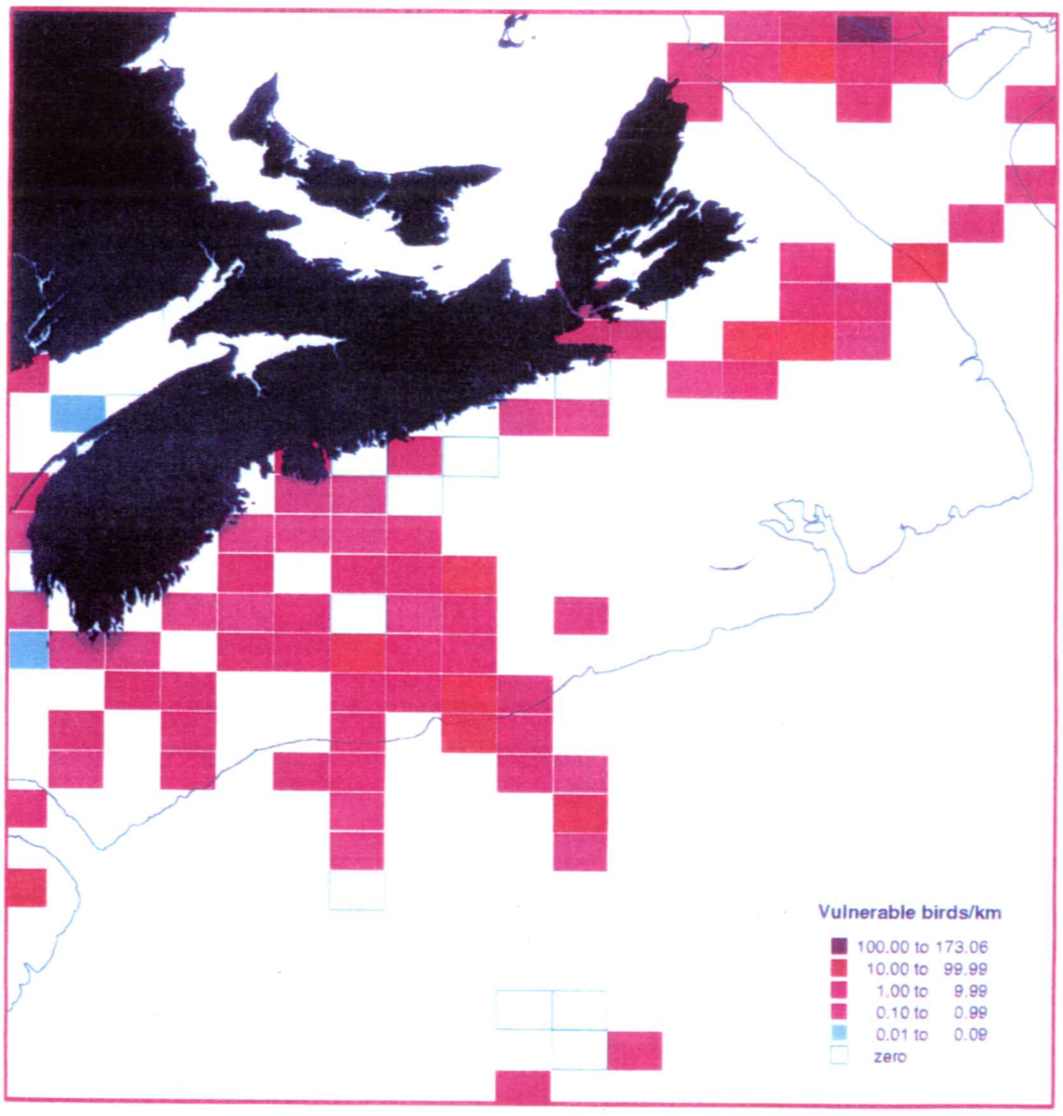
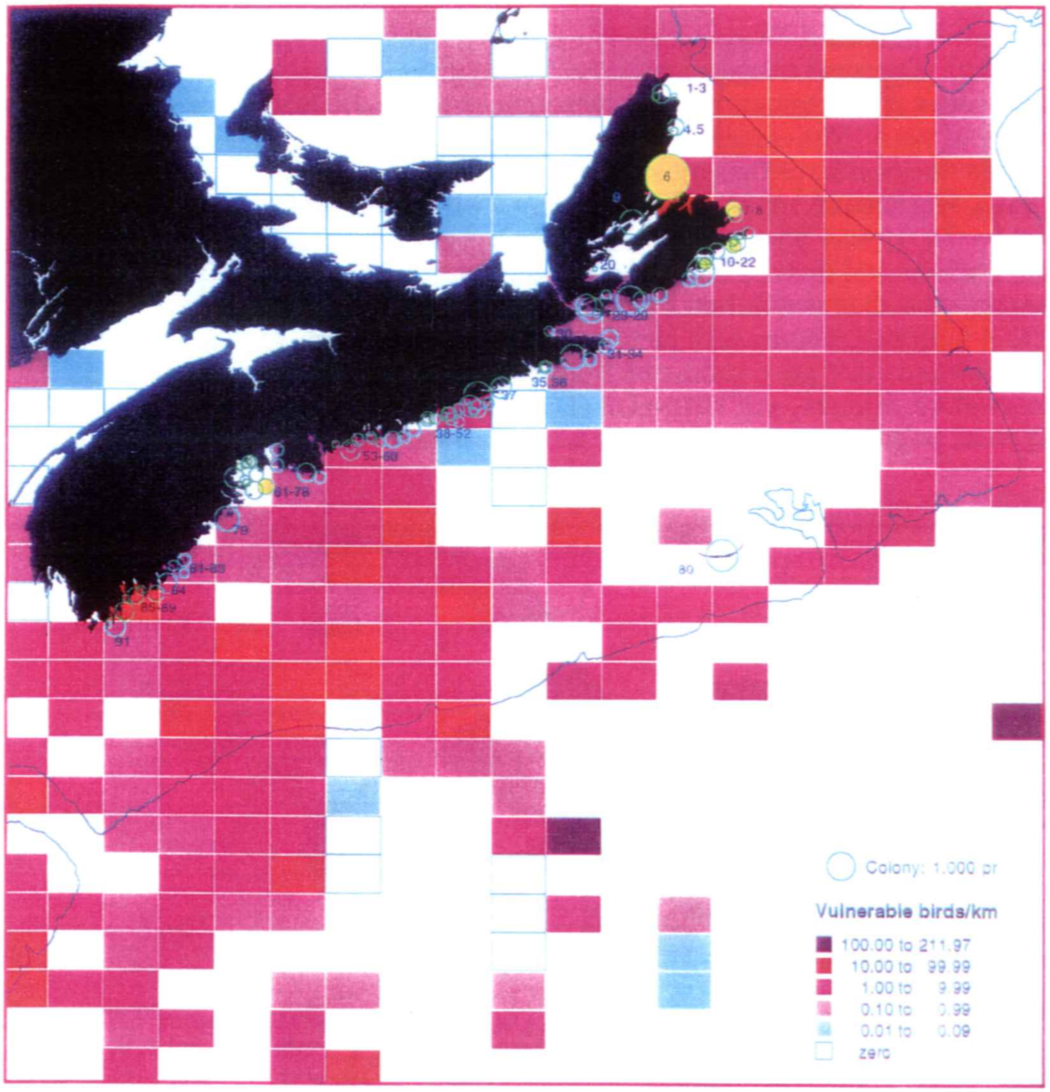


Figure 8-2. Distribution of pelagic seabirds vulnerable to oil pollution, January to March (from Lock et al. 1994). Count data are not available for squares that are not outlined or coloured.



Index of coastal seabird colonies (numbers indicate locations above)

1. Lead Island
2. Money Point
3. White Point Island
4. Ingonish Island
5. Middle Head
6. Bird Islands
7. Cape Percé (Northern Head)
8. Cape Morien (South Head)
9. Spectacle Island
10. Hay Island
11. Hatchet Rocks
12. Isle aux Cannes
13. Unid. island, Cape Breton
14. Chameau Rock
15. Baleine, unid. island
16. Rocky Island
17. Kennington Rocks
18. Green Island
19. Sugar Loaf Island
20. Ranald Island
21. Guyon Island
22. Fourchu, unid. island
23. Quetique Island
24. St. Esprit Island
25. Red Island
26. Basque Island
27. Campbell Island
28. Delorier Island
29. Crid Island
30. Guysborough Harbour, unid. island
31. Frying Pan Shoal
32. Black Island
33. Western Island
34. Millstone Island
35. Coddles Harbour, unid. island
36. Thrumcap Island
37. Tobacco Island
38. Island in Back Cove
39. Little Halibut Island
40. Gull Rock
41. Middle Halibut Island
42. Goose Island
43. Long Island
44. Bowens Ledge
45. Speck Island
46. The Pancake
47. Hardwood Island
48. Green Island
49. Leslie Island
50. Mushaboom, unid. island
51. Big Brother Island
52. The Brothers Islands
53. Outer Island
54. Eel bed Island
55. Bale Island
56. Fisherman's Beach
57. Steering Beach
58. Long Island
59. Jeddore Rock
60. Cole Harbour
61. Ball Island
62. Wedge Island
63. Shut-in Island
64. Mountain Island
65. Saddle Island
66. Snake Island
67. Quaker Island
68. Wreck Island
69. Squid Island
70. Mackerel Island
71. Grassy Island
72. Westhaver Island
73. Sambro Island
74. Bluff Head, unid. island
75. Chockle Cap Island
76. Pearl Island
77. Big Duck Island
78. Lake Rossignol, unid. island
79. Indian Island
80. Sable Island
81. Jackies Island
82. Bijou Rocks
83. Little Hope Island
84. Green Rock
85. Thrum Cap
86. Ram Island
87. Blue Gull Rocks
88. McNutts Island
89. Gull Rock
90. Crow Neck
91. Blanche Island

Figure 8-3. Distribution of vulnerable pelagic seabirds, April to June. Location of colonies of vulnerable species are shaded yellow. Colonies of other seabirds are circled in green (from Lock et al. 1994). Count data are not available for squares that are not outlined or coloured.

Because available distribution data reflect different degrees of effort in each area and at different times of year, they are difficult to use in their current form to pick small, discrete locations with higher or lesser numbers of seabirds. Shipboard observers have noted that specific species have been sighted more often in some areas. Fulmars are common on the shallow banks in the winter, especially Banquereau and Misaine Bank off Cape Breton and in the area between those banks and the Cape Breton Coast. They are also commonly sighted on Browns and Baccaro Bank and the shelf edge south of those banks (P. Lane and Associates 1992). During the summer and early fall, Cory's Shearwaters occur in areas of water influenced by the Gulf Stream, while Greater Shearwaters are found in cooler waters to the north (Brown 1986). Kittiwakes tend to be found near their breeding colonies in Cape Breton during the summer while in the winter they range widely offshore.

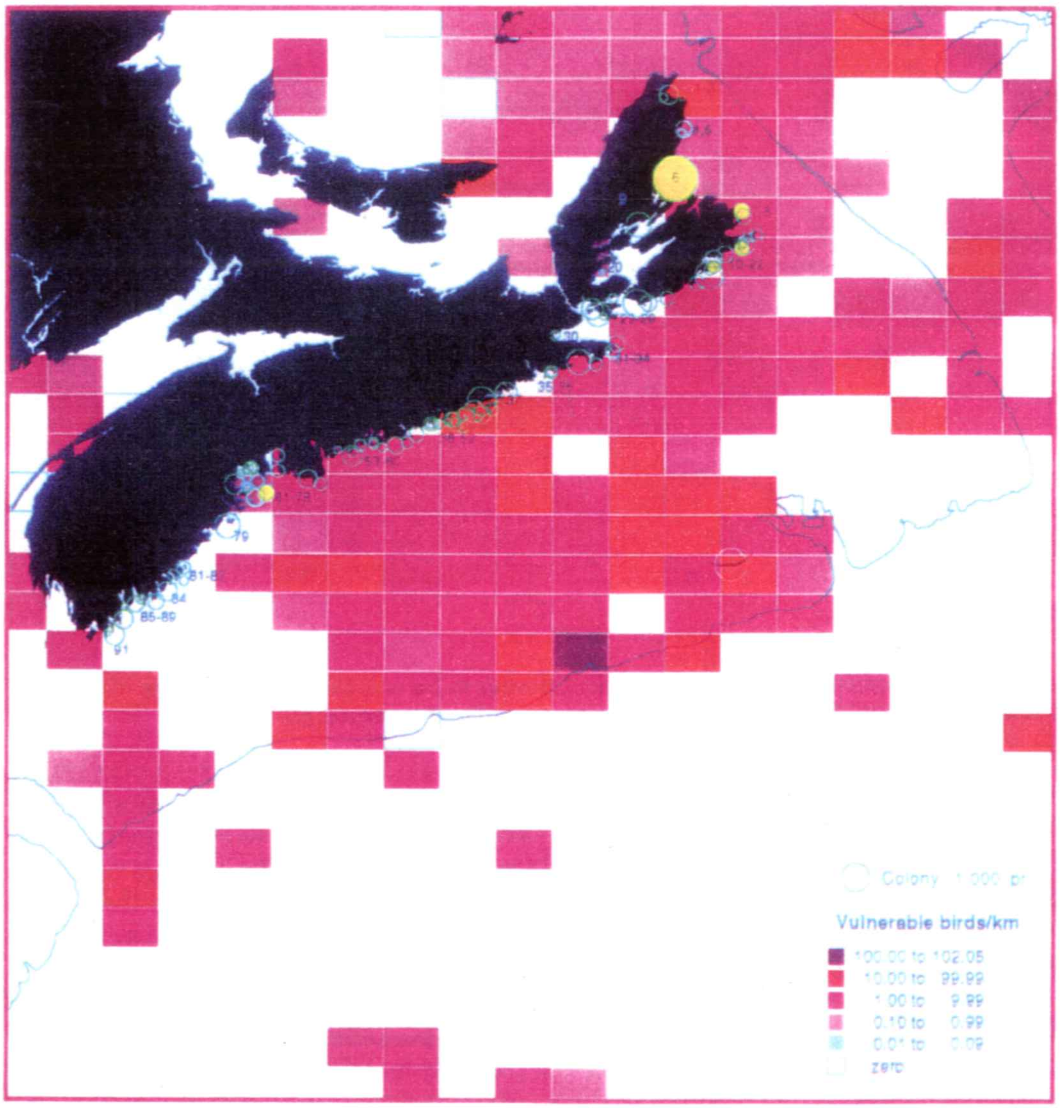


Figure 8-4. Distribution of vulnerable pelagic seabirds, July to September (from Lock et al. 1994). Colonies are the same as for Figure 8-3. Count data are not available for squares that are not outlined or coloured.

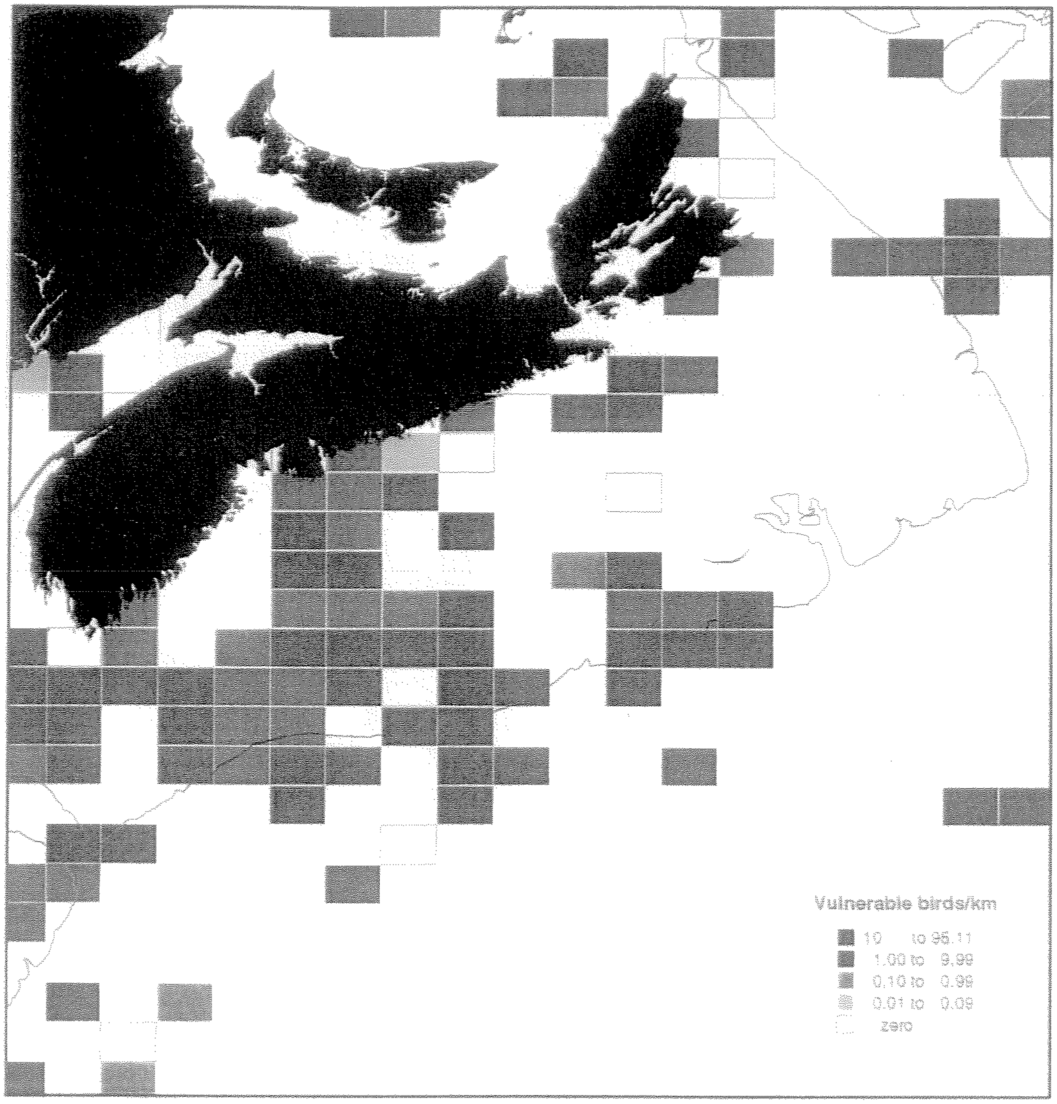


Figure 8-5. Distribution of vulnerable pelagic seabirds, October to December (from Lock et al. 1994). Count data are not available for squares that are not outlined or coloured.

The auks are most common in the offshore during the winter. Dovekies are common along the edge of the Scotian Shelf southwest of Sable Island in those months, where they feed on concentrations of zooplankton at the shelf break (Brown 1986). Razorbills are also often sighted on the southwestern part of the shelf. Thick-billed Murres are found over the banks during the winter. Puffins have a scattered distribution in offshore areas (P. Lane and Associates 1992).

Brown (1988a, 1988b) observed associations between oceanographic features and particular species. He made many research cruises to observe seabirds in Atlantic Canada and records from his research are found in the PIROP database. He found that the summer distributions of Leach's and Wilson's Storm-petrels were closely tied to oceanographic conditions in the Bay of Fundy, Scotian Shelf, and Georges Bank (Brown 1988a). Storm-petrels were associated with areas with tidal currents and other areas where currents interacted with topographical features. On the Scotian Shelf, high numbers of storm-petrels were observed feeding and resting in long east-west "streaks" visible on Browns Bank. Brown speculated that these streaks, perhaps convergent fronts, were areas where zooplankton were concentrated. Storm-petrels were also observed in some numbers at the shelf break front. Off Cape Breton, flocks of Wilson's Storm-petrels were observed on the Nova Scotian side of the slope of the Cabot Strait.

Like storm-petrels, Dovekies were found to be associated with oceanographic features (Brown 1988b). Brown observed that the highest concentrations of Dovekies were observed at the shelf break front, where they were feeding on zooplankton. Not mentioned by Brown, but evident from his maps, are the concentrations of Dovekies in the area known as the Western Gully, the depression between Emerald and Western Banks. This feature is near known concentrations of zooplankton on Western Bank and is also commonly used by whales (see Chapter 7).

Huettmann and Diamond (in press) used the PIROP database to develop a model predicting probable presence/absence of seabirds in the offshore during the summer. He related various environmental factors to the presence and absence of several species. For example, he found water temperature at 30 metres below the sea surface to be a significant factor explaining the distribution of northern gannets, based on the PIROP records. For species considered in his model, ten environmental factors explained 70 to 94 percent of the deviance in the southern part of the area considered (i.e., they are likely the most important factors affecting seabird distribution). He used those factors to predict the probability of observing seabirds in offshore foraging areas. The model used large areas for its grid (1° latitude by 1° longitude) and areas off Nova Scotia considered to be highly probable locations for seabirds are geographically large. New analyses of the PIROP database, combined with data from observers on petroleum exploration vessels, may provide new insights on important bird areas in the offshore.

Important Offshore Areas

The only island of the outer continental shelf — Sable Island — has been designated a Migratory Bird Sanctuary and identified as an Important Bird Area (see Figure 8-1 for location). It is an important tern nesting area, with Roseate Terns nesting among larger colonies of Common and Arctic Terns. Herring and Great Black-backed Gulls also nest on the island, as do Leach's Storm-petrels, waterfowl, and shorebirds. McLaren (1981) described the birds of the island, noting that it is a prime spot for the occurrence of species that have strayed from their normal breeding or migratory ranges.

Other sites in the offshore have not been officially designated. In ocean areas, seabirds can be commonly found in areas where upwelling and mixing of water masses regularly occurs, for example, along the shelf edge and in tidal rips at the mouth of the Bay of Fundy (Brown 1986). Fronts where different water masses meet concentrate prey and are attractive feeding areas for seabirds. These include both large-scale fronts such as the shelf-slope front, and smaller scale fronts such as those found on Browns Bank (Brown 1986, 1988a). High concentrations of seabirds can commonly be found on shallow offshore fishing banks (Lock et al. 1994) and along the shelf break. The area north of Sable Island, where there is mixing of waters caused by a gyre on Sable Island Bank, is an area of consistently high seabird numbers (Lock 1998). The area of the Western Gully also regularly has high numbers of seabirds. Pelagic birds gather around large headlands where there is mixing of currents, for example, off Cape North, Chebucto Head, and Cape Sable. These areas, like the offshore upwelling areas, tend to support large phytoplankton and zooplankton communities. Some seabirds feed directly on these concentrations of zooplankton. Others feed on the small fish that are abundant because of the high plankton concentrations (Lock et al. 1994).

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9 SEA TURTLES[1]

Introduction

All three sea turtles known to occur on the Scotian Shelf are listed as endangered or threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or by the United States National Marine Fisheries Service (NMFS). None of these turtles nest in Canada. Although conservation efforts to protect sea turtle populations have largely been directed at protecting beaches used for nesting, entanglement in fishing gear by adult and juvenile animals and ingestion of marine debris also contributes to low population levels (CWS 2001, James 2001, Wynne and Schwartz 1999).

Habitat for sea turtles can be broken into four groups based on life stages: juvenile nursery habitat, juvenile developmental habitat, adult foraging habitat, and adult nesting and breeding habitat (Musick and Limpus 1997). The Scotian Shelf is used regularly as a foraging area by adult leatherback and juvenile loggerhead turtles, and is occasionally visited by Kemp's ridley turtles.

Species Descriptions

Leatherback turtle (Dermochelys coriacea)

Adult leatherback turtles are regularly observed on the Scotian Shelf from June to October, with records as late as December. Although records of the species in Atlantic Canada were few prior to the late 1990s, a research program monitoring sighting of the species by fisherman has dramatically increased the recorded number of leatherbacks seen in Nova Scotia waters (James 2000, see also LTWG 2001). Preliminary findings from this project suggest that individual turtles migrate and forage widely throughout the region during the summer months (James et al. in press). The species is listed as endangered by COSEWIC and the NMFS.

Female leatherbacks seen off Nova Scotia likely migrate southward to nest on island and mainland beaches in the Gulf of Mexico and Caribbean. Nesting occurs in the period from March to July. On average, females nest six times in one nesting period, with nesting periods occurring every two or three years, although an individual female may nest up to 10 times in a single period (National Research Council 1990). Male leatherbacks spend their entire lives at sea. The turtles travel vast distances: one female turtle found entangled in a fishing net off Newfoundland had been tagged in French Guiana 128 days earlier, almost 5000 kilometres away (Goff et al. 1994).

Adult leatherback turtles are the largest reptiles in the world, 1.2 to 2.5 metres in length and weighing from 300 to 500 kilograms on average. The heaviest recorded weight for a leatherback was over 900 kilograms (Eckert and Luginbuhl 1988). They feed primarily on jellyfish – plentiful in Atlantic Canadian waters in the summer – and may mistake plastics discarded at sea for their prey, a further threat to this endangered species (Lucas 1992, Laist 1987, Wynne and Schwartz 1999). The distribution of leatherbacks is thought to be

[1] The authors would like to thank Jerry Conway and Mike James for their comments on earlier versions of this chapter.

dependent on the distribution of jellyfish and similar invertebrates that make up their prey (Bjorndal 1997). The prey animals are often found near zones of convergence or boundaries between water masses, where there are sudden changes in water density and downwelling. Carr (1987) found that in general, marine debris also tended to concentrate in these convergence zones.

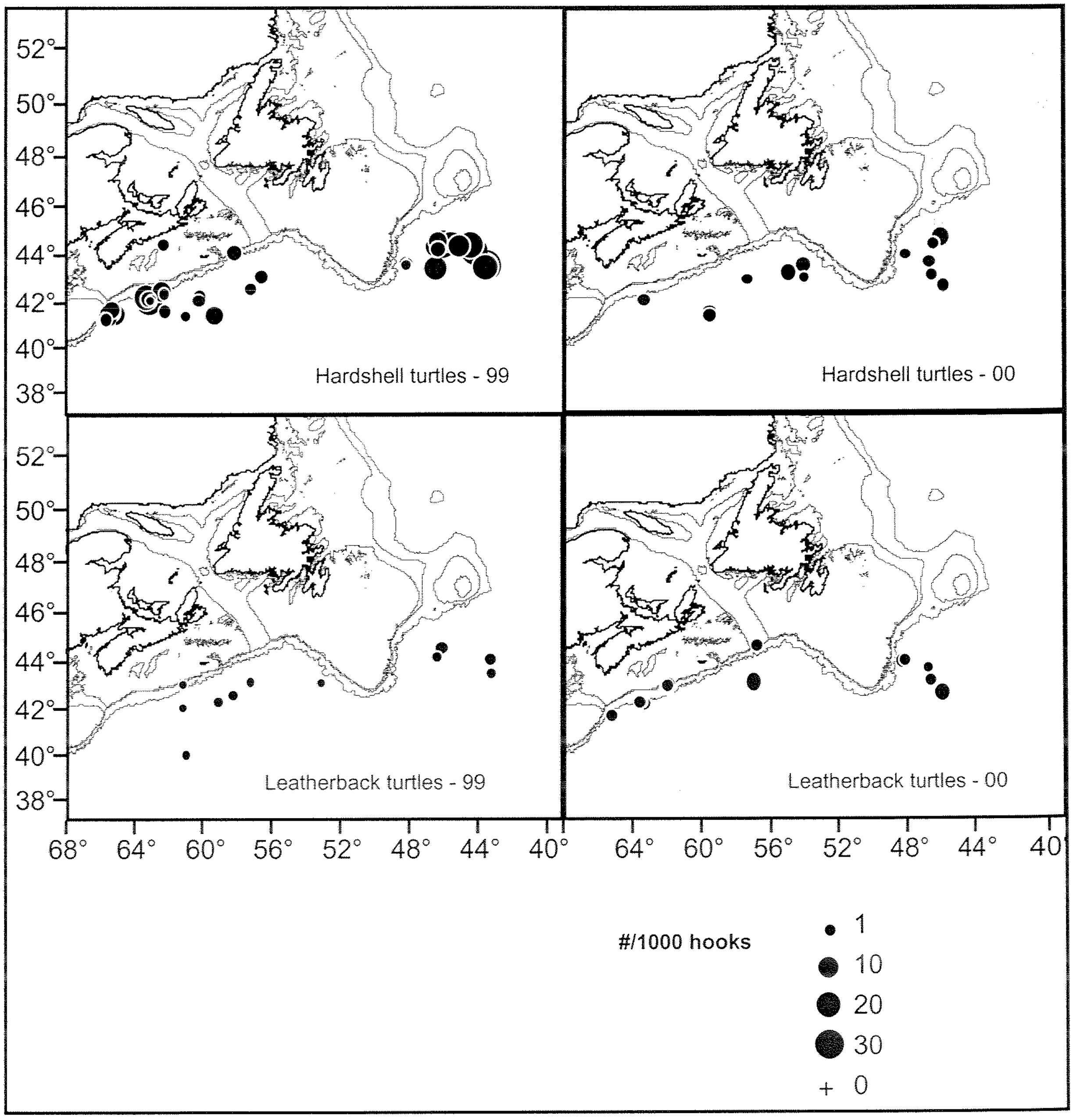

Figure 9-1. Catch rates of sea turtles in 1999 and 2000 in the pelagic longline fishery from domestic observer data (from Smith 2001). Much of this fishery takes place seaward of the shelf edge and turtles are likely to occur in locations other than those indicated.

Although cold-blooded, leatherback turtles are able to survive in cool waters better than other sea turtles due to their large volume to surface ratio, a thick layer of fat, and other specialized physiological adaptations (see Davenport et al. 1990). They can maintain body temperatures up to 18°C higher than the surrounding water (CWS 2001). They use open ocean habitats much more than any other sea turtle (Musick and Limpus 1997); however, their ocean travels and open ocean distribution are still not well-known. In preliminary results from James et al. (in press), tagged animals were found to travel in a fairly direct route from waters off eastern Canada to the Caribbean and South America.

Loggerhead turtle (Caretta caretta)

The loggerhead turtle is not listed by COSEWIC but is considered a threatened species by the U.S. National Marine Fisheries Service (NMFS 1991). Like leatherbacks, adult loggerheads migrate north in the summer to feed, but unlike them, their preferred foods are benthic invertebrates such as crabs, other crustaceans, and some molluscs (National Research Council 1990). They may also feed on seaweeds and organisms found in the water column, such as jellyfish (Bjorndal 1997). Juvenile loggerheads are more commonly observed than adults in eastern Canadian waters and are likely feeding on jellyfish (James pers. communication).

Loggerhead turtles have not been observed as frequently as leatherbacks on the Scotian Shelf and there were few published records of occurrences north of Georges Bank until recently. However, bycatch records from pelagic longline fisheries suggest that these animals are found regularly in Atlantic Canadian waters as far north as the Grand Banks (see e.g., Smith 2001, Figure 9-1). Many of these loggerheads are pelagic-stage juveniles, perhaps following the North Atlantic gyre (James pers. communication, see also Witham 1980). As loggerheads are thought to reach sexual maturity relatively late, aged somewhere between 12 and 30 years (Frazer and Ehrhart 1985), the survival of juvenile and breeding-age turtles is important for the health of the population.

Kemp's (Atlantic) ridley (Lepidochelys kempii)

Juvenile Kemp's ridley turtles are accidental summer visitors to eastern Canada. As adults, they live primarily in the waters of the Gulf of Mexico. The Scotian Shelf is not believed to be important habitat for these animals, as there are only two records of them from Atlantic Canada (McAlpine 2001). The Kemp's ridley turtle is considered an endangered species by the U.S. National Marine Fisheries Service (USFWS 1992).

Location of Turtles in Atlantic Canada

Smith (2001) examined bycatch records from Canada's east coast pelagic longline fishery. Maps from his report show areas where turtles were caught in 1999 and 2000 (Figure 9-1). These records are only from fishing trips with fisheries observers aboard, about 9 percent of the trips taken by that fleet for those two years. Much of this fishery takes places seaward of the shelf edge. Boats with observers cover only a small part of Atlantic Canada's offshore and turtles are likely to occur elsewhere. Observers use two turtle categories in their records – hardshell turtles and leatherbacks. Hardshell turtles are likely loggerheads, since the Kemp's ridley turtle is the only other hardshell turtle known to occur off Atlantic Canada and it is thought to be a rare visitor.[2] Fishermen considered 1999 to be a year with a high incidence of turtles compared to other years (Smith pers. communication). These maps suggest that sea turtles are common visitors to areas along the slope and rise seaward of the Scotian Shelf.

Information from the pelagic longline fleet is a recently used and important source of information on sea turtles found off Canada's east coast. Until about two years ago, loggerhead turtles were thought to be accidental, rare visitors to eastern Canada. However, records from the American longline fleet revealed that 3000 loggerhead turtles were taken as bycatch off Newfoundland from 1992 to 1995 (McAlpine 2001).[3] Myers (2001) is using data from pelagic longline fisheries to examine the conservation status and distribution of turtles off eastern Canada.

Important Areas

The local movements of leatherback and loggerhead turtles while in eastern Canadian waters are not well known. Based on the limited data available, areas at the edge of the shelf and further offshore appear to be important for sea turtles; however, the animals have also been sighted in nearshore waters (James pers. communication). Turtles found off Nova Scotia are highly migratory. They will move in search of aggregations of prey and will stay in areas where there are high concentrations of prey. Preliminary results from recent research on leatherbacks suggest that they occupy foraging areas on the shelf for extended periods of time before migrating south (James et al. in press). The habits of the loggerheads of the shelf are less known; they likely migrate regularly through eastern Canadian waters during the pelagic-juvenile stage. While research in the last few years has greatly enhanced our understanding of sea turtles found off Atlantic Canada, more research on times of residence and areas regularly used may allow important areas for turtles to be identified.

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[2] James (pers. communication) suggests that the green turtle (*Chelonia mydas*) may also be an occasional visitor to offshore areas.
[3] Many of these turtles are released alive; however, the rate of survival after being caught and released is not known.

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10 RARE, VULNERABLE AND ENDANGERED SPECIES[1]

Introduction

Governments and non-government organizations have increasingly recognized the importance of conserving biodiversity. One way to do this is to protect individual species considered endangered or threatened. In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) evaluates the status of wildlife across Canada and produces a national listing of species at risk. As of yet, this listing confers no special legislative status on these species, although federal agencies and departments, provincial governments, and non-governmental organizations often initiate special programs to protect species at risk. The *Species at Risk Act* under consideration by the Canadian parliament will confer legal standing on the species listed by COSEWIC. Some species found in Canada are also evaluated by the United States federal government and listed in their endangered species legislation. In fact, several species found on the Scotian Shelf have an American endangered species designation but no Canadian status.

Within Canada, several provinces, including Nova Scotia, have endangered species legislation that protect rare and endangered species. The species listed under that legislation are chosen by a provincial panel of experts. Globally, the World Conservation Union (IUCN) prepares a red list of endangered and threatened species. The IUCN categories are slightly different than those used by COSEWIC; however, the IUCN criteria for assessing species status have been adopted as guidelines by COSEWIC.

COSEWIC chooses species to evaluate based on the nominations of government and external experts. While the status of nearly all the cetaceans found off eastern Canada has been examined, the same is not true of marine fish and invertebrates. For many of these marine species, there is little information available on their status. As further research is carried out on the Scotian Shelf, it is likely that other species will be identified as rare or with limited distributions – and perhaps needing a special COSEWIC status. In this chapter, species that have been specially designated as at risk by different groups will be discussed. A very small section on other rare or vulnerable species that have no formal designation is included. This is not a comprehensive listing of all rare and vulnerable species, since not enough information is available to assess the status of all species of the Scotian Shelf.

Species Designated by COSEWIC

Each year, COSEWIC prioritizes species to be evaluated and evaluates or re-evaluates the status of the highest priority species. According to the November 2000 and May 2001 listings of Canadian species at risk, several species found in the waters of the Scotian Shelf or adjacent coastal areas have been given the status of "endangered," "threatened" or "special concern," in decreasing order of risk (see Table 10-1) (COSEWIC 2000, 2001a). An "endangered" species is facing extinction or extirpation from Canada; a "threatened" species is likely to become endangered unless current limiting factors are reversed; a species of "special concern" is particularly vulnerable to human activities or natural events and may become threatened or endangered.

[1] The authors would like to thank Rod Bradford and Jerry Conway for their comments on earlier versions of this chapter.

Table 10-1 Species at Risk found on the Scotian Shelf, including coastal waters		
Common Name	**Latin Name**	**COSEWIC Status**
Mammals		
Northern right whale	*Eubalaena glacialis*	endangered
Harbour porpoise	*Phocoena phocoena*	threatened
Blue whale	*Balaenoptera musculus*	special concern
Fin whale	*Balaenoptera physalus*	special concern
Humpback whale	*Megaptera novaeangliae*	special concern
Northern bottlenose whale (Gully population)	*Hyperoodon ampullatus*	special concern
Sowerby's beaked whale	*Mesoplodon bidens*	special concern
Birds		
Harlequin Duck	*Histrionicus histrionicus*	special concern
Piping Plover	*Charadrius melodus*	endangered
Roseate Tern	*Sterna dougallii*	endangered
"Ipswich" Savannah Sparrow	*Passerculus sandwichensis princeps*	special concern
Reptiles		
Leatherback turtle	*Dermochelys coriacea*	endangered
Fish		
Atlantic salmon	*Salmo salar*	endangered
Atlantic (Acadian) whitefish	*Coregonus huntsmani*	endangered
Atlantic cod	*Gadus morhua*	special concern
Northern wolffish	*Anarhichas denticulatus*	threatened
Spotted wolffish	*Anarhichas minor*	threatened

In the past, many of the marine species evaluated for the COSEWIC have been mammals, birds, and reptiles. The status of benthic invertebrates and marine fish, for example, have rarely been investigated. However, the May 2001 list of candidate species includes 18 high priority marine fish species whose range includes the Scotian shelf, as well as many other lower priority candidate species. Two of the eighteen species found on the Scotian Shelf will be the subject of status reports in the year 2001 – the barndoor skate (*Dipturus laevis*) and the cusk (*Brosme brosme*) (COSEWIC 2001b).

Endangered and threatened species

The right whale (*Eubalaena glacialis*) and the leatherback turtle (*Dermochelys coriacea*) can be found in the waters of the Scotian Shelf and slope during the summer and fall. The Northwest Atlantic population of the harbour porpoise (*Phocoena phocoena*) is listed as a threatened species by COSEWIC, since it is vulnerable to entanglement in gillnets. Efforts to protect this species are largely focussed on the Gulf of Maine and Bay of Fundy sub-population, where the porpoises are known to spend much time foraging in areas of high gillnet activity and where there high rates of mortality due to entanglement (CWS 2000b). More information on these three animals can be found in the chapters on marine mammals and sea turtles, chapters 7 and 9.

The endangered Atlantic (Acadian) whitefish (*Coregonus huntsmani*) spends part of its life in salt water, returning to fresh water habitats to spawn. The marine habitats and movements of this anadromous species are not known. Those caught and dissected have eaten invertebrates such as marine worms, periwinkles, and small crustaceans, as well as discards from a herring processing plant. The fish is endemic to Nova Scotia and thought to spawn only in two watersheds in the southwestern part of the province (Scott and Scott 1988).

Salmon populations that spawn in rivers bordering the inner Bay of Fundy were listed as endangered by COSEWIC in May 2001 (COSEWIC 2001a). The Scotian Shelf is used as transit area between the rivers and distant oceanic feeding areas and may also be an overwintering area for these stocks (Amiro pers. communication). Movements of the Atlantic salmon while at sea are not well-known. More information on the Atlantic salmon can be found in Chapter 6, Fish.

The endangered Roseate Tern (*Sterna dougallii*) [2] nests on Sable Island and six or seven small islands and islets along Nova Scotia's coast, the most important being the Brothers Islands in Yarmouth County. Roseate Tern numbers in eastern Canada remained stable in the early 1990s, despite predation by gulls. Because they breed at only a few sites, they are vulnerable to damage to habitat or environmental change in those areas. For example, observers estimated that only two chicks were fledged from Brothers Islands in 1998, out of 59 nests, due to predation by a crow and poor weather (D'Eon 1998). With only about 100 to 150 breeding pairs in eastern Canada, this lack of breeding success is significant.

The Piping Plover (*Charadrius melodus*), also an endangered species, nests on beaches in southwest Nova Scotia. Piping Plovers prefer to nest on sandy beaches in this area, making them vulnerable to human use of beaches. The Atlantic population in Canada is scattered at beaches in Nova Scotia, New Brunswick, Prince Edward Island, Newfoundland, and the Magdalen Islands. The 1996 International Piping Plover Census found that numbers in Nova Scotia had declined since the 1991 census, from 113 to 80 birds, as had the overall population in Atlantic Canada (CWS 1998, see also Plissner and Haig 2000).

Two marine fish, the northern wolffish (*Anarhichas denticulatus*) and the closely related spotted wolffish (*Anarhichas minor*), were listed in May 2001 as threatened species by COSEWIC. In the western Atlantic, the spotted wolffish is distributed from Western Greenland to Massachusetts. The northern wolffish has a more northerly distribution, ranging from the Arctic to Sable Island. These two species are the first marine fishes to be listed as threatened by COSEWIC (COSEWIC 2001a).

Species of special concern

The eastern population of the Harlequin Duck (*Histrionicus histrionicus*) was downlisted in May 2001 from an endangered species to a species of special concern (COSEWIC 2001a). A few harlequins winter in areas along Nova Scotia's Atlantic coast and more of them stage along the coast during migration (Lock et al. 1994). Harlequin Ducks winter off rocky coasts from southern Newfoundland to Chesapeake Bay, feeding in shallow water on molluscs and crustaceans and resting in deeper water. Wintering areas are relatively few and scattered and the ducks return to the same places each year; thus, they are vulnerable to disturbances in those areas. Outer headlands and exposed shoals are preferred habitat in wintering areas and may correspond to areas of local upwelling. In Nova Scotia, important areas for harlequins have been identified as the Eastern Shore Islands Wildlife Management area, an area near Canso, and in the Port Joli Migratory Bird Sanctuary (Montevecchi 1995). They

[2] Common names of birds are capitalized throughout this chapter, as is standard practice in ornithological literature. The common names of other species are not capitalized, unless they include a proper name, again following standard practice.

have occasionally been spotted in other areas, such as off Chebucto Head and the Aspotogan Peninsula and work is ongoing to identify other staging and wintering areas. The numbers of Harlequin Ducks seen in Nova Scotia during the Christmas Bird Count steadily declined in the 1980s and early 1990s (Montevecchi 1995).

COSEWIC lists several other species found on the Scotian Shelf listed as being of special concern, since they are vulnerable to disturbances by humans. For example, one of the listed species, the Ipswich Sparrow, is a sub-species of the Savannah Sparrow that breeds almost exclusively on Sable Island. Its restricted breeding territory makes it vulnerable to any disturbance of that habitat. The other species of special concern on the Scotian Shelf are the Atlantic cod and the blue, fin, humpback, and northern bottlenose whales. More information on cod and the whale species can be found in the chapters on fish and marine mammals respectively.

Species with Other Designations

The Roseate Tern, Piping Plover, and Harlequin Duck were among the first ten species designated under Nova Scotia's 1999 Endangered Species legislation. The legislation prohibits destroying or disturbing designated species and also provides for protecting their habitat where necessary (DNR 2000). The Kemp's ridley sea turtle (*Lepidochelys kempii*) has been designated as an endangered species and the loggerhead turtle (*Caretta caretta*) as a threatened species under the United States Endangered Species Act. More information on the habits of these species in Nova Scotia waters can be found in chapter 9, Sea Turtles. Two whale species found off Nova Scotia have no COSEWIC designation but are listed under the American legislation. North Atlantic populations of both the sei and sperm whales are listed as endangered under the U.S. legislation, although population trends are not well known (Waring et al. 2000).

Rare Species with no Designation

At least five species or sub-species of insects – a beetle (*Pyrrhalta sablensis*), a nematode (*Koerneria mulveyi*), and three noctuid moths (*Agrotis arenarius*, *Papaipema sp.*, *Orgyia leucostigma sabelensis*) – have been found only on Sable Island (Beson 1998, NS Museum/SIPT 2001, Davis and Browne 1996). The freshwater sponge found in two ponds on the island was formerly classified as a distinct species endemic to the island and called *Heteromeyenia macouni*. It is now considered an unusual ecomorph of *Anheteromeyenia ryderi*, which is distributed throughout eastern North America (Ricciardi and Reiswig 1993).

The status and distribution of many marine invertebrates is not well known. As further research is carried out on these animals, it is likely that other animals will be identified as rare or with limited distributions.

Extinct and Extirpated Species

Several other marine species – the Atlantic walrus, grey whale, sea mink, Great Auk, and eelgrass limpet – are no longer found in Nova Scotia waters due to overexploitation or loss of habitat. The Great Auk (*Pinguinus impennis*) was an early victim of overhunting with the last positively identified speciments killed in 1844. This flightless bird spent much of its time at sea but was easy prey when nesting in large colonies on rocky islands. Nova Scotia was likely the most southerly part of its range. Sea minks (*Mustela macrodon*) were hunted for their fur in the Maritime provinces and New England. They are thought to have occurred from Connecticut to the Bay of Fundy and perhaps further east along the Atlantic coast to Newfoundland. The last known sea mink was captured at Campobello, New Brunswick, about 1894 (CWS 2000c). The eelgrass limpet (*Lottia alveus*) lived and fed solely on eelgrass that lived in highly saline conditions. The dramatic decline of North Atlantic eelgrass in the early 1930s is thought to have resulted in total loss of habitat for the limpet (CWS 2000a). No eelgrass limpets have been reported since the late 1920s, despite searches for them.

The Atlantic walrus (*Odobenus rosmarus rosmarus*) was prized for its ivory tusks and oil and was extirpated from the Northwest Atlantic in the mid-nineteenth century due to hunting. It formerly bred on Sable Island. There have been suggestions of reintroducing this species to its former range (P. Lane and Associates 1992). The grey whale (*Eschrichtius robustus*) was extirpated from North Atlantic waters in the nineteenth century, also due to overhunting.

Important Areas

The importance of preserving the habitat of endangered species has been recognized in existing and proposed legislation aimed at protecting these species. Important areas for birds are discussed in Chapter 8 on marine-associated birds. Besides the birds mentioned in that chapter, the Ipswich Sparrow is a land-associated bird that breeds almost exclusively on Sable Island. Sable Island is also important for several land-based invertebrate species thought to occur only on the island.

Some of the important areas for marine mammals at risk are highlighted in Chapter 7; however, the movements of whales and their use of the Scotian Shelf are still not entirely known. The distribution of Atlantic cod and Atlantic salmon at different life stages are discussed in Chapter 6, Fish. Again, aspects of their life history and distribution on the Scotian Shelf are still not completely understood. For example, rivers where Atlantic salmon spawn are well documented, but the movements of salmon at sea and important areas for them on the Scotian Shelf remain unknown.

For the other threatened and endangered species discussed in this chapter – the leatherback turtle, Atlantic whitefish, and the two wolffish species – important areas are even less well-known. Determining the critical areas on the Scotian Shelf for species at risk should be a priority in the future.

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11 SUMMARY AND KNOWLEDGE GAPS

Introduction

The Scotian Shelf, slope, rise, and the abyssal plain within this report's study area contain many different oceanographic environments and provide habitat suitable for numerous species. The processes affecting this area and the organisms inhabiting it vary spatially and seasonally. This large marine region has many distinct, yet interconnected environments, with different features and processes prominent in different areas. The slope and rise of the shelf and the abyssal plain are connected with the shelf through currents and tidal processes but have their own distinct characteristics. This report reviews some of the prominent processes and features of the Scotian Shelf study area discussed in previous chapters. The major processes are discussed first followed by an overview of prominent features by geographic area.

This chapter also reviews some of the major knowledge gaps limiting our understanding of the ecology of the study area. This document has summarized many of the major findings of research programs that have been carried out on the Scotian Shelf. These efforts have allowed us to understand many aspects of the shelf's ecology, yet there are still many areas where more research is needed. In compiling this report, many knowledge gaps were identified. Research targeted at filling those gaps will help in making informed management decisions. As this research is carried out, this overview should be updated to account for new research and ensure that appropriate management measures are taken.

Major Biological and Physical Processes

The Scotian Shelf marine environment and adjacent waters are influenced by the convergence of three major currents: the Labrador Current, the outflow from the Gulf of St. Lawrence, and the Gulf Stream. These water masses interact with each other and the topography of the Scotian Shelf and slope to create circulation patterns on the shelf. The influence of these three currents varies seasonally as well as spatially. The southwestern part of the shelf, near the coast, is highly influenced by tidal currents. The enhanced vertical and horizontal mixing of waters in that area make it an area of high primary productivity year-round. At the shelf break, the interaction of tidal processes with the steep topography causes internal waves in the water column. The dissipation of these waves results in enhanced vertical mixing, leading to increased primary productivity.

During much of the year, the Gulf of St. Lawrence outflow is a significant source of nutrients on the shelf. The Gulf Stream influenced slope waters are seasonally important as a nutrient source, especially on the central Scotian Shelf. Internal sources of nutrients, from the excretion and decomposition of organisms, may also be important sources at particular times of year.

Differences in density throughout the water column drive currents, and these density differences are believed to be the primary mechanism driving retention on the Scotian Shelf. The density gradients, influenced by the topography of the shelf, support gyre-like circulation over banks. Other retention areas are caused primarily by tidal processes that create gyre-like structures on the edges of banks and basins. These partial gyres retain plankton, including fish larvae. Areas of retention may result in better survivability for the larvae, perhaps because they are retained with their prey or because they are retained in areas with more suitable habitat characteristics, such as preferred substrate.

The distribution of surficial sediments on the Scotian Shelf was largely influenced by the last glaciation and resulting reworking of sediments by the advancing sea level at the end of the glacial period. The outer shelf banks have well-sorted sediments of sand and gravel, while the large basins have large deposits of muddy silt at the bottom, as well as areas of glacial till. The inner shelf region and the eastern part of the middle shelf have rough topography, reflecting scouring by glaciers. The topography and sediments of each area influences what organisms are found there.

Geographic Overview

This section discusses key features of the Scotian Shelf by geographic area: coastal Nova Scotia; eastern Scotian Shelf; central Scotian Shelf; western Scotian Shelf; channels; shelf edge, upper slope, and submarine canyons; and lower slope and abyssal plain. It compiles most of the material found in the "Important Areas" section at the end of the preceding chapters. The places included in each section have been grouped for ease of discussion. While they may share some similar qualities, they may also be quite different from one another. For example, Banquereau and the small basins near Misaine Bank are influenced by the cool waters from the Gulf of St. Lawrence. However, the surficial sediments of those two areas are quite different, with sand and gravel occurring on Banquereau, and finer clay and silt in the basins.

Coastal areas

Nova Scotia's rocky Atlantic coast has many important areas for seabirds. Many of these sites are small, uninhabited rocky islands and islets that are used as nesting colonies. With no human residents and few predators, these islands remained a safe refuge as other coastal sites became inhabited. The eastern shore of Nova Scotia has many small, uninhabited islands used by birds, as do parts of the Cape Breton coast. Off southwestern Nova Scotia, the Tusket Islands, including Seal Island, are highly used during migrations.

Sydney Bight, off Cape Breton, is a large shallow area adjacent to the coast. It has the highest surface temperature variability of any part of the study area, with temperatures near 18°C in summer and near 0°C in winter. As pack ice develops in the Gulf of St. Lawrence, many groundfish species move to the waters of Sydney Bight and adjacent Laurentian Channel to overwinter. Herring from the Gulf of St. Lawrence also overwinter in Sydney Bight.

Chedabucto Bay, near Canso, is an overwintering site for herring from the Bay of Fundy/southwest Nova population. Some herring also overwinter near Chebucto Head and in Halifax Harbour. Herring from the Bay of Fundy/southwest Nova population traditionally spawned around Seal Island (Tusket Island group) as well as German Bank, Trinity Ledge, and Lurcher Shoals. Spawning appears to no longer occur around Seal Island. In the summer, small stocks of herring are found in inshore areas along the Atlantic coast. Mackerel also move to coastal areas when waters warm up in the summer. They are known to spawn in St. Margaret's Bay, the centre of Nova Scotia's mackerel trap fishery. Spawning likely occurs in other bays along the Atlantic coast. Whales appear regularly in coastal areas where there are concentrations of small, pelagic fish.

Waters off southwestern Nova Scotia are highly mixed due to strong tides in the Bay of Fundy. This results in enhanced phytoplankton production in this area and likely generally enhanced productivity throughout the food chain. Large aggregations of herring spawn off southwestern Nova Scotia, both inside and just outside the study area. Lobster Bay, Yarmouth County, is a highly productive lobster nursery area. Lobster also use other sheltered bays and inlets with rocky bottoms along the Atlantic coast. The rough topography of the bottom provides shelter for juvenile lobster. Other organisms may also use coastal regions as nursery areas. For example, juvenile groundfish likely use certain bays and estuaries as nurseries; however, little research has been carried out on coastal fish nursery areas in Nova Scotia.

Marine algae (seaweeds) are found in coastal areas. The seaweeds found along Nova Scotia's coast and the species associated with them were not examined in any detail in this report. However, some offshore species may use marine algae during particular stages of their life history. For example, juvenile fish may use seaweeds and eelgrass for shelter and the edges of seaweed beds are prime locations for trapping lobster.

Eastern Scotian Shelf

Much less research has been carried out on the eastern Scotian Shelf as compared to other parts of the Scotian Shelf and many of its features are still not well understood. Misaine Bank and the adjacent area of small banks separated by small, deep basins (holes) have been little researched. Temperatures are relatively stable in this area, with cool water sitting in the basins year-round. Surface temperatures are also cool on this bank for most of the year. Shrimp and snow crab are abundant in the holes. Other invertebrate species that seek a cool, stable temperature regime may also be found there in numbers. Species using this area are not well-known.

Like Misaine Bank, Banquereau is more heavily influenced by the cool St. Lawrence outflow than the other outer banks. However, slope water periodically affects this bank and it has a less stable temperature regime than Misaine Bank. Some groundfish species spawn there, but larval fish diversity is somewhat less than the large outer banks of the central Scotian Shelf. Beds of Arctic surf clams are found in areas of Banquereau.

Central Scotian Shelf

Sable Island Bank is a large, shallow, sandy bank used as a spawning area for many species of groundfish, and by herring. More species of fish have been captured by the bottom trawl research survey on this bank than any other on the shelf. Scallop beds are found in many areas of the bank. Sable Island is an exposed part of the bank and the only island on the outer continental shelf. The island is an important seal pupping area. It has the largest breeding population of grey seals in the world and is the only offshore pupping area for harbour seals. Seals forage for sand lance that are plentiful in the shallows around the island. Many terns and gulls, including the endangered Roseate Tern, nest there. There are several species of land-based invertebrates endemic to the island.

During the process of creating this overview, the Western/Emerald Bank complex emerged as one of the most important areas of research and ecological interest. Western Bank is a well-known spawning area for cod, haddock, and many other fish species. This large bank has a high diversity of larval and adult fish. The loose gyre found over this bank and occasionally part of Sable Island Bank is thought to improve retention of fish larvae and other zooplankton and result in higher survivability of fish larvae. A portion of Western Bank and Emerald Bank have been closed to groundfish fishing to protect juvenile haddock.[1]

An area encompassing the westernmost part of Western Bank, the channel between Western and Emerald Bank (known as the Western Gully), and the easternmost part of Emerald Bank appears to be regularly used by many whale species. It was a favourite hunting area of whalers based out of Blandford, Lunenburg County, and there have been numerous sightings of North Atlantic right whales, sei whales, humpback whales, sperm whales, fin whales, and blue whales. Dovekies and other pelagic seabirds have often been sighted in the Western Gully.

Emerald and LaHave Basins are the deepest areas on the shelf itself. Euphausiids, particularly *Meganyctiphanes norvegica*, are numerous in the basins and copepods overwinter there. These basins are thought to be used regularly by baleen whales during the summer. They also have large populations of silver hake.

Sambro Bank, the Mackenzie Spot, the Patch, and French Bank are some of the smaller banks found in the middle and inner Scotian Shelf. Sponges are thought to occur in some numbers on the Mackenzie Spot and perhaps in other areas of the middle shelf with ice-rafted boulders. Middle Bank is a larger but still relatively small bank just northeast of Sable Island Bank. Unlike the other small banks, it has ranked high in studies measuring the diversity of larval and adult fish. Middle Bank has rich scallop beds that have been heavily fished.

Western Scotian Shelf

The basins and banks of the western Scotian Shelf are influenced by the Bay of Fundy tides and the high primary productivity off southwestern Nova Scotia. Many whales and seabirds use and pass through this area. Roseway Basin is well-known as a feeding area for the endangered North Atlantic right whale. Many other whale species also visit this basin and nearby areas to feed on abundant zooplankton and small schooling fish.

Browns Bank is an important spawning area for groundfish, particularly haddock. It has a partial gyre that retains fish larvae and other zooplankton and is thought to improve the survivability of the fish larvae. The gravel bottom found on much of the bank is the preferred habitat of juvenile haddock. Scallop beds are common over Browns Bank.

Baccaro, LaHave, and Roseway Banks are relatively small banks of the western Scotian Shelf. Compared to the large outer banks, there appears to be little spawning on these banks and diversity of larval fish is lower on these small banks than on the larger banks. Overall diversity of fish, as measured by the groundfish research survey, is also relatively low on the small banks.

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[1] The current moratorium on groundfish fishing in 4W means that the area around the haddock nursery area is also currently closed.

Channels

The Laurentian Channel was formed by the outflow from the Gulf of St. Lawrence. Bedrock outcrops along the Channel at the shelf edge (Stone Fence) support deep-sea corals and other filter feeders. Redfish live along the slope of the channel and cod and other groundfish from Gulf of St. Lawrence stocks overwinter along the slope of the channel.

The Northeast Channel lies between the Scotian Shelf and Georges Bank. Strong tidal currents move through the channel, carrying plankton and detritus. Deep-sea corals are found in the channel and at its mouth and there are high numbers of other filter feeders found throughout the channel. The Northeast Channel has many glacial features, such as ice-rafted boulders and iceberg furrows.

Shelf edge, upper slope, and submarine canyons

The steep topography of the shelf edge causes enhanced vertical mixing and leads to heightened phytoplankton production. Slumping and landslides along the slope occasionally change its shape and disturb the organisms living on and in the sediments. During the summer months, whales and swordfish travel along the shelf edge. High numbers of seabirds are found at the shelf edge at all times of the year. Sea turtles are also found at the shelf edge, slope, and further seaward in the summer and fall. Halibut are found in concentrations along the bottom at the shelf edge. Mackerel overwinter along the shelf edge south of Sable Island Bank and further to the southwest. The invertebrates of the slope are not well-known. Deep-sea crab species are found in some areas and portions of the slope support solitary stony corals.

There are several submarine canyons that indent the edge of the shelf. The Gully is the largest. Recent research indicates that it has varied habitats. Northern bottlenose whales live in the canyon year-round, feeding on deep sea squid. Sperm whales are also found regularly in the vicinity and other whales and dolphins are sighted consistently in the area. Deep sea corals and other filter feeders are found on hard substrates along the canyon walls. The deepest areas of the canyon have not been explored. Little research has taken place in the other canyons of the Scotian Shelf; they too may have varied habitats and support species with restricted habitat requirements.

Lower slope and abyssal plain

The lower slope and abyssal plain within Canada's 200-nautical mile limit is a vast area that is relatively unknown. Geological studies have been carried out in the area of the Laurentian Fan, where the Laurentian Channel meets the deep ocean. Sediments from the Gulf of St. Lawrence outflow are deposited there. Large pelagic fish are found in waters over the slope, particularly during the summer. Beaked whales from the genus *Mesoplodon* are likely to be found along the slope and further seaward.

Knowledge gaps and information needs

Gaps in knowledge about the Scotian Shelf and adjacent waters can be grouped in two broad categories: gaps in the knowledge of particular geographic areas and knowledge gaps within particular fields of study. Within the first broad grouping, the largest knowledge gap is our knowledge of the deep waters of the slope and the abyssal plain. While the shelf itself has been fairly extensively studied, the slope has not. Areas deeper than 200 metres have not been as well-studied as those less than 200 metres, areas deeper than 400 metres have been rarely studied, and, with the exception of the research carried out in The Gully, there are perhaps a dozen studies that look at areas deeper than 800 metres off Nova Scotia. In the second category of knowledge gaps, a large and obvious knowledge gap is the lack of knowledge about non-commercial species. Many studies have been oriented to commercial species, either directly or indirectly. For example, studies of benthic productivity have often attempted to quantify that productivity and relate it to commercial fish populations. Major knowledge gaps identified in this report are listed below and discussed in more detail in the text that follows:

Geographic knowledge gaps

- deep waters of the channels, canyons, shelf slope and rise, and the abyssal plain
- eastern Scotian Shelf, particularly Misaine Bank and adjacent holes
- detailed studies of particular areas, i.e., at the scale of a bank or basin, that link physical and biological processes

Knowledge gaps within particular fields of study

- non-commercial species in general (biodiversity, ecology, etc.)
- benthic invertebrates (species present, distribution, biology, etc.)
- distribution of whales and sea turtles
- particular aspects of the life history of commercial fish and invertebrates
- variability in the oceanographic environment
- variability in the occurrence of particular events, e.g., spawning
- detailed knowledge of physiography and surficial geology, i.e., at the scale of a bank or basin
- the degree that human activities have impacted habitats and species

Much of the research on the Scotian Shelf has focussed on broad processes and features. These studies have aimed to broadly characterize such things as the shelf's surficial sediments, physical oceanography, and state of commercial fish stocks. These broad characterizations have enabled scientists to understand many of the processes at work on the Scotian Shelf. However, detailed descriptions of particular areas are generally not available. Thus, while we may know generally how areas are different from one another, our knowledge of most of these areas remains at scales of tens, hundreds, or thousands of kilometres. Knowledge at a scale of tens or hundreds of metres would help greatly in making management decisions. For example, detailed habitat descriptions would give us a better understanding of whether changes in the environment have been caused by natural events or human activities.

Studies of small, discrete areas of the shelf may also allow physical processes in the marine environment to be more closely tied to the marine organisms that occur in those areas. For example, it has often been suggested that density differences in the water column and areas of retention are important for biological events. However, little research has been dedicated to exploring this relationship on the Scotian Shelf. A better understanding of the links between the physical oceanography of particular areas and the natural history of specific organisms would greatly improve our ability to manage marine ecosystems. For example, important biological events appear to occur regularly in an area covering part of Western

Bank, the Western Gully, and Emerald Bank. Although there has been some speculation as to why fish larvae, whales, and seabirds are often found in this area, the links between the physical environment of this region and its marine life should be explored in greater depth to better manage this area.

A better understanding of natural variability would also help in making management decisions. There is a great deal of spatial and temporal variability in the environments of the Scotian Shelf and slope. While we may be able to say that particular events generally occur in certain areas, the scale of these events and the precise location may vary widely over the years or decades. For example, groundfish spawn regularly on Western Bank; however, the survivability of larvae from a particular year may depend on the availability of prey, amount of predation, the strength of the retentive gyre, and the occurrence of storms and other seasonal events. These factors may be influenced by the relative strength of the major currents that influence the Scotian Shelf.

One of the factors currently limiting a description of variability on the shelf is the variability of the data available. It also makes it difficult to present a current picture of the ecology of the shelf. For example, there are summer research trawl survey data on groundfish from 1970 to the present, yet most data on larval fish were collected from 1978 to 1982. Most observations of seabirds were collected from 1966 to 1979. The variability in the periods that data were collected makes it difficult to compare different data sets and link changes observed at one trophic level with other trophic levels. Seasonal variability is also not well understood. Overall, most of the data collected on the shelf, in almost every field, are from the summer, with few observations made in winter.

Variability may be caused by both natural events and human activities. The impacts that activities such as fishing and petroleum development have had and are having on the ecology of the Scotian Shelf are not completely understood. For example, the reduction of groundfish stocks on the eastern Scotian Shelf in the 1980s impacted both the targeted species as well as non-commercial species. Populations of some species have increased to fill the niche formerly occupied by cod. These changes cause a chain reaction in the ecosystem, with a change in one species resulting in changes in other species, and so on. Changes occur at all trophic levels. However, most research has focused on changes in commercial species, even though these species are affected by the changes in populations of non-commercial species.

The focus of many of the studies on Scotian Shelf fish has been on assessing the status of commercial species. Even though commercial species have been highly studied compared to non-commercial species, there are still important gaps in our knowledge of their life history. For example, the use of Nova Scotia's coastal areas by juvenile fish has not been looked at in detail. For some species, areas used by spawning adults and distributions during winter need to be better explored. We also need to better understand the interactions of commercial fish with other species. Existing data from demersal research trawl surveys could be used to study some non-commercial species. However, some species are not easily caught by the demersal trawl and different methods are needed to study those animals.

The bottom-dwelling invertebrates have been a particularly neglected group of animals. While the few commercial benthic invertebrates are fairly well-known, the non-commercial invertebrates are not and it is likely that detailed studies would expand the range of many known species and record new ones in Nova Scotia's waters. Studies of the distribution and life history of the benthos should be coupled with studies about their relationship with other parts of the ecosystem.

Little research attention has focussed on the epi-, meso- and bathypelagic fish species that live in the water column. These species inhabit submarine canyons, and the slope, rise and abyssal plain – areas that have generally not been well-studied. The interaction of these species with other aspects of the ecosystem needs to be better understood. On the shelf, the distribution of non-commercial pelagic species and their relationship with other trophic levels needs more research. In particular, the vertical distribution of phytoplankton in the water column and the relationship of these organisms with the distribution of other trophic levels should be better explained.

The life histories of large migratory species, such as whales and turtles, are better known than many other non-commercial species. However, their distribution on the shelf and slope is still lacking in detail. Most of the available data is from the summer months and few efforts have been made to observe these animals during the winter. Their seasonal distribution and movements need to be better understood, especially because the populations of some of these species are endangered or threatened and may be negatively impacted by human activity on the Scotian Shelf. There may be potential to use existing datasets, such as the PIROP data, to look at distributions of these species and the factors that influence distribution.

In this report, we attempted to include both the Scotian Shelf and the adjacent waters of the slope and abyssal plain within Canada's 200-nautical mile limit. However, the bulk of the report refers to shelf waters and species because so much more is known about the continental shelf. Our ability to study slope waters has been limited by the availability of equipment and a general lack of emphasis placed by researchers on this area in the past. The increasing interest in the resources of the slope by both petroleum companies and the fishing industry should make research in the slope area more of a priority.

The scientific focus on general characterizations of the Scotian Shelf has tended to average out the unique, important, significant, or "special" features of the shelf. There are few detailed descriptions of small areas within the larger study area described in this report. For that reason, it is difficult to identify small areas with special features on the Scotian Shelf from the existing scientific literature. This is a reflection of the type of research that has been carried out on the shelf, rather than a lack of special areas. Research targeted at characterizing the ecology of smaller areas, such as recent research carried out in The Gully, Browns Bank, and the Northeast Channel, has added greatly to our understanding of the Scotian Shelf and has found particular sites that could be considered special or unique. Other detailed research, such as in-situ observation and sampling programs, and re-examination of the existing data will increase our understanding of the different habitats of the Scotian Shelf.

To further support ocean planning efforts, the ecological overview of the Scotian Shelf should be regularly updated to address the gaps described above. These updates would focus on reporting new research findings. They would also allow for the reinterpretation of existing datasets in support of specific management objectives and needs, such as biodiversity conservation and the identification of important and sensitive areas. The maintenance of a current synthesis document will ensure that timely information is available to make informed decisions for ocean planning and management.

Appendices

APPENDIX 1 EXAMPLES OF SEAWIFS IMAGES

(From <http://www.mar.dfo-mpo.gc.ca/science/ocean/ias/seawifs/seawifs_3.html>)

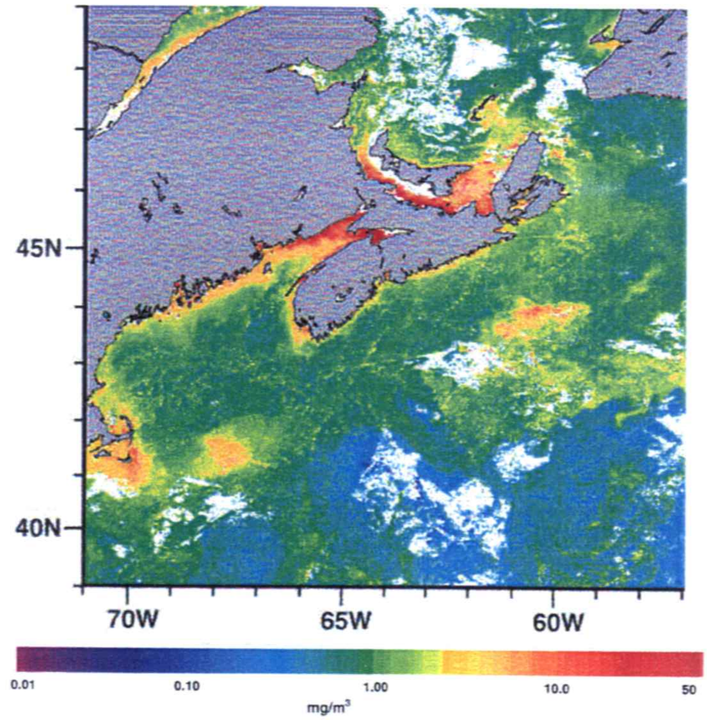


Figure AP1-1. SeaWiFS Chlorophyll-a Concentration (OC-4 algorithm), 16-31 January 1999 composite image.

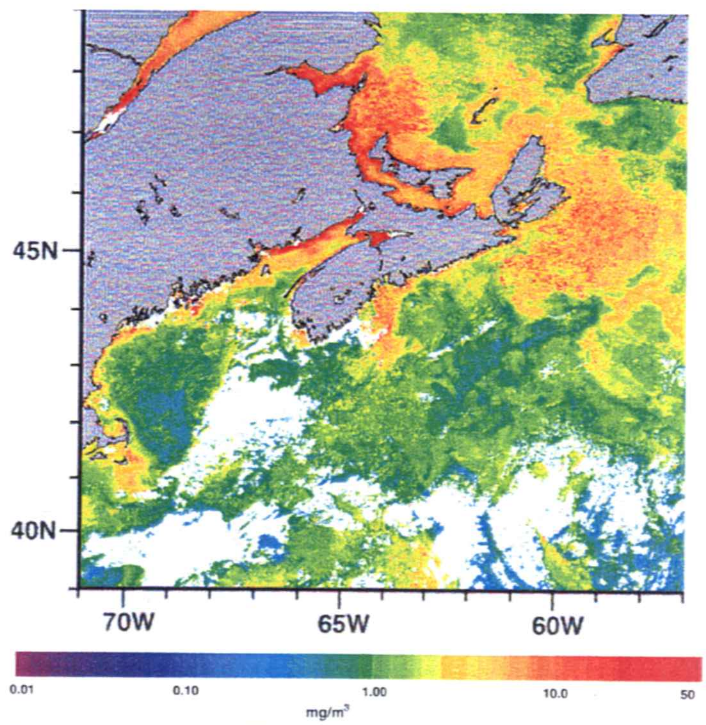
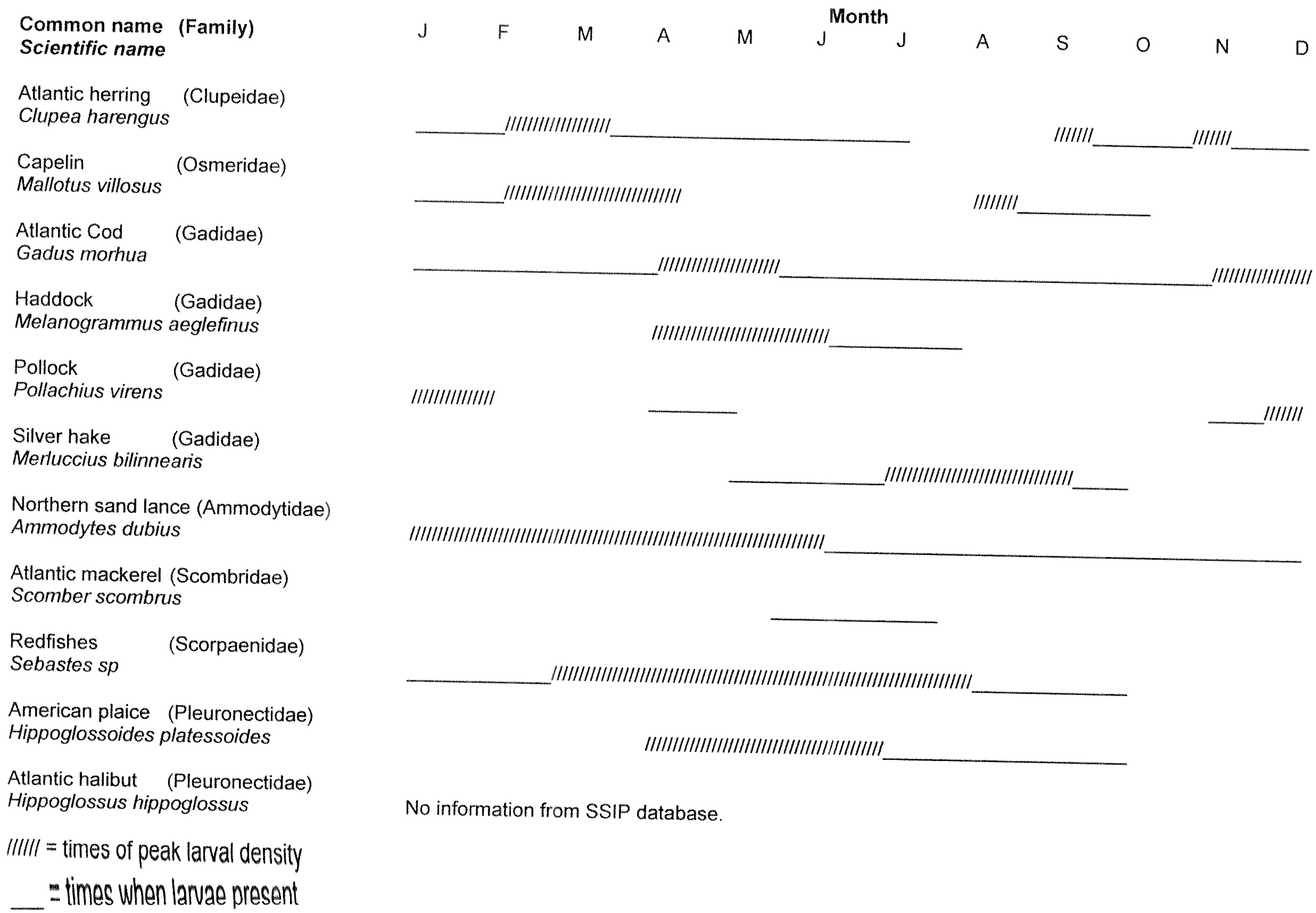


Figure AP1-2. SeaWiFS Chlorophyll-a Concentration (OC-4 algorithm), 16-30 April 2000 composite image.

APPENDIX 2

Summary of temporal distribution of selected species of fish larvae on the Scotian Shelf, from the Scotian Shelf Icthyoplankton Program (SSIP), 1978-1982 (modified from work done by K. Frank and N. Shackell by M.A. Silva).



APPENDIX 3 ASSOCIATIONS OF FISH LARVAE OF THE SCOTIAN SHELF

(adapted from Shackell and Frank 2000)[1]

Cluster	Genus	Common Name(s)	Egg type[2]
1. Shallow (less than 200 metres), cool (between 5°C and 10°C)	*Leptagnonus*	Atlantic poacher	ProbD
	Hippoglossoides	American plaice	P
	Clupea	Atlantic herring	D
	Melanogrammus	Haddock	P
	Liparis	Snailfish	D
	Gadus	Atlantic cod	P
	Pseudopleuronectes (Pleuronectes)	Winter flounder	D
	Phycis	Hakes	P
2. Shallow (less than 200 metres), warmest (greater than 15°C)	*Apogon*	Cardinalfish	D
	Hoplunnis	Hoplunnis	Unknown
	Ophichthus	Eels	Unknown
	Psenes	Driftfish	P
	Scomberesox	Saury	P
	Aristostomias	Loosejaw	Unknown
	Synodus	Red lizardfish	P
	Citharichthys	Gulf stream flounder	Unknown
	Glyptocephalus	Witch flounder	P
	Prionotus	Northern searobin	P
	Svetovidovia	Svetovidovia	ProbP
	Urophycis	Red, white hakes	P
	Limnanda (Pleuronectes)	Yellowtail flounder	P
	Merluccius	Offshore, silver hakes	P
	Scophthalmus	Windowpane	P
	Gasterosteus	Stickleback	D
	Peprilus	Butterfish	P
	Scomber	Atlantic mackerel	P
	Bascanichthys	Sand-eel	Unknown
	Enchelyopus	Fourbeard rockling	P
	Lophius	Monkfish	P
	Tautogolabrus	Cunner	P
	Syacium	Channel flounder	P
3. Deep (greater than 600 metres), cold (less than 6°C)	*Argyropelecus*	Hatchetfish	P
	Bathylagus	Deepsea smelts	P
4. Deep (greater than 600 metres), warmest (greater than 15°C)	*Diplogrammus, Foetorepus, and Paradiplogrammus*	Dragonnets	P
	Hildebrandia	Conger	Unknown
	Lobianchia	Lanternfish	ProbP
	Hygophum	Lanternfish	ProbP
	Gymnothorax	Green moray	Unknown
	Notoscopelus	Notoscopelus	Unknown
	Valenciennellus	Valenciennellus	P
5. Shallow (less than 200 metres), cold (less than 6°C)	*Ammodytes*	Sandlance	D
	Triglops	Moustache sculpin	ProbD
	Aspidophoroides	Alligatorfish	ProbD
	Icelus	Sculpin	ProbD
	Myoxocephalus	Sculpin	D

[1] Groups were determined by hierarchichal agglomerative cluster analysis. Note that some genuses were much more abundant than others in the cluster groupings. See Shackell and Frank (2000) for details.

[2] Egg type: P=pelagic, ProbP=probably pelagic, D=demersal, ProbD=probably demersal, O=oviviparous, ProbO=probably oviviparous.

Cluster	Genus	Common Name(s)	Egg type[2]
	Stichaeus	Arctic shanny	D
	Pholis	Rock gunnel	D
	Pollachius	Pollock	P
	Anarhichas	Wolffish	D
	Cryptacanthodes	Wrymouth	ProbD
	Lumpenus	Shanny, eel blenny	D
	Artediellus	Hookear sculpin	D
	Anguilla	American eel	Unknown
	Reinhardtius	Greenland halibut	P
6. Middepth (between 200 and 600 metres), warmer (between 12.4°C and 15°C)	*Argentina*	Argentine	P
	Maurolicus	Mullers pearlsides	P
	Bolinichthys	Lanternfish	ProbP
	Protomyctophum	Protomyctophum	Unknown
	Echiodon	Chain pearlfish	P
	Paraconger	Conger	Unknown
	Vinciguerria	Lightfish	P
	Uroconger	Threadtail conger	Unknown
7. Middepth (between 200 and 600 metres), cool/warm (between 5°C and 12.5°C)	*Benthosema*	Lanternfish	Unknown
	Chauliodus	Viperfish	O
	Nemichthys	Snipe eel	Unknown
	Paralepis	Barracudina	Unknown
8. Deep (greater than 600 metres), warmest (warmer than 15°C).	*Ceratoscopelus*	Lanternfish	ProbP
	Scorpaena	Smoothehead scorpionfish	P
	Myctophum	Lanterfish	Unknown
	Symbolophorus	Largescale lanternfish	Unknown
	Gigantactis	Anglerfish	Unknown
	Howella	Howella	P
	Lampanyctus	Lanternfish	Unk own
9. Deep (greater than 600 metres), warm (between 9°C and 12.5°C)	*Myrophis*	Worm eel	Unknown
	Nezumia	Marlin-spike	ProbP
	Notolepis	Barracudina	Unknown
	Stomias	Dragonfish	O
10. Middepth (between 200 and 600 metres), warmest (warmer than 15°C)	*Bothus*	Eyeed flounder	ProbP
	Pontinus	Scorpionfish	Unknown
	Diaphus	Lanternfish	ProbP
	Cyclothone	Anglemouth	Unknown
	Peristedion	Armoured searobin	P
11. Shallow (less than 200 metres), warm (between 9°C and 12.5°C)	*Brosme*	Cusk	P
	Hippocampus	Lined seahorse	ProbO
	Ulvaria	Radiated shanny	D
	Mallotus	Capelin	D
	Sebastes	Redfish	O

APPENDIX 4 AREAS WITH FISHING RESTRICTIONS

(All areas are not included.)

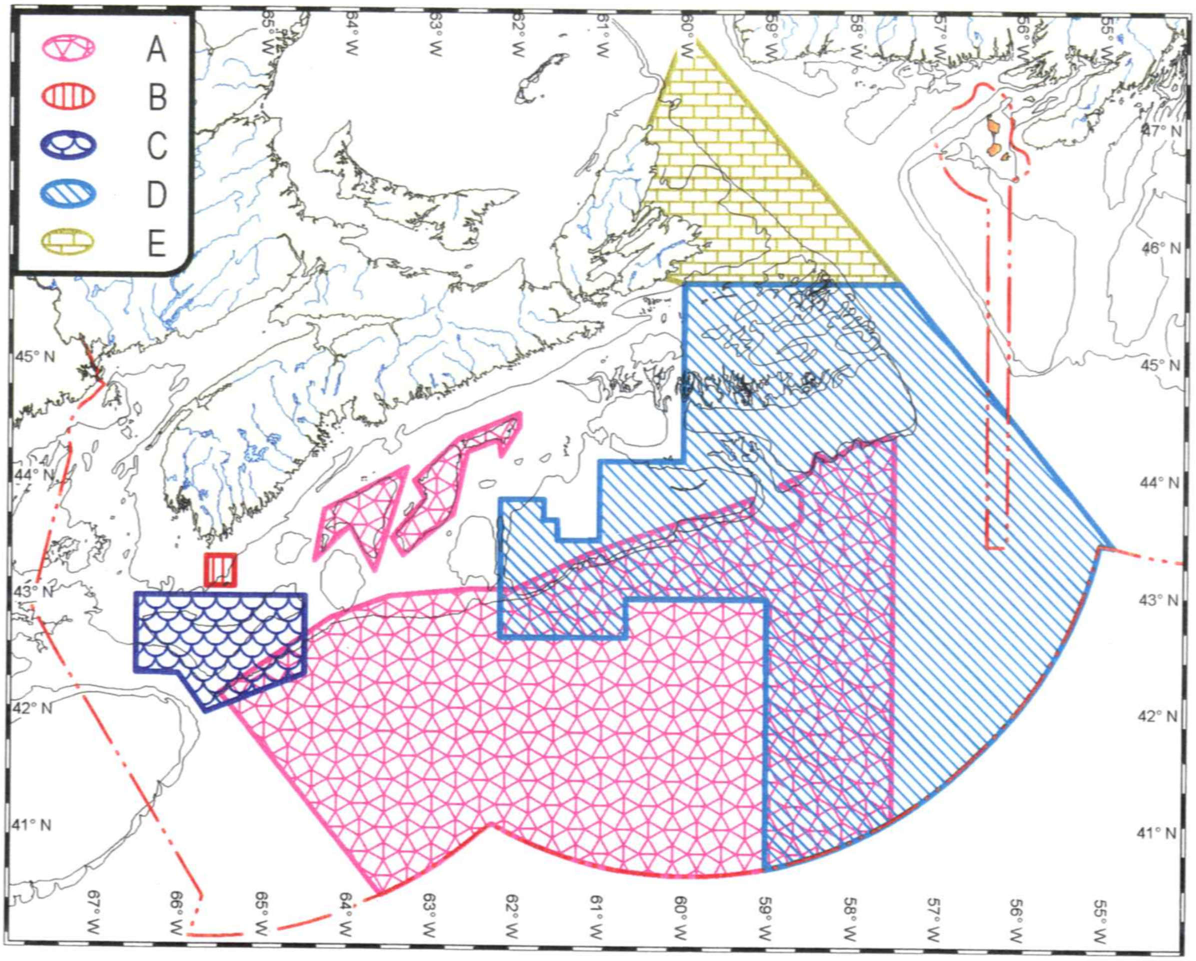


Figure AP4-1. Restrictions affecting redfish and silver hake fisheries.

General restriction:
Otter trawlers directing for redfish cannot fish in areas shallower than 50 fathoms (91 metres) using small mesh gear (less than 130 mm).

A. Silver hake box and basins. Otter trawlers using small mesh gear to direct for silver hake are restricted to Emerald and LaHave Basins and an area seaward of the continental shelf (the area indicated). Foreign vessels are not permitted to fish in the basins.

B. Bowtie. Otter trawlers directing for redfish cannot use small mesh gear (less than 130 mm) in this area, in order to protect juvenile redfish.

C. Browns Bank haddock spawning area. Otter trawlers directing for redfish cannot use small mesh gear (less than 130 mm) in this area between January 1 and June 30.

D. Groundfish closure. This area is closed between January 1 and June 30 to mobile gear vessels <65 feet directing for redfish. The closure between May 1 and June 30 is to protect spawning stock.

E. Groundfish closure. This area is closed between January 1 and June 30 to mobile gear vessels <65 feet directing for redfish. The closure between May 1 and June 30 is to protect spawning stock.

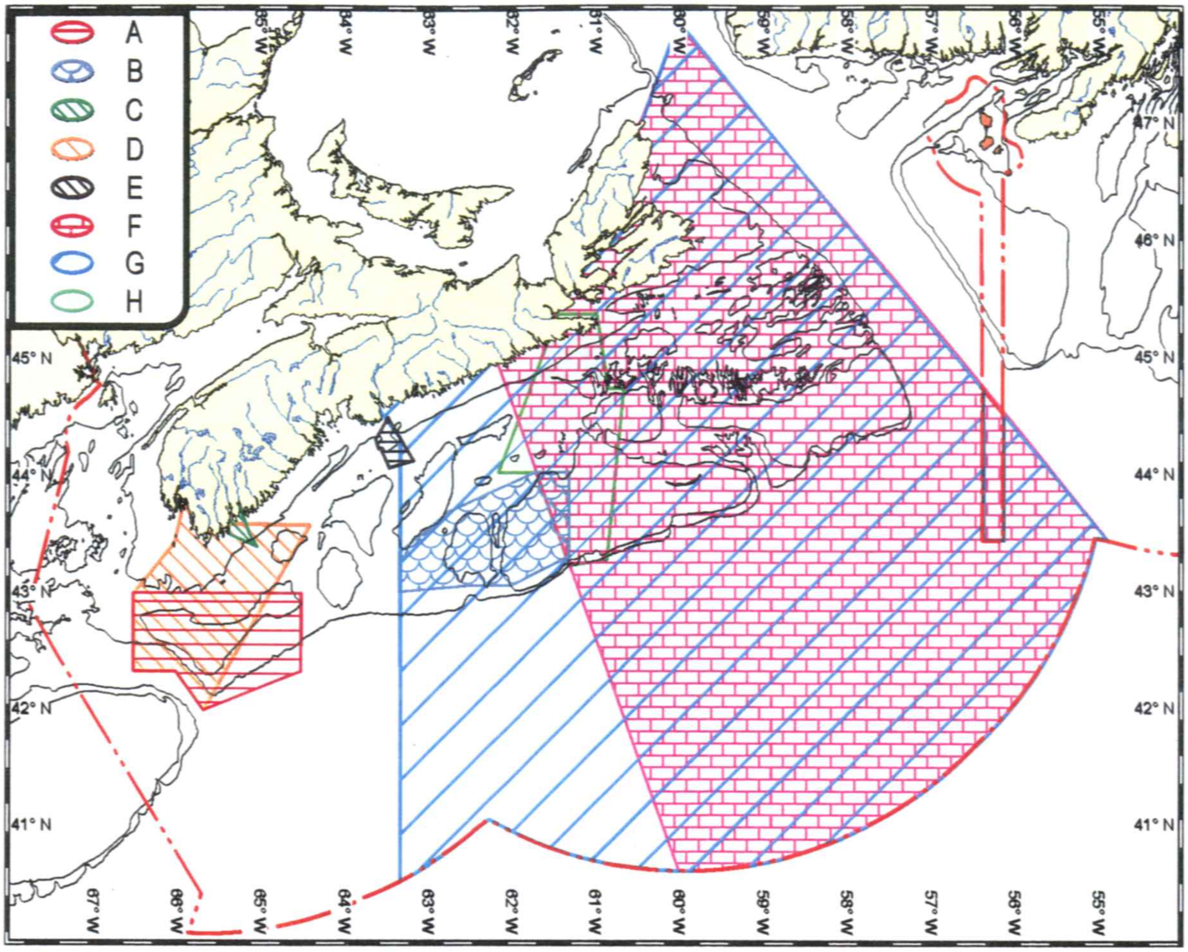


Figure AP4-2. Restrictions affecting gillnet fisheries for groundfish, and haddock and cod fisheries (all gears).

General restrictions:
Large trawlers may not fish within 12 miles of the coast.

A. Brown's Bank haddock spawning area. Closed to groundfish fishing from 1 February to 15 June.
B. Haddock nursery area (haddock box). Closed to groundfish fishing year-round.
C. Shelburne gill net box. Only area in Shelburne gillnet area where fishing with gillnets for groundfish is allowed.
D. Shelburne gill net area. Fishing with gillnets for groundfish not allowed, except in C (gill net box).
E. Little Sambro gillnet restriction. Closed to fishing with gillnets between February 1 and March 31.
F. Mitchell Bay Line. Fishing with gillnets in this area is prohibited (east of Mitchell Bay Line), except for in H.
G. 4VsW and 4Vn groundfish moratorium. Directed fishing for cod and haddock prohibited year-round at this time (note that this make some specific closures redundant). 4Vn is also closed to pollock fishing (vessels <65 feet) and flatfish fishing (vessels > 100 feet).
H. Canso gill net box. The only area east of Mitchell Bay line where groundfish gillnetting is allowed.

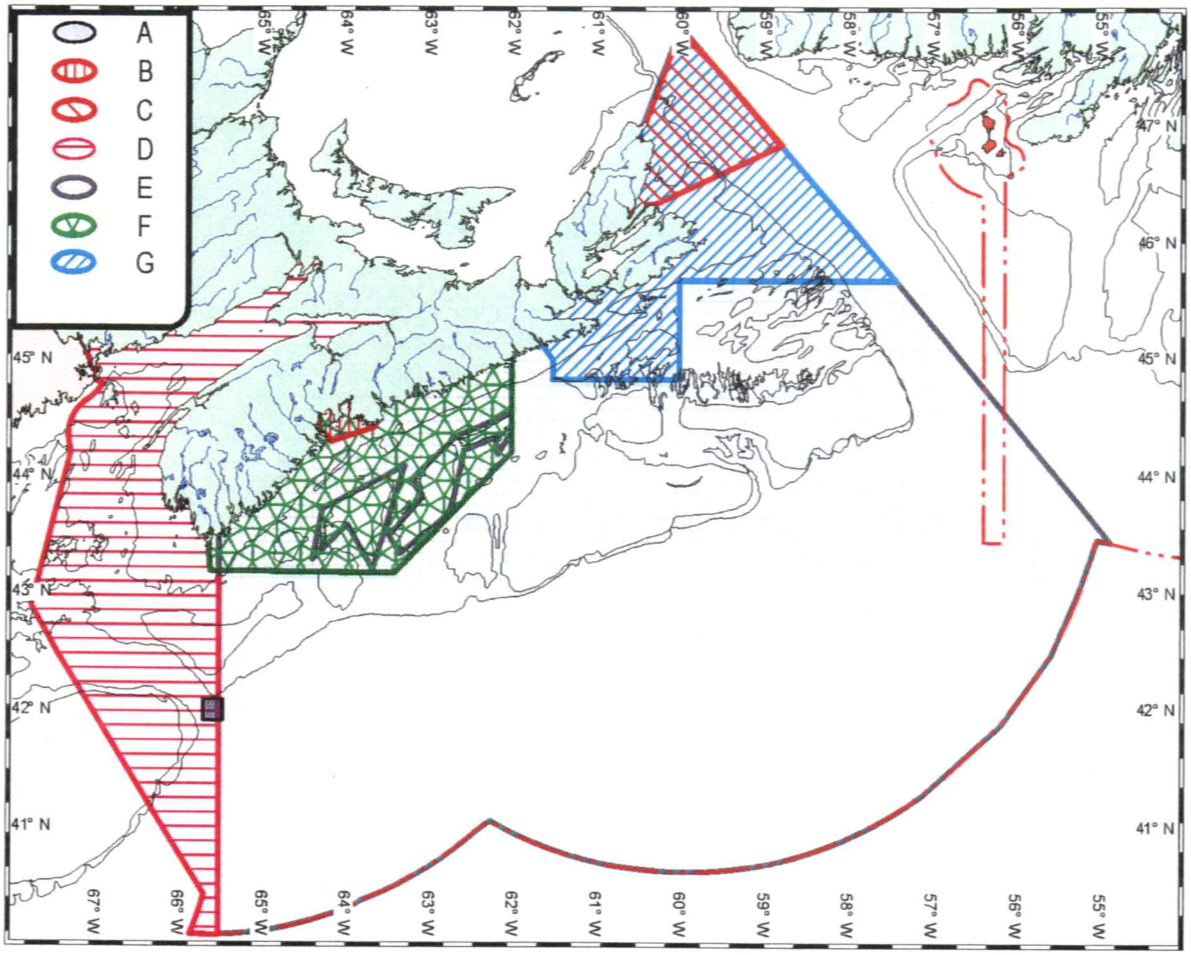


Figure AP4-3. Restrictions affecting large pelagic fisheries (swordfish, tunas, shark) and mackerel fisheries.

General restrictions:
Swordfish fishery opens June 1 east of 65°30' and on August 1 west of 65°30'.

A. Hell hole. Closed to pelagic longline fisheries (swordfish, shark, and bigeye/yellowfin/albacore tunas) if bycatches of bluefin tuna become a problem.
B. St. Margaret's Bay and Mahone Bay. Closed to mobile gear tuna fishery to prevent conflicts with tuna and mackerel trap fishery.
C. Mackerel fishing area 17. Closed from January 1 to May 31.
D. West of 65°30'. Closed from June 1 to December 31 to bigeye/yellowfin/albacore tuna fisheries, to protect bluefin tuna and juvenile swordfish. Swordfish fishery opens in this area on August 1.
E. Areas east of 65°30'. Swordfish fishery opens June 1 (except Emerald and LaHave Basins).
F. Area closed to swordfish and bigeye/yellowfin/albacore tuna fishing from September 1 to December 31 to protect large swordfish (broodstock).
G. 4Wd and 4Vn tuna closure. No fishing for bigeye/yellowfin/albacore tunas in 4Wd; rod and reel only for bluefin. No fishing for tuna in 4Vn.

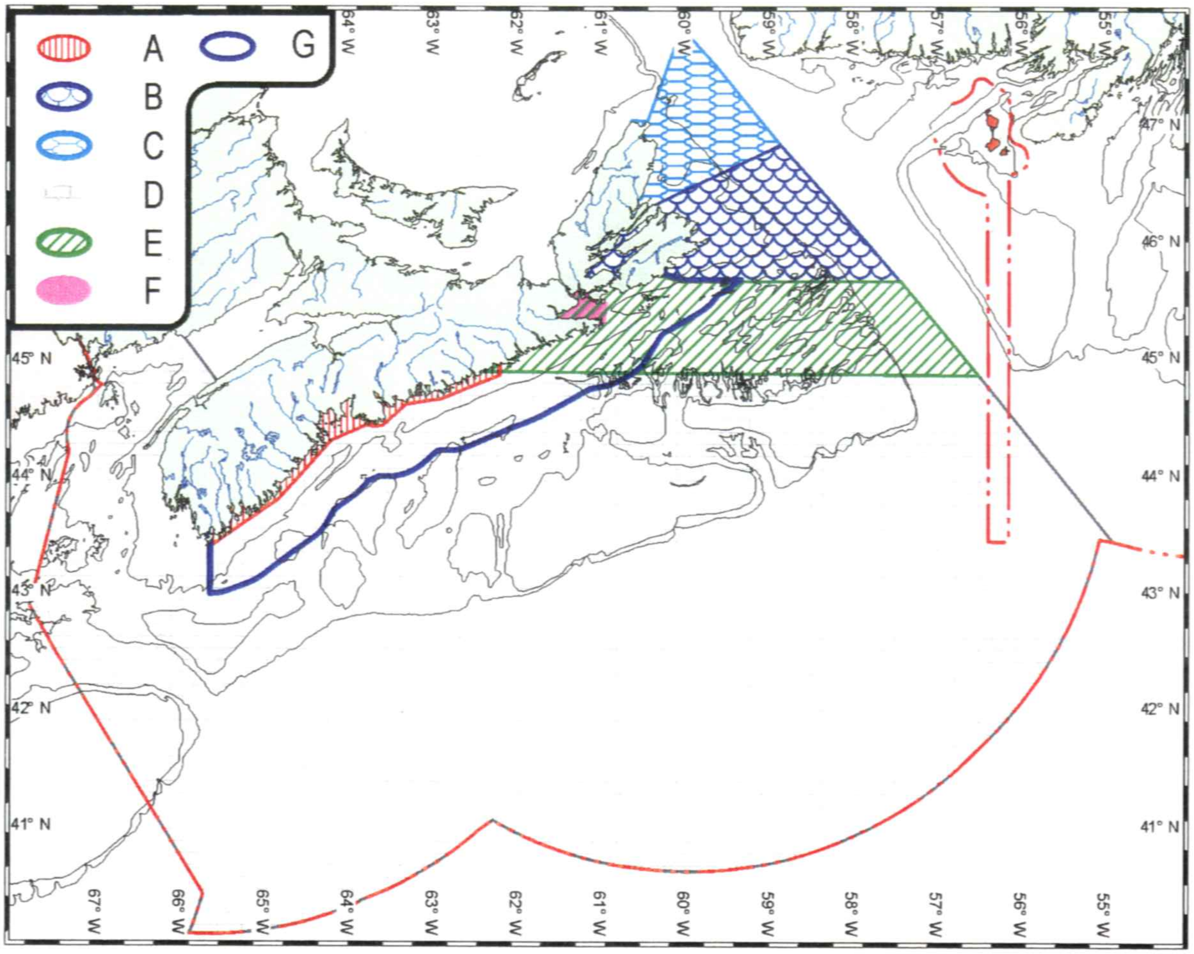


Figure AP4-4. Restrictions affecting herring fisheries.

Other restrictions:
Trinity Ledge area is closed from August 15 to September 15 (may vary according to when spawning is present) to protect spawning herring (area not shown on map).

A. Embayment line. Area shoreward of this line is closed year-round to protect spawning populations.
B. Mobile gear closure. This area is closed from April 1 to November 6 to herring fishing using mobile gear (herring not present until after November 6).
C. Herring fishing area 18. This area is closed year-round to herring fishing using mobile gear.
D. Mobile gear closure. This area is closed from April 1 to November 6 to herring fishing using mobile gear (herring not present until after November 6).
E. Herring fishing area 20 is closed to mobile gear from January 1 to April 30 and to midwater trawl (vessels <19.8 metres only) from May 16 to October 14.
F. Mobile gear closure. Closed year-round to keep mobile gear out of area with traps and weirs.
G. 25-mile line. Area to the shoreward side of this line closed to herring fishing with mobile gear (purse seiners and mid-water trawl).

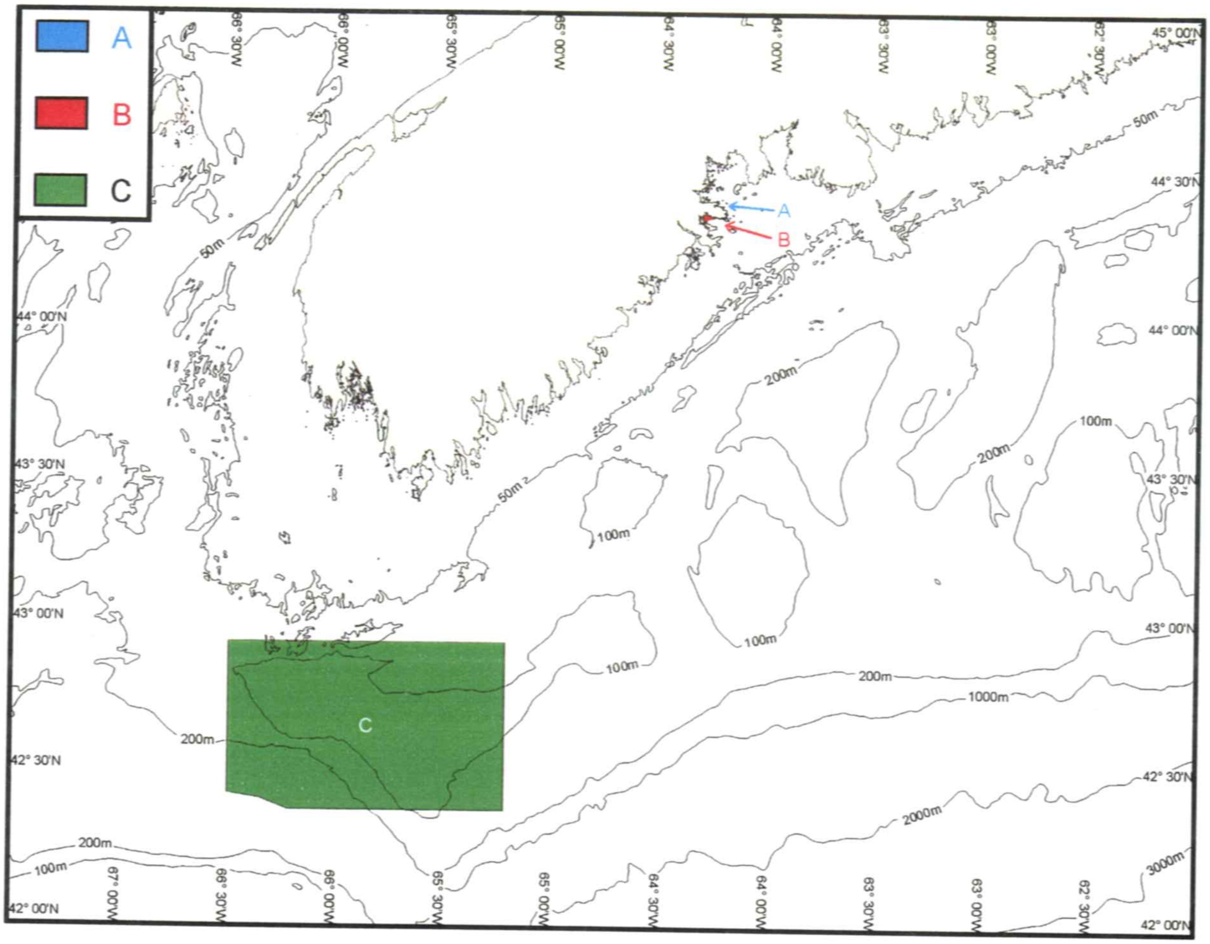


Figure AP4-5. Restrictions affecting scallop and lobster fisheries.

A. Coastal waters of Second Peninsula closed to scallop fishing.
B. Coastal waters near Bayport closed to scallop fishing.
C. Browns Bank closed to lobster fishing.