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Inshore Scotian Shelf Ecosystem Overview Report: Status and Trends

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Foreword

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

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

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LIST OF ACRONYMS

ACES	Applied Coastal Ecosystem Science
ACAP	Atlantic Coastal Action Program
ACZISC	Atlantic Coastal Zone Information Steering Committee
BoFEP	Bay of Fundy Ecosystem Partnership
CHS	Canadian Hydrographic Service
CMEP	Centre for Marine Environmental Prediction
CMA	Coastal Management Area
COSEWIC	Committee on Status of Endangered Wildlife In Canada
CTD	Conductivity-Temperature at Depth
CWS	Canadian Wildlife Service (Environment Canada)
DFO	Department of Fisheries and Oceans
DOC	Dissolved Organic Carbon
EBM	Ecosystem Based Management
EBSA	Ecologically and Biologically Significant Areas
EOR	Ecosystem Overview Report
FSRS	Fishermen and Scientists Research Society
FDGC	US Federal Geographic Data Committee
HAB	Hazardous Algal Blooms
IBA	Important Bird Areas
ITQ	Individual Transferrable Quota
IBQ	Individual Boat Quota
ICCAT	International Commission for the Conservation of Atlantic Tuna
IEP	Inshore Ecosystem Project
LEK	Local Ecological Knowledge
LOMA	Large Oceanographic Management Area
LTTM	Long Term Temperature Monitoring Program
MIDI	Marine Invertebrate Diversity Initiative Society
NAFO	North Atlantic Fisheries Organization
NGO	Non- government Organization
NMFS	National Marine Fisheries Services
NSDFA	Nova Scotia Department of Fisheries and Aquaculture
NSDNR	Nova Scotia Department of Natural Resources
NRCan	Natural Resources Canada
OAP	Oceans Action Plan
PAR	Photosynthetically-active radiation
PCB	Polychlorinated biphenyl
SARA	Species At Risk Act
SEAWIFS	Sea viewing Wide Field-of-view sensor
SIMBOL	Science for the Integrated Management of the Bras d'Or Lakes
SHACI	Significant Habitats: Atlantic Coast Initiative
SSIP	Scotian Shelf Ichthyoplankton Programme
TAC	Total Allowable Catches
VMS	Vessel Monitoring System

ABSTRACT

The Inshore Scotian Shelf Ecosystem Overview Report (EOR) describes the geological, oceanographic and biological systems of the inshore region and their relationships at the habitat and ecosystem levels. Its objectives are to provide the ecological context for integrated management, a baseline for impact assessment and planning for sustainable use of the area.

The geographical scope of the Inshore Scotian Shelf EOR is the waters less than 100 m deep or less than 25 km offshore Nova Scotia between Cape North and Cape Sable Island. This definition is largely based on the inshore limit of the Fisheries and Oceans Canada (DFO) Research Vessel trawl surveys, and does not necessarily fully reflect either the functional role of the inshore region in the structuring and population dynamics of diadromous and marine species, or the distribution of species, habitats and ecological processes considered in this report. However, it does contain distinct habitat and species that do not occur in deeper waters. Information is also presented from outside of these boundaries when relevant to the ecological and biological processes of the larger Scotian Shelf ecosystem.

There is a long history of coastal marine research in Nova Scotia, although it is patchy in nature, focusing on specific areas, specific time periods, or both. As a result, the quantity of information is not equally distributed across species, habitats or ecological processes, meaning that information quantity is not necessarily related to relative importance. Information is drawn from primary literature; provincial, federal, municipal and environmental consultants' reports; and preliminary analyses from the DFO Inshore Ecosystem Project. Although a historical perspective is provided, this report is largely based on information from the last 50 years.

Most of the inshore region is characterized by relatively rugged and hard bedrock outcrop terrain at or immediately below the seabed. Mapping along the Atlantic coast shows that sand and gravel are present over most of the inner shelf but in such a thin layer as to have little effect on the seabed morphology. Shoreline habitats include rocky shores and headlands, large bays and inlets, estuaries, salt marshes and sandy and rocky beaches.

The entire coastline is influenced by periodic forcing of large scale shelf processes, such as coastal upwelling and the Nova Scotia Current (NSC). The NSC is a longshore current bringing fresher water from the Gulf of St. Lawrence onto the shelf, resulting in an along-shore gradient of increasing salinity and decreasing stratification from east to west. However, many of the invertebrate and fish species of the inshore region are ubiquitous. Community composition and diversity vary at the habitat level, with the degree of exposure to the open ocean largely defining the inter-tidal and sub-tidal communities.

The inshore and offshore regions are linked through the export of production by macrophytes, larvae from sessile invertebrates, and anadromous fishes. There is also a net loss of production to migrating birds, reptiles, large pelagic fishes and marine mammals that seasonally visit and feed in the inshore region. Many species caught offshore in shelf-based commercial fisheries use the inshore region as a nursery area and also feed upon the anadromous fishes and larvae exported into the pelagic food chains of the offshore region. Human activities that have the largest influence on inshore ecosystems are fishing, aquaculture, coastal development and infilling, transportation, mining, and climate change. Four centuries of fishing have left the inshore region low in abundance of traditional fish species and depauperated of spawning areas for species such as cod and herring, while the abundance of invertebrates such as lobsters and crabs has increased. Macrophytes, the defining biological feature upon which inshore organisms depend for food and habitat, will be impacted by the effects of climate change on shoreline habitats. The nature and extent of these impacts are currently unknown, requiring urgent research.

Rapport d'ensemble de l'écosystème de la région côtière du plateau néo-écossais : état et tendances

RÉSUMÉ

Le Rapport d'ensemble de l'écosystème de la région côtière du plateau néo-écossais (REE) décrit les systèmes géologiques, océanographiques et biologiques de la région côtière et leurs relations au niveau de l'habitat et de l'écosystème. Il a pour objectif de fournir le contexte écologique pour la gestion intégrée, une base de référence pour l'évaluation de l'incidence et la planification de l'utilisation durable de la zone.

La portée géographique du REE de la région côtière du plateau néo-écossais comprend les eaux de moins de 100 m de profondeur ou distantes de moins de 25 km des côtes de la Nouvelle-Écosse entre le cap North et l'île Cape Sable. Cette définition repose en grande partie sur la limite côtière des relevés au chalut effectués par les navires de recherche de Pêches et Océans Canada (MPO), et ne reflète pas nécessairement en totalité le rôle fonctionnel de la région côtière dans la structure et la dynamique des populations d'espèces diadromes et marines, ou la répartition des espèces, des habitats et des processus écologiques pris en considération dans le présent rapport. Toutefois, elle contient bien un habitat et des espèces distincts qui ne sont pas présents en eaux plus profondes. Il contient également des renseignements provenant de l'extérieur de ces limites lorsqu'ils sont pertinents pour les processus écologiques et biologiques de l'écosystème du plateau néo-écossais dans son ensemble.

Il existe une longue tradition de recherche sur le milieu marin côtier en Nouvelle-Écosse, même si les recherches sont faites de manière inégale, se concentrant sur des zones particulières ou des périodes précises, ou sur les deux. Par conséquent, la quantité de renseignements n'est pas uniforme selon les espèces, les habitats ou les processus écologiques, ce qui signifie qu'elle n'est pas nécessairement liée à l'importance relative. Les renseignements sont tirés des publications principales, des rapports fédéraux, provinciaux territoriaux et de ceux de consultants en environnement et des analyses préliminaires du Projet sur l'écosystème de la région côtière du MPO. Même si un point de vue historique est fourni, le présent rapport est en grande partie fondé sur les renseignements datant des 50 dernières années.

La plus grande partie de la région côtière est caractérisée par un terrain relativement accidenté avec des affleurements de substrat rocheux dur immédiatement sous le fond marin. La cartographie le long de la côte de l'Atlantique montre que du sable et du gravier sont présents au-dessus de la plus grande partie de la plateforme continentale, mais en couche si mince qu'ils n'ont que peu d'effet sur la morphologie du fond marin. Les habitats riverains comprennent les rivages rocheux et les promontoires, les grandes baies et les bras de mer, les estuaires, les marais salants et les plages sablonneuses et rocheuses.

L'ensemble du littoral est influencé par le forçage périodique des processus de plateau à grande échelle, comme la remontée d'eau côtière et le courant de la Nouvelle-Écosse. Le courant de la Nouvelle-Écosse est un courant littoral qui apporte de l'eau plus fraîche du golfe du Saint-Laurent sur le plateau, ce qui a pour conséquence l'augmentation du gradient de salinité et la diminution de la stratification le long de la rive de l'est vers l'ouest. Toutefois, de nombreuses espèces d'invertébrés et de poissons de la région côtière sont omniprésentes. La composition et la diversité des communautés varient au niveau de l'habitat, le degré d'exposition à la haute mer définissant en grande partie les communautés intertidales et infratidales.

Les régions côtières et extracôtières sont liées par l'exportation de la production par les macrophytes, les larves d'invertébrés sessiles et les poissons anadromes. Il y a également une perte nette de production en raison des oiseaux migrateurs, des reptiles, des grands poissons

pélagiques et des mammifères marins qui visitent de façon saisonnière la région côtière pour s'alimenter. De nombreuses espèces capturées au large par la pêche commerciale sur le talus continental utilisent la région côtière comme aire de croissance et pour également se nourrir de poissons anadromes et de larves exportés dans la chaîne d'alimentation pélagique de la région extracôtière. Les activités humaines qui ont la plus grande incidence sur les écosystèmes côtiers sont la pêche, l'aquaculture, l'aménagement du littoral et le remblayage, le transport, l'exploitation minière et les changements climatiques. Après quatre siècles de pêche, l'abondance de la région côtière en espèces de poissons traditionnelles est faible et les zones de frai pour les espèces comme la morue et le hareng sont appauvries, tandis que l'abondance d'invertébrés tels que le homard et le crabe a augmenté. Les macrophytes, la caractéristique biologique dominante dont dépendent de nombreux organismes côtiers pour la nourriture et l'habitat, seront touchés par les effets des changements climatiques sur les habitats riverains. À l'heure actuelle, la nature et l'étendue de ces répercussions sont inconnues; des recherches urgentes sont nécessaires.

INTRODUCTION

1. PROJECT DEFINITION

The Inshore Scotian Shelf Ecosystem Overview Report (EOR) provides the ecological context for integrated management, a baseline for impact assessment and planning for sustainable use of the area as well as an assessment of knowledge gaps and research needs. It includes a description of geological, oceanographic and biological systems and their interrelationships at the habitat and ecosystem levels. The entire coastline is influenced by the Nova Scotia Current and periodic forcing by large scale shelf processes such as coastal upwelling. The degree of exposure to the open ocean largely defines the inter-tidal and sub-tidal communities. Winter ice is also an important structuring process in Cape Breton, distinguishing this area from mainland Nova Scotia. The human activities that have the largest influence on the Inshore Scotian Shelf ecosystems are fishing and aquaculture, transportation, mining, oil and gas and climate change. Fishing has the longest history and greatest impact, dating back to the 16th century. However, although we give an historical perspective, this report is largely based on information from the last 50 years. The agencies responsible for regulating activities in these inshore areas include municipal, provincial and federal government departments including the federal departments of Fisheries and Oceans Canada (DFO), Environment Canada, and Parks Canada and the Nova Scotia Departments of Environment and Labour, Agriculture and Fisheries, and Natural Resources.

During the DFO/ Fishermen Scientist Research Society (FSRS) Workshop on the Inshore Ecosystems and Significant Areas of the Scotian Shelf, Sydney Bight and Halifax Harbour were identified as the most heavily impacted areas (2007). The Strait of Canso also has a significant history of industrial development but is not as polluted as Sydney and Halifax. Other than these large harbours, the coastline is not heavily developed, but land-use practices in the watersheds of the numerous small embayments including deforestation and a history of mining can impact local conditions. On a coast-wide scale, global warming and invasive species are impacting the inshore ecosystems. There has been no directed study on the significance of the inshore to the Scotian Shelf, but the shallow bays and estuaries provide nursery habitat for many marine species, are essential migratory areas for diadramous and catadromous fish, and nesting and moulting areas for resident and migratory birds.

1.1. Context and Purpose of Report

Canada’s *Oceans Act* states that, “conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment.” Taking an ecosystem approach to oceans management, or ecosystem-based management (EBM), recognizes the complexity of marine ecosystems including the interrelationships between organisms, their habitats and the physical environment. Before EBM can be implemented in a management area, managers and stakeholders need to know the status and trends of the area’s ecosystem and must conduct an ecological assessment to demonstrate what impacts human activities will have on that ecosystem. As laid out in the *Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada* (DFO 2002), the social, economic and cultural aspects of a management area will be discussed in other documents.

1.2. Boundaries of Study Area

The geographical scope of the Inshore Scotian Shelf EOAR is the waters less than 100 m deep or less than 25 km (12 miles) offshore Nova Scotia between Cape North and Cape Sable Island (Figure 1). This definition is largely based on the current inshore limit of the DFO Research Vessel Trawl Survey, although it has some physiographic basis. Firstly, the bedrock geology from Digby to Canso comprises a physiographic province very similar to the adjacent land, with hard (metamorphosed or igneous) rocks, abundant outcrops, relatively high local relief compared to father offshore, and abundant small hills and basins, mainly with little sediment cover but with a dominant sand and gravel cover and more limited mud fill in small basins. Almost everywhere, this zone extends to at least 25 km or more offshore. Generally the zone gives way to younger, smoother, less consolidated bedrock types further offshore. From Southwest (SW) Nova to Canso, it is typically 30 km wide and as much as 50 km wide off Halifax. East of Canso, the rock types are different and much more variable, but generally of a simialar hard nature and undulating topography. The greatest departure from this is the Cape Breton coast from Sydney to Grand Narrows, where the coal measures extend offshore and present a smoother macro-relief on the seabed. Secondly, the post-glacial low-stand of sea-level in the nearshore had a major influence on washing and redistribution of sands muds and gravels as the coastline advanced through the zone. This zone of influence is generally between 100 and 70 m water depth, with the greatest influence perhaps in the shallower waters, as the rate of relative sea-level rise diminished, affording greater time for processes to have an effect.

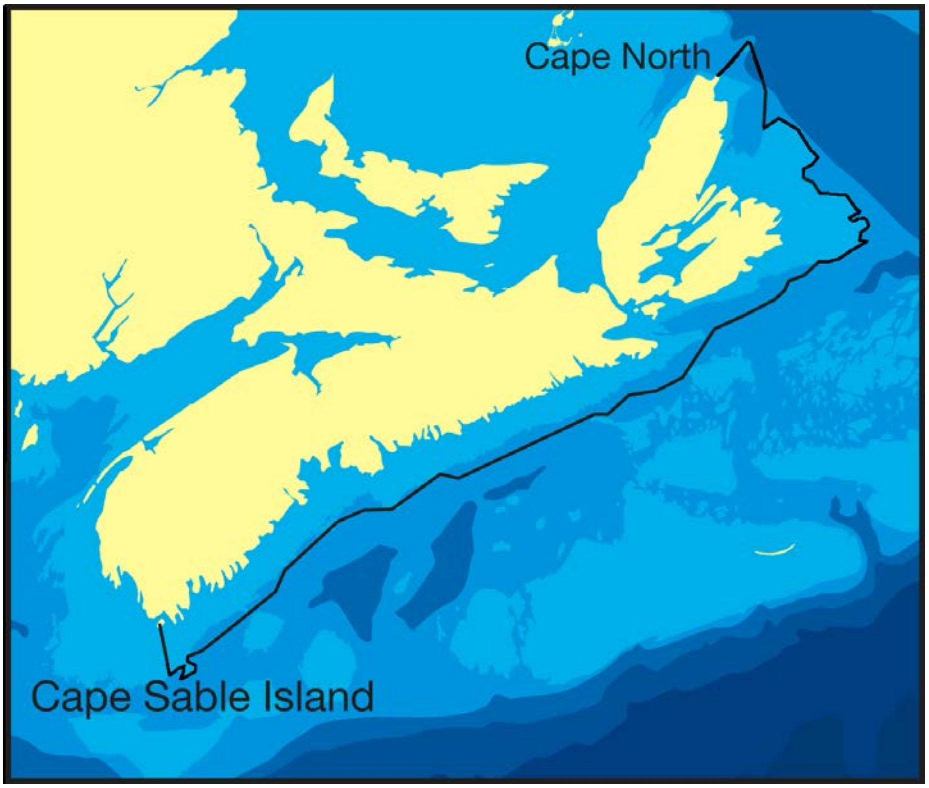

Figure 1. Map of Nova Scotia, Canada, showing the the approximate boundaries of the study area, 100 m contour line (50 fm) and the 25 km (12 mile) offshore line.

From a biological perspective, these limits do not necessarily reflect the functional role of this ocean area in the structuring and population dynamics of diadromous or marine species, nor constrain the distribution of species, habitats and ecological processes. In this document, information is presented from outside these boundaries, when relevant to the ecological and biological processes of the larger ecosystem.

2. METHODOLOGY

2.1. Sources of Information

There is a long history of coastal marine research in Nova Scotia, although it is patchy in nature, focusing on specific areas, specific time periods, or both. As a result, the quantity of information is not equally distributed across species, habitats or ecological processes, meaning that information quantity is not necessarily related to relative importance. As a result of the patchy distribution of studies, some components of the ecosystem are poorly represented due to lack of data.

Much of this research has been summarized in consultant and government reports. This document draws upon the primary literature, provincial, federal and municipal reports, and environmental consultants' reports.

Further, expertise found in the federal government (e.g. information on geological processes, oceanography, fisheries, marine birds); the province (e.g. land-based sources of pollution); academia and non-governmental organizations (NGOs); and local communities (e.g. Local Ecological Knowledge) has been drawn upon. Expert opinion has been solicited through: 1) a review process outlined at the beginning of each section, 2) a workshop held in January 2006 and 3) a mapping exercise described in the proceedings of the DFO/FSRS Workshop on Inshore Ecosystems and Significant Areas of the Scotian Shelf (DFO 2006). Fishermen's ecological knowledge was solicited through a survey of commercial fishermen along the Altlantic coast of Nova Scotia (Bundy 2007a).

This overview is compiled primarily from information gathered over the last fifty years. It is recognized that the characteristics of the study area are, to a certain extent, continuously evolving. These changes occur on several time scales as a result of a number of different causes. Some examples include sea level rise and other aspects of climate change that have been occurring over the last few millennia (Bernier and Thompson 2006), ecosystem trophic cascades triggered by over-fishing occurring over the last several decades (Frank et al. 2005, Bundy and Fanning 2005) and the North Atlantic Oscillation, which varies over shorter periods (Petrie 2007). The effect of the longer time scale variations is to make any overview a snapshot representative only of a particular point in time. The shorter time scale changes may bias a particular study or introduce confusing deviations into the observations depending upon the duration of the dataset under consideration. These factors should be borne in mind when using this overview.

Wherever possible, recent peer reviewed sources have been used in this document and discrepancies between or within these information sources have been highlighted.

This report has taken a number of years to produce (2007-2014), and many scientist have contributed to its development. While efforts have been made to ensure that information is up to date at the time of publication, some recent information has not been incorporated.

PART A – GEOLOGICAL SYSTEMS

3. MARINE GEOLOGY

Contributed by E. King and N. den Heyer with futher contributions by Michelle Greeenlaw and Alex Levy.

Nova Scotia is on the trailing edge of the American plate (Owens and Bowen 1977). The underlying bedrock is predominantly deformed lower Paleozoic sedimentary rocks, although the Atlantic coastline of mainland Nova Scotia is mostly resistant metamorphic and igneous outcrops overlain by till and drumlins. With the exception of Chedabucto Head and Northern Cape Breton, the Atlantic coastline has low relief (<100 m). Large coastal embayments, harbours and headlands have similar topographies extending to the nearby offshore. The headlands tend to be bedrock controlled projections (locally till-dominated) with little sediment cover and the embayments often have an associated seabed topographic depression, often with a greater sediment cover over tills or bedrock. Most of the sediments are from glacial deposits, which have been washed and sorted, such that the clays and finer sediments spread to the deep basins.

All of mainland Nova Scotia and most of the nearshore waters were covered by late Wisconsinan ice masses (Stea et al. 1998). The nearshore was submersed by postglacial sea-level rise: between AD 100 and AD 1800 sea level rose at 17 cm per century, and between AD 1900 and AD 1920 sea level rise increased to 3.2 mm/year (Gehrels et al. 2005). Due to crustal adjustments (subsidence), this rise is still in progress following glaciation.

Most of the nearshore zone shallower than about 80 m water depth is generally characterized by relatively rugged and hard bedrock outcrop terrain at or immediately below the seabed. This bedrock zone exhibits rough topography and little sediment cover. Estimates show that, commonly, 70% of the area has bedrock outcrop or outcrop covered with gravel cobble and boulders. Beyond this, at about 25 to 30 km from the coast, the bedrock-dominated zone gives way to the inner-shelf basins, generally with much thicker sediment cover. The transition is generally at the (buried) contact with much younger (Mesozoic) bedrock that has been more effectively sculpted by the glaciers and where glacial deposits are thick. Bedrock unit distribution is locally mapped (King and Webb 2009) although large areas remain undifferentiated.

Bedrock: The bedrock generally exhibits small-scale relief reflecting variations in the rock type, especially with changes from sandier to finer-grained rock types in the metasediments. These give rise to small ridges and valleys along the bedding planes. Folding of the strata is common and results in a pattern of curving “U” and “S” shapes in plan-view. A coast-parallel north-northwest – south-southeast (NNW-SSE) “fabric” or linear trends of the bedrock morphology is common. Some pronounced bedrock ridges are continuous for tens of kilometers. Glacially-excavated valleys cut in bedrock (generally partly buried) are generally oriented approximately perpendicular to the coast. Faults and joints often give rise to an orthogonal pattern of small-scale relief in plan view.

Pleistocene Sediments: Bedrock is commonly covered with a variety of sediment types that reflect the geologic evolution of the area. Glaciation has left isolated but locally expansive till (glacial deposits) overlying proglacial deposits (cohesive diamict (poorly sorted sediment)), and locally of several metres thickness. The roughness and high sediment distribution variability partly reflects the glacial style of erosion and deposition in this hard bedrock and partly that the zone has undergone a post-glacial marine transgression. The transgression by the sea (i.e. coastal reworking) during sea-level rise, which is still active in headland areas, eroded and “washed” much of the glacial sediment, leaving an abundance of gravel with cobbles and boulders, often as thin blankets overlying the till, bedrock, or both. The coastal processes also lead to local post-glacial mud deposition and redistribution of these glacial deposits. The result is a highly variable topography, highly variable sediment type, thickness and distribution.

Sediment types thus generally include:

- till, both as a sheet of a few metres thickness to till in ridges (moraines) and drumlins
- glacimarine diamicts (generally stratified) infilling topographic lows, with surficial sandy and gravelly lag deposits
- overlying sand and gravel-dominated sub-littoral (near wave base) deposits (poorly stratified) derived from redistribution of coastal erosion products, and
- mud derived from these erosion products and generally confined to in the inner harbours and deeper-water offshore basins

Till: The differentiation of till outcrop from bedrock outcrop is commonly subjective, depending on the type of raw data used for mapping. Hence, some maps depict an undifferentiated bedrock/till map unit, characterized by relatively rough topography and a gravelly or bouldery surface. Till is quite common at the seabed on the inner shelf and it is also commonly buried by pro-glacial and early post-glacial muds. Morphologically, the till generally occurs in the form of blanket deposits, drumlins, and moraines of various scales, often with considerable relief or, less commonly, infilling bedrock topographic lows (Stea et al. 1994). It has a variable thickness, especially in drumlin and moraine fields. The smallest morainic ridges occur as expansive fields of ridges up to kilometers in length, 50 to 200 metres spacing, decimetres to metres high and metres to tens of metres across. The ridges generally parallel the coastline trend and bathymetric contours. In general it should be assumed that the seabed in areas of till outcrop have a medium to high density of boulders. The most dense are in the order of 100 to 200 boulders per hectare (10,000 m^2) while they are more typically 10 to 50 per hectare (King et al. 2002). A common phenomenon in coastal Nova Scotia is erosion of till forms (typically drumlins), associated with continued (though slow) sea-level rise. The result of this is typically a single-clast layer gravel-cobble “pavement” on top of the relatively un-modified till.

Glacimarine Mud: More low-lying areas between bedrock or till outcrop generally have a much smoother relief and correspond to local basinal infill. It generally comprises glacimarine muds with sand and a minor gravel component. These deposits were generally also washed (reworked) during the transgression and, in shallower areas, by present currents and waves, to leave sand and gravel veneers (cm to dm thickness) at the seabed.

Sub-littoral Sand and Gravel: Locally, estuarine or lacustrine, glacial and coastal deposits have been cut, eroded or overlain by sediments redistributed after having gone through the shallow water environment (at times of lower sea-level). The higher energy levels within storm wave base in the immediate offshore, have redistributed these into blankets up to several metres thick. They are capped by sands and gravels commensurate with the present hydraulic regime or that of the recent past. They extend beyond the headlands, locally beyond the 25 km limit, mainly in the lower-lying topography.

Mud: In the more energy-sheltered inner harbours and bays, Holocene age marine mud deposits are common. They are the fine grained depositional product of the transgression processes noted above. Some of the mud product was transported seaward to the offshore basins, generally in greater than 100 m water depth. The harbour deposits can be several metres thick and often have associated methane gas just below the seabed.

3.1. Sediment Distribution and Surficial Maps

Survey transects perpendicular to the coast across a bedrock-dominated and a till-dominated inner shelf were used to generate the range/distribution of seabed types and textures in Table 1.

Table 1. Percentages of seabed coverage along approximately 25 km long linear transects perpendicular to the coastline (modified from King et al. 2002).

Seabed Type	Bedrock	Till (boulder to clay range)	Glacimarine mud (cohesive with gravel)	Post-glacial (soft) mud
Shelburne area Transect	1	19	79	0

Seabed Grain Size / Texture	Gravel	Sand	Sand and Gravel Patches	Clay
Shelburne area Transect	27	7	66	0
Liverpool area Transect	28	12	50	10

Shelburne and Liverpool represent near end-members (extremes) in terms of bedrock occurrence. For comparison, a similar transect off Sheet Harbour, Eastern Shore, though not quantified in this way, likely has values near the mid-range of the Shelburne and Liverpool areas.

The detailed geology of the inshore areas of the Scotian Shelf was not well described until recently. A series of surficial geology maps generated by L.H. King and co-workers (King 1970) in the 1970s and 1980s provided a stratigraphic formational classification of the area. The inner shelf region, generally shallower than 100 m water depth and within the 25 km limit, was largely mapped as undifferentiated sand and gravel deposits (Sable Island Sand and Gravel), formed when washed in a paleo-coastal environment during the post-glacial rise in sea-level noted above. These maps of the inner shelf are conceptual, as time and technology have revealed a much more variable surficial geology. More recent mapping work has been site-specific, mainly along the Atlantic coast, and generally confined to outside the headlands and the largest bays. These show that sand and gravel are indeed present over most of the inner shelf (including much of the bedrock “outcrop”) but commonly in such a thin layer as to have little effect on the seabed morphology.

The most comprehensive maps are from Piper et al. (1986), but only cover the South Shore from Sable River to St. Margaret’s Bay (shown in Figure 2 slightly modified). The Halifax to Jeddore area of the Eastern Shore was mapped as part of a Dalhousie University thesis topic (Figure 3; Hall 1985). Multibeam data covering small areas of the South Shore have validated these maps but also shown large discrepancies in details (Parrott 2000; King and Hynes 2009). Generally bedrock was difficult to differentiate from till using the older technologies and other discrepancies arise from very sparse data coverage and inaccurate interpolations of seismic and sidescan control, based on sparse bathymetric maps. This has been improved somewhat using bathymetric renderings of Canadian Hydrographic Service (CHS) spot water depths derived from original field sheets. This was applied to the area from Port Mouton to Green Harbour (King and Hynes 2003, 2009). The Eastern Shore was generally characterized by Stea et al. (1994) and Stea (1995): a geomorphologic characterization of the inner shelf provides an example of the morphologic characterization from the Eastern Shore (Figure 4), and Figure 5 shows a preliminary version of the multibeam-based map for offshore Sheet Harbour.

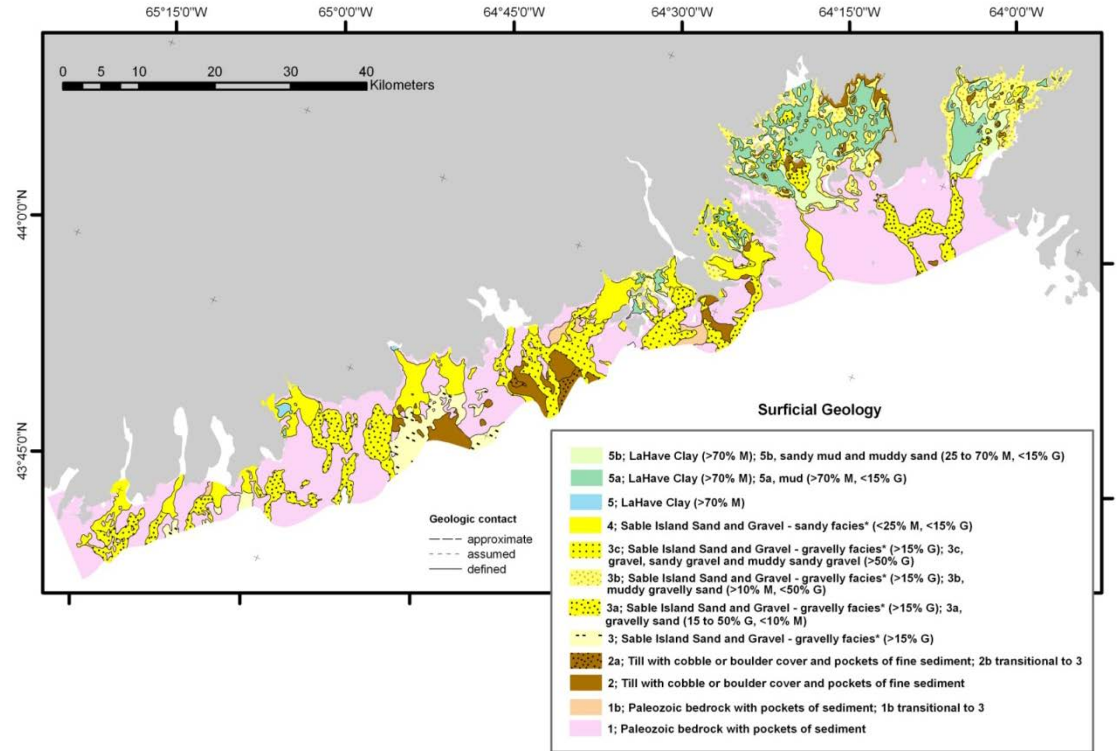

Figure 2. Surficial geology of the South Shore (From Piper et al. 1986, modified by King and Hynes 2009).

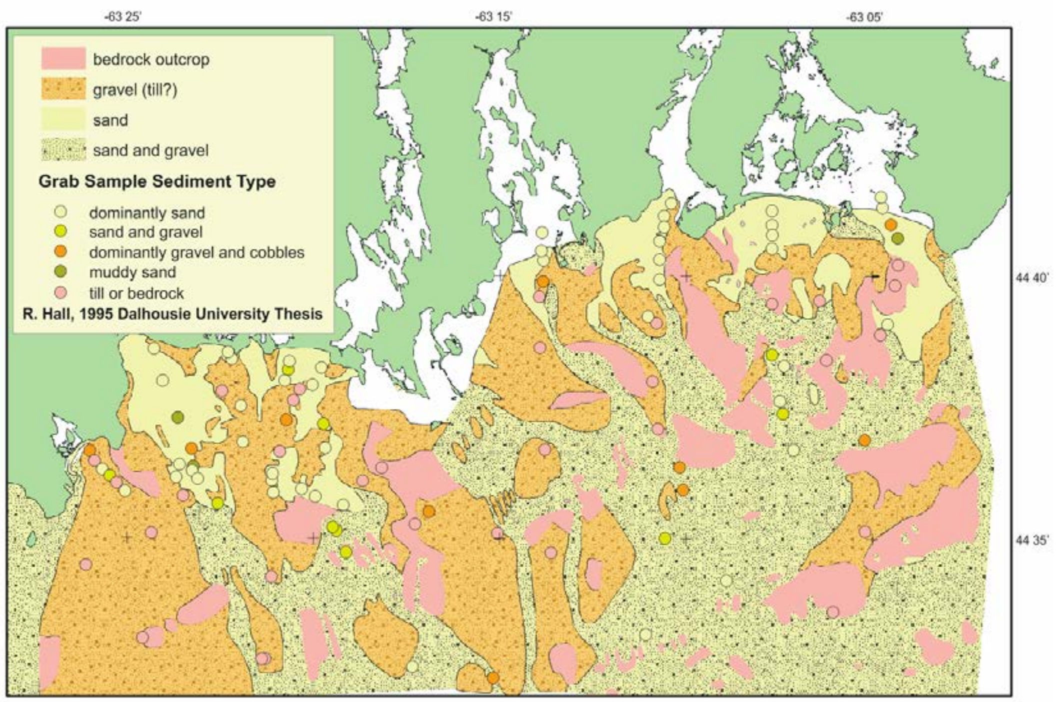

Figure 3. Surficial geology of the inner shelf from Halifax to Jeddore. Bedrock outcrop is rough and boulder-gravel-strewn. Gravel increases farther seaward where, at times of lower sea-level, underlying glacigenic (gravel to clay) sediments were modified under coastal processes. Gravel-coated till occurs as thin blankets and locally as glacial landforms (Modified from Hall 1985).

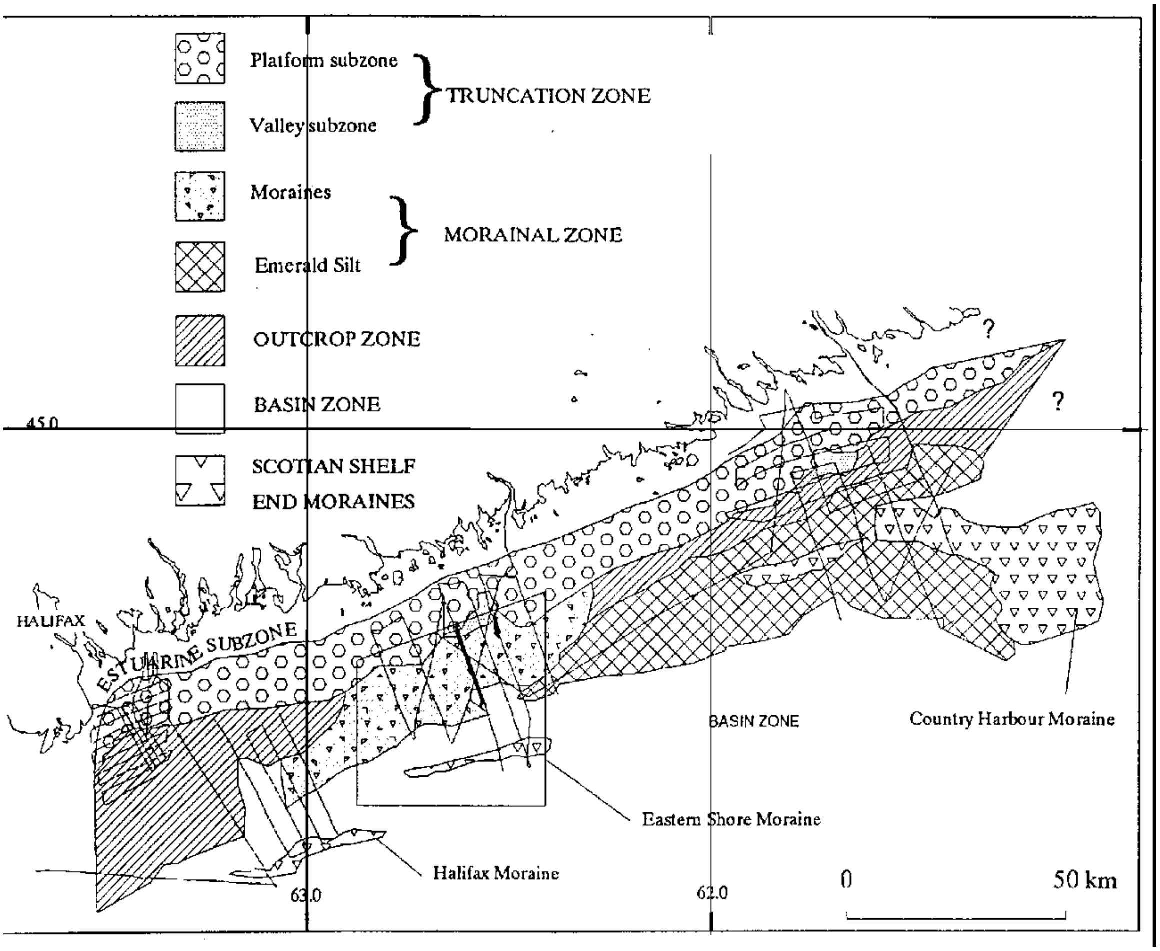

Figure 4. Generalized characterization of the Eastern Shore inner continental shelf based on bathymetric maps, and limited seismic and sidescan transects (solid lines). The truncation zone is sand and gravel rich, having been subject to the coastal processes during sea-level rise. "Emerald Silt" is the "glacimarine mud" noted above (from Stea et al. 1995).

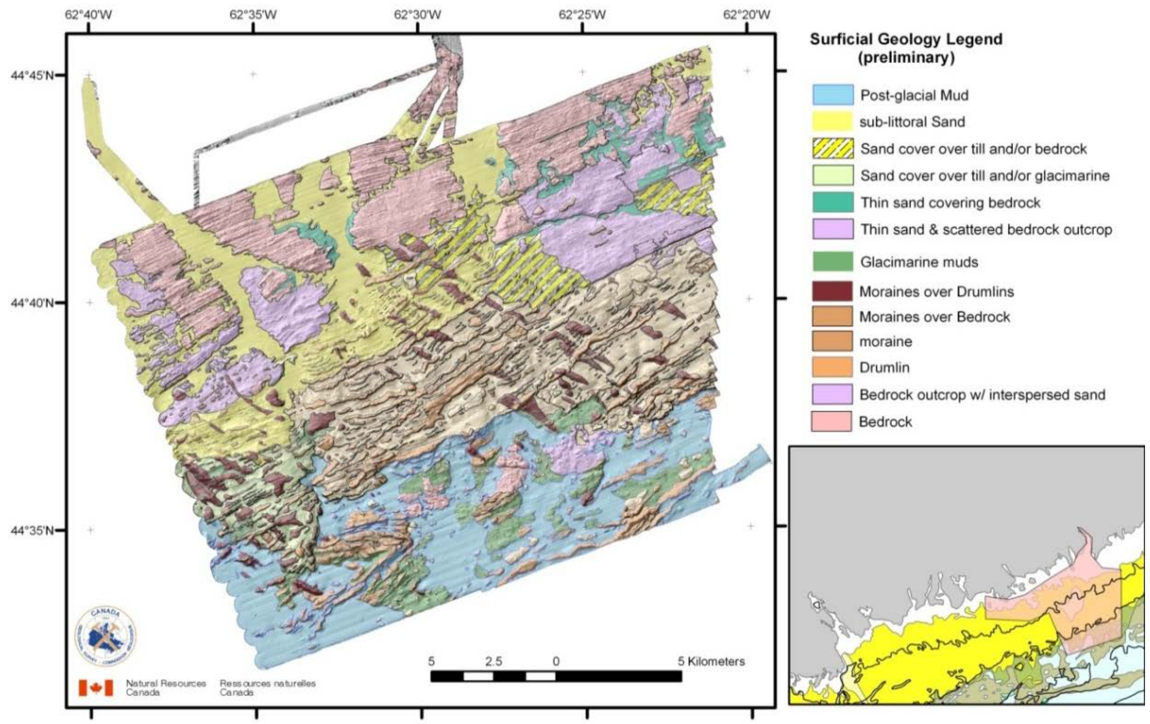

Figure 5. Preliminary compilation of the surficial geology offshore Sheet Harbour, derived primarily from multibeam bathymetric coverage. The index map shows the map area in relation to the surficial geology map of King (1970). The legend refers to the map at left and is preliminary. This map demonstrates the detail and variability in some areas of the inner shelf that is made possible with multibeam coverage (Modified from King and Webb 2009).

Natural Resources Canada (NRCan) efforts to compile readily-accessable seabed and sub-surface maps are ongoing. Bedrock and various surficial geology maps are in production as are updates of the seabed geo-features. An atlas is in production that will provide over 400 selected examples of the features and attributes characterizing the seabed. Surficial geology and/or multibeam bathymetry maps are in production off the Yarmouth area, Lunenburg Bay, Liverpool, St. Margaret's Bay, Halifax and approaches, offshore Sheet Harbour, parts of Chedabucto Bay, offshore Louisbourg, and the Bras d'Or Lakes. While some are prioritized and will soon be available, others are proceeding slowly. Most datasets are extant as GIS-based databases and selected sub-sets are generally available as custom-generated maps from individual scientists upon request. NRCan multibeam data holdings (full resolution images) are available. Value-added geological interpretations for Halifax, Yarmouth and Lunenburg areas are near completion.

In the Inshore Scotian Shelf, there is sporadic multibeam coverage with varying degrees of interpretation, but in general there are very few data inside of the headlands (Figure 6). Outside of the headlands, less than 5% of the inshore has been covered by multibeam, but 90-100% of the South Shore and 40% of the Eastern Shore have been mapped with sidescan and seismic mapping. Note that the latter mapping is derived from very sparse data coverage (seismic, sidescan, sampling) together with morphological rendering of bathymetric spot depths; map derivatives involve considerable interpolation, unlike areas with multibeam coverage. Most of the multibeam surveys that have been completed were for resource management and assessment (e.g. scallops) or planning and mitigating developments such as pipelines, cables, and the Halifax Harbour Solutions Project. Interpretation of multibeam data can indicate ice age history, seabed habitat, and earthquake activity (Edgecome et al. 1999; Fader and Buckley 1995), but not all the multibeam data have been fully interpreted.

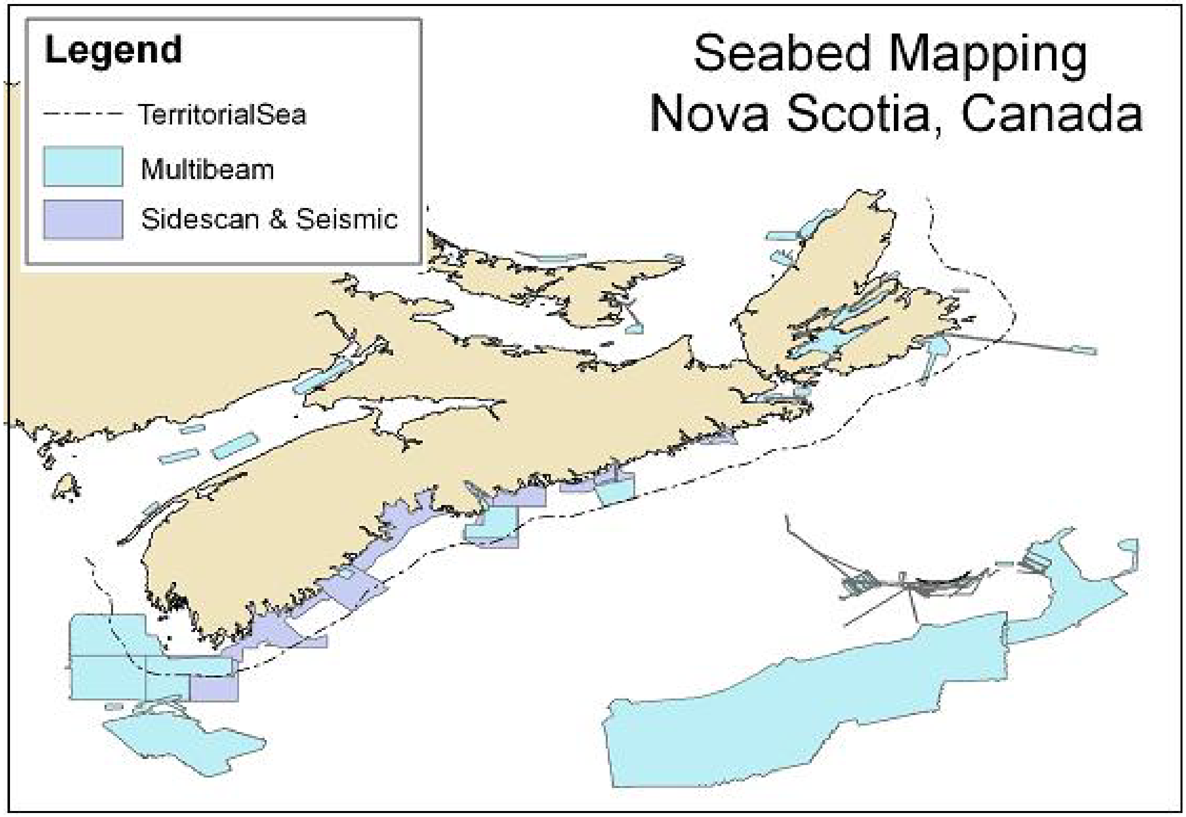

Figure 6. Map of multibeam, seismic and sidescan mapping completed prior to 2006 around Nova Scotia (King and Lucas, unpublished).

3.2. Other Geologic Features and Processes

3.2.1. Shallow Gas and Pockmarks

Shallow gas (likely biogenic methane) in sediment is a common phenomenon in the muds of inner harbours of the Atlantic coast. This is usually manifest in sub-bottom high-resolution seismic profiles as broad areas of continuous gas acoustic masking at depths of two to several metres below the seabed. Associated pockmarks (gas escape erosional cone-shaped features) are present but not nearly as common as in the offshore basins (deeper than 100 m).

3.2.2. Sediment Mobility

Ripple-like bedforms in sand are the strongest indicators that sediments are moving, at least periodically. They are generally very low relief features manifest as elongate strips of coarser (usually gravelly) sediment alternating with sandy strips in plan view. Most are likely less than 25 cm in amplitude. They vary in wavelength from metres to tens of metres. Numerous varieties indicate wave- or current-dominated flows of different flow regimes. They generally form in areas which topographically focus tidal or storm-generated currents and have limited spatial coverage. Channel-like features have also been observed locally; these suggest that flow and seabed sediment entrainment and erosion are at least periodic and maintained over distances over 1 km. Their extent and distribution are largely unknown. Erosional or non-depositional moating of the mud around topographic highs is common.

4. GEOMORPHOLOGY

Contributed by N. den Heyer and E. King

4.1. Topography of Coastal Landscapes

The Atlantic shoreline of Nova Scotia, from Cape North to Cape Sable, is extremely diverse in its physical character. It varies in topography, composition, sediment availability and exposure to marine processes. Earlier descriptions of the coastal geology recognized this diversity and subdivided the coastline into 14 morph-dynamic units (Owens and Bowen 1977; Munroe 1980, 1982; Taylor and Frobel 2001). Since the 1980s, the best descriptions of coastal characteristics and condition are derived from low altitude oblique video of the coastline that was flown in the 1980s by Petro Canada (Woodward Clyde 1982) and again between1989 and 1992 by the Geological Survey of Canada and Canadian Coast Guard (Taylor and Frobel 1996, 2001). More recently, Davis and Browne (1996b) developed a theme region classification system based on the geology, surficial materials, landforms, topography, hydrology, plant and wildlife communities, as well as other aspects of the natural environment (Figure 7). Of the nine theme regions, five occur in the Inshore Scotian Shelf as defined in this project: Theme Region 900 Offshore/Continental Shelf; Theme Region 200 Highlands; Theme Region 400 Atlantic Interior; Theme Region 500 Carboniferous Lowlands; and Theme Region 800 Atlantic Coast (Figure 7). Each of these regions is further divided into districts. For example the study area encompassed by Theme Region 900 contains two units, District 911 Atlantic and District 915 Sydney Bight. The geological characteristics of the Districts encompassed by the DFO/FSRS Inshore Ecosystem Project are described in Table 2.

Most of the study area is contained in Theme Region 800 Atlantic Unit which extends from Scatarie Bank off eastern Cape Breton Island to Brier Island on the west coast of Nova Scotia. In this area, the seafloor is a combination of sandy/gravelly till, larger rocks and boulders, and exposed bedrock ledges. Surficial features include gravel waves, bedrock folding, drumlins, and small glacial moraines. The bedrock slopes gradually offshore for 25 km to depths of approximately 110 m. Nearshore areas can have a variety of sediments as a result of local formation. A few localized depressions such as Chedabucto Bay contain pockets of clay. Onshore coal formations in the Sydney area extend northward to Georges Bay, Newfoundland but these are generally buried beneath soils varying in thickness from a thin veneer to over 100 m. Off the Cape Breton Highlands, nearshore rocks are igneous and the slope is steep. There is a relatively flat bottom, sloping gradually offshore in Sydney Bight. This forms St. Anns Bank, the only major bank in the study area.

Table 2. Description of the Theme Regions and Districts of the Inshore Scotian Shelf encompassing the coastal habitat of the study area (Davis and Browne 1996b).

Theme Region	**Geological Character**
	200 Highlands
210 Plateau-Fir Forest	Ancient metamorphic and granitic rocks which are resistant. *Glacial deposits are dominated by compacted glacial till and erratics are common.*
	500 Carboniferous Lowlands
510 Till Plain	Carboniferous sedimentary rock with more resistant Horton Group sandstones. *The district is heavily blanketed with glacial debris and outwash. Deposits are common.*
530 Stony and Wet Plain 531 Sydney Coalfields	Carboniferous sedimentary rock with flat-lying sandstones and shales that are poorly drained. The strata contain numerous seams of coal. *The terrain varies from flat to rolling and is evenly covered with a generally thin layer of sandy to stony glacial till. Bedrock is frequently exposed at the crests of minor ridges.*
550 Coastal Fringe 552 Victoria Coastal Plain	Narrow fringe of Carboniferous sedimentary rock. *Sedimentary rock underlies coastal plains at the base of the steep cliffs. Between St. Anns Bay and Cape Smokey the band of sedimentary rock is very narrow. The Windsor Group deposits are being eroded very rapidly. Where gypsum underlies the surface, karst topography has formed*.
	400 Atlantic Interior
460 Bays Mahone & St. Margaret's Bays	Carboniferous sea-deposited limestone and evaporites. Most of limestone and evaporite strata have been eroded away, and only a fringe is left around the margins of the two bays. Granite is the dominant rock, with slate forming a series of peninsulas on the west side of Mahone Bay. *Drumlins, particularly in Mahone Bay, form islands called "whalebacks". These have been extensively eroded by the sea.* *Finer sediment is deposited in small salt-marshes in the low-energy environments at the heads of the bays. Small, sandy pocket beaches are present on exposed coasts at the bay heads. Deep water, inland of sills at the bay entrances, has prevented the rising sea level from moving nearshore sand deposits onto the present coastline.*
	800 Atlantic Coast
830 Beaches and Islands 831 Tusket Islands 832 LaHave Drumlins 833 Eastern Shore Beaches 834 Bay of Islands	Slate bedrock includes outcrops of greywacke/quartzite and granite. The slate and greywacke bands are interfolded and the fold axes are either perpendicular to (Tusket Islands) or, more commonly, parallel to the coast. *Differential erosion of softer slate and harder greywacke has created a ridge and valley topography.* *The shoreline is submergent and exhibits drowned headlands and estuaries.* *Sand is found in sheltered coves and inlets, on the lee side of headlands and islands, and where a change in direction of the coastline provides a sink for sediment transported along the shore.*
840 Quartzite Headlands 841 Capes and bays 842 Guysborough Harbours	The coastline is submerged and indented with headlands and long inlets but few islands. There are large areas of exposed bedrock dominated by greywacke/quartzite and granite. Till deposits are thin and there are few drumlins. *Coastal fringe deposits tend to be limited in volume and composed of coarse material. Sand eroded from now submerged glacial deposits forms very limited beaches.*

Theme Region	**Geological Character**
	200 Highlands
850 Granite Barrens 851 Pennant Barrens 852 Canso Barrens	Exposed granite headlands and knolls. The rounded hills have a very thin till cover with many large boulders. Sediment supply is very poor, although quartz can produce pocket white sandy beaches. *The Canso Barrens is composed of rounded bodies of granite rising up to 200 m above sea level. Thin deposits of granite, schist, and slate tills cover about 50 per cent of the surface, but the remainder is exposed bedrock. A few drumlins composed of red-brown till derived from Carboniferous deposits are found on the northeast side of Tor Bay and south of Canso Harbour. The supply of coastal sediment is very limited.*
860 Sedimentary Lowland	Sedimentary rocks deposited during and after the formation of Pangaea in the late Devonian and Carboniferous periods. *The oldest deposits in this district are coarse conglomerates, including volcanics, which have been faulted up against younger rocks on Isle Madame. The coarse conglomerates and related deposits are extensively exposed in eastern Guysborough County, on Isle Madame, and between L'Ardoise and Loch Lomond.* *Deposits consisting of Windsor Group slates, reddish Canso Group siltstones, and fine Riversdale Group sandstones, which are relatively soft, have formed a rolling lowland which slopes towards Chedabucto Bay and the Strait of Canso.* *The Strait of Canso and Chedabucto Bay were drowned river systems in theTriassic and Cretaceous. Glacial ice deposited a locally derived red-brown sandy till.* *Marine erosion provides abundant coastal sediment for numerous small gravel beaches. The beaches often enclose small lagoons or salt marshes.*
870 Till Plain	Precambrian Fourchu volcanics bedrock with large outcrops of Cambrian granite and metamorphic sediments. Drumlins are common. Glacial ice during the Wisconsian period deposited a thick mantle of sands and gravels (commonly up to 30 m thick and on average 12 m thick). *The coastline topography is relatively even. Gabarus Bay is the only stretch of coast where sea cliffs are found. Inland the terrain is low-lying and rolling, rising across a series of ridges to about 125 m in the northwest.* *Sediment supply along the coast is variable. North of Gabarus, rocky shorelines, boulders, and cobble beaches are most common; south of Gabarus, the coast is indented with protected bays. Sand and gravel beaches are numerous. Between Point Michaud and Fourchu Bay an extensive series of cobble barrier beaches enclose large barachois ponds.*

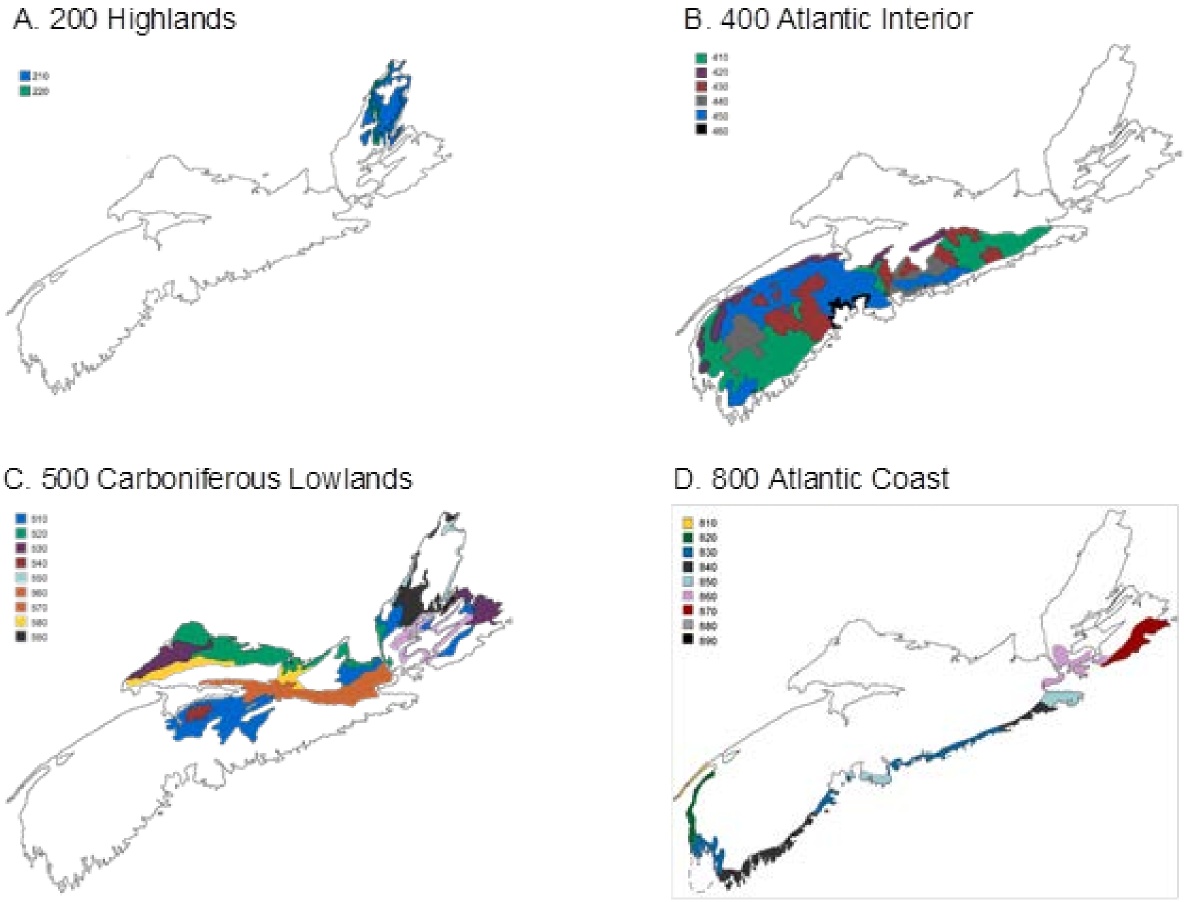

Figure 7. Theme Regions and Districts of the Inshore Scotian Shelf: A. 200 Highlands Districts, B. 400 Atlantic Interior, C. 500 Carboniferous Lowlands, D. 800 Atlantic Coast (Davis and Browne 1996b).

Focusing on the Atlantic coast of Nova Scotia, several classification schemes have been developed over recent years. Traditionally, the region is described as the South Shore, Eastern Shore and Cape Breton, primarily based on socio-economic characteristics, which are not independent of resources and geomorphological characteristics. A recent classification scheme used by DFO is the Significant Habitats: Atlantic Coast Initiative (SHACI; Figure 8; Table 3; McCullough et al. 2005). To investigate longitudinal variation in species community composition, habitats and species associations, the DFO/FSRS Inshore Ecosystem Project (IEP; Bundy 2007b) identified three zones: Zone 1, Cape Breton; Zone 2, Eastern Shore; and Zone 3, South Shore (Table 4).

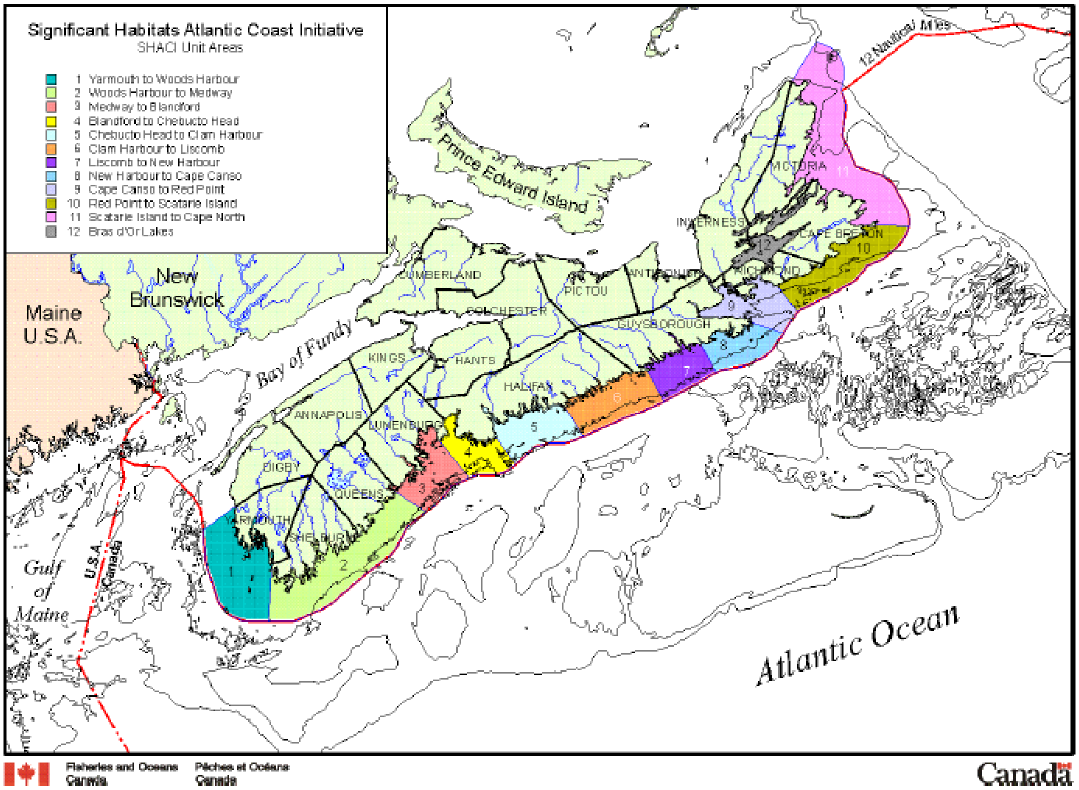

Figure 8. Map of Significant Habitats: Atlantic Coast Initiative (SHACI) units and counties of Nova Scotia (McCullough et al. 2005).

Table 3. A comparison of the Significant Habitats Coastal Initiative (SHACI) units, the Natural History of Nova Scotia Theme Regions and the DFO–FSRS Inshore Ecosystem Project (IEP) zones.

IEP Zone	SHACI UNIT	NHNS Theme Region
1	11 – Scaterie Island to Cape North (Sydney Bight)	District 530 Stoney and Wet Plain Unit 531 Sydney Coalfield District 550 Coastal Fringe Unit 552 Victoria Coastal Plain
1	10 – Red Point to Scaterie Island	District 870 Till Plain
1 & 2	9 – Cape Canso to Red Point (Chedabucto Bay)	District 880 Sedimentary Lowlands
2	8 – New Harbour to Cape Canso	District 850 Granite Barrens Unit 852 Canso Barrens
2	7 – Liscomb to New Harbour	District 840 Quartzite Headlands Unit 834 Bay of Islands
2	6 – Clam Harbour to Liscomb	District 830 Beaches and Islands Unit 834 Bay of Islands
2 & 3	5 – Chebucto Head to Clam Harbour	District 830 Beaches and Islands Unit 833 Eastern Shore Beaches
3	4 – Blandford to Chebucto Head	District 850 Granite Barrens Unit 851 Pennant Barrrens
3	3 – Medway to Blandford	District 830 Beaches and Islands District 832 LaHave Drumlins
3	2 – Woods Harbour to Medway	District 840 Quartzite Headlands 841 Capers and Bays

Table 4. Number, total area (hectares) and percent of total area of coastal habitat in eight counties in the three DFO/FSRS Inshore Ecosystem Project (IEP) zones (data from Hanson and Calkins 1996).

	Salt Marsh			**Estuarine Flats**			**Saline Ponds**			**Dunes**			**Beaches**			**Islands**		
County	**#**	**Area, ha**	**% of coast**	**#**	**Area, ha**	**% of coast**	**#**	**Area, ha**	**% of coast**	**#**	**Area, ha**	**% of coast**	**#**	**Area, ha**	**% of coast**	**#**	**Area, ha**	**% of coast**
Zone 1																		
Cape Breton	56	281	0.2	36	191	0.2	73	202	0.2	116	2757	2.4	58	110584	95.0	102	2388	2.1
Richmond	75	306	0.3	49	316	0.3	64	173	0.1	157	10324	8.6	61	107062	88.8	134	2340	1.9
Victoria	55	242	1.6	36	112	0.7	63	165	1.1	94	1800	11.6	62	11369	73.0	104	1884	12.1
Zone 2																		
Guysborough	44	157	0.7	25	125	0.5	49	437	1.8	284	11823	49.7	58	10654	44.8	56	600	2.5
Halifax	119	881	3.4	32	2661	10.4	47	507	2.0	514	7714	30.1	105	13293	51.9	31	564	2.2
Zone 3																		
Lunenburg	53	259	2.8	17	50	0.5	58	240	2.6	240	4123	44.5	28	4517	48.8	8	74	0.8
Queens	60	263	3.9	18	108	1.6	34	166	2.54	58	599	9.0	13	5157	77.1	19	399	6.0
Shelburne	147	1260	5.9	37	308	1.4	43	207	1.0	157	5448	25.4	32	13579	63.3	30	640	3.0
Total	**609**	**3649**	**1.1**	**250**	**3871**	**1.1**	**431**	**2097**	**0.6**	**1620**	**44588**	**13.1**	**417**	**276215**	**81.4**	**484**	**8889**	**2.6**

Using GIS techniques and a suite of bio-physical indicators, Greenlaw (2009) classified over 4000 km of the coastline of Nova Scotia into three categories: inlet type, productivity regime (benthic, mixed and pelagic), and inlet complexity (simple, intermediate and complex). The three inlet types were classified as embayments (low freshwater input relative to their tidal volume and mid levels of exposure), estuaries (low levels of exposure and high freshwater input) and coves (mid levels of freshwater input and high levels of exposure). Greenlaw (2009) calculated that there were 137 inlets between St. Marys Bay and Chedabucto Bay. Of these, 41 inlets were embayments, 14 estuaries, and 82 coves (Figure 9a); 19 had benthic productivity regimes, 86 mixed productivity regimes and 32 pelagic productivity regimes (Figure 9b); 28 were simple inlets, 77 intermediate inlets and 32 complex inlets. Further, Greenlaw (2009) used fuzzy set membership to classify the bays according to their membership to each of these categories (Figure 9c). Coves with intermediate complexity and a mixed dominant productivity regime were most frequent in the classification.

Other classification systems are based on the distribution of habitats, individual species or community assemblages. Coastal wetlands (Hanson and Calkins 1996) and shore and seabird colonies (Lock et al.1994) have also been described and mapped. Estuarine flats are the most common wetlands along our coast (Table 4). As a proportion of area, estuarine flats and saline ponds are most common in Zone 1 (Cape Breton), while islands make up more of the coastline in Zone 2 (Eastern Shore) than any other area. Salt marshes are the most common wetlands in Zone 3 (South Shore).

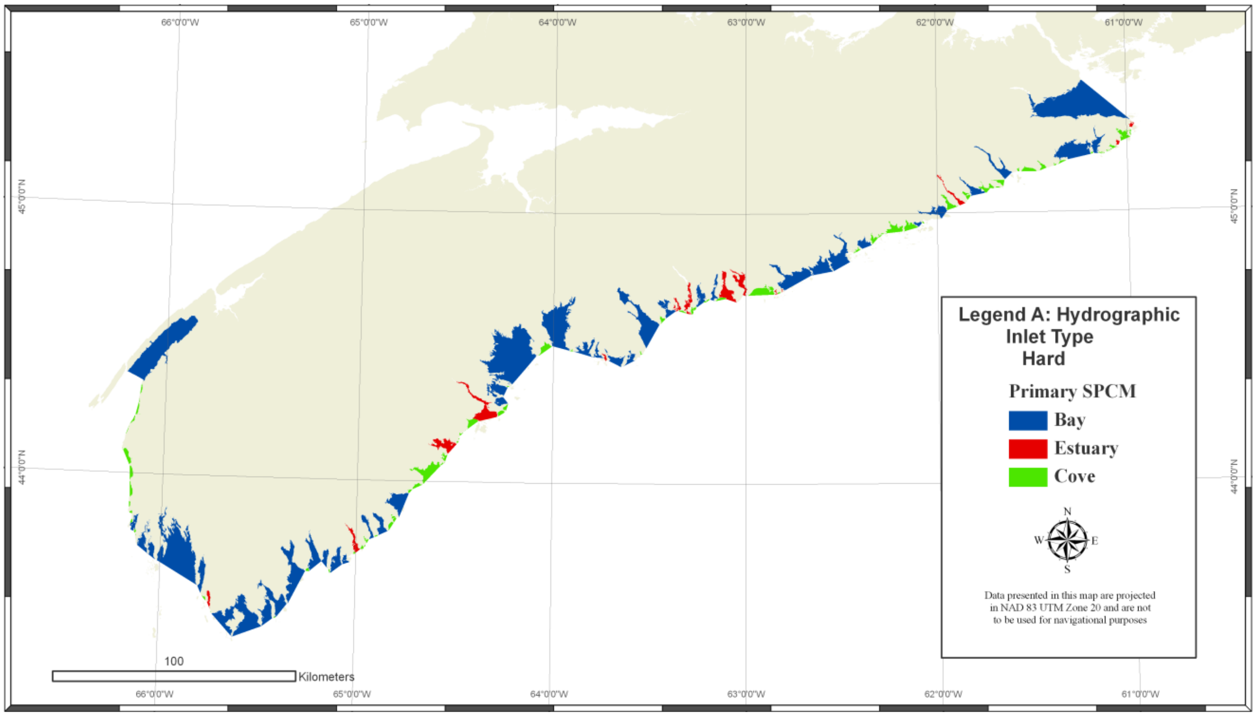

Figure 9a. Classification of inlets into bays, estuaries or coves (Greenlaw 2009).

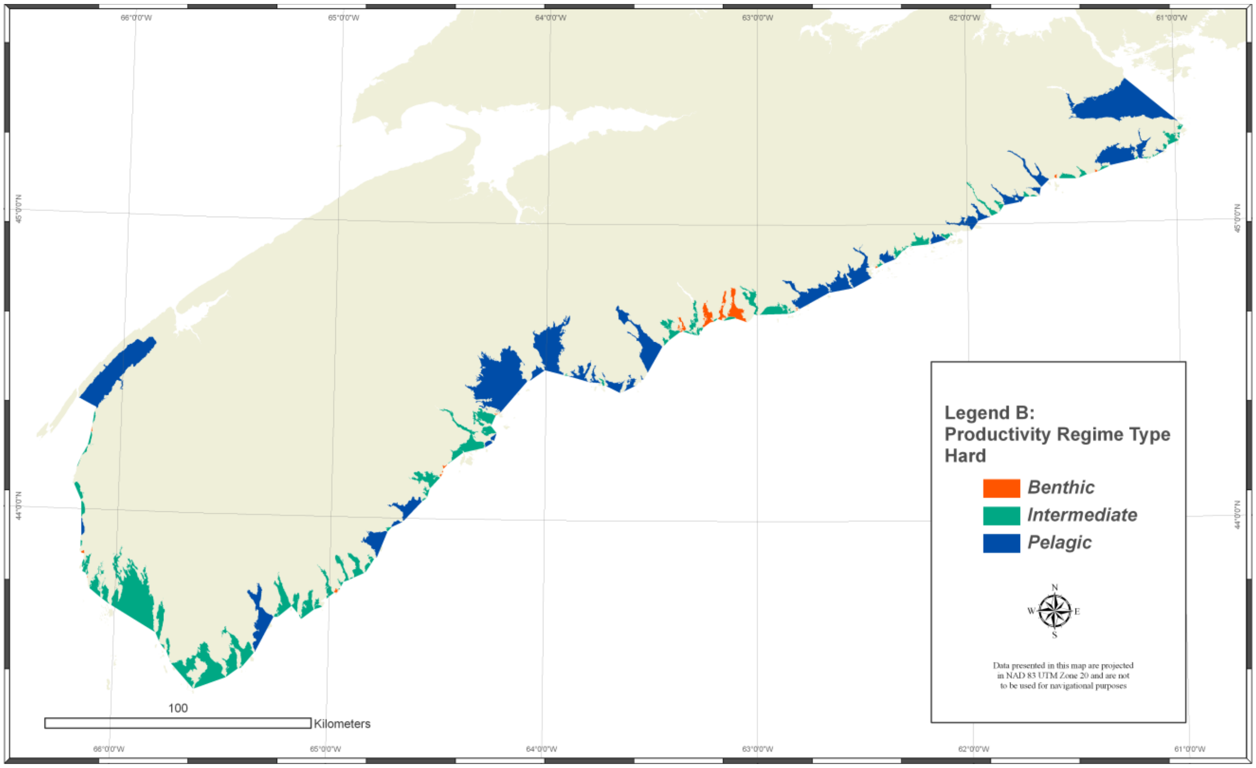

Figure 9b. Classification of inlets into benthic, mixed or pelagic productivity regimes (Greenlaw 2009).

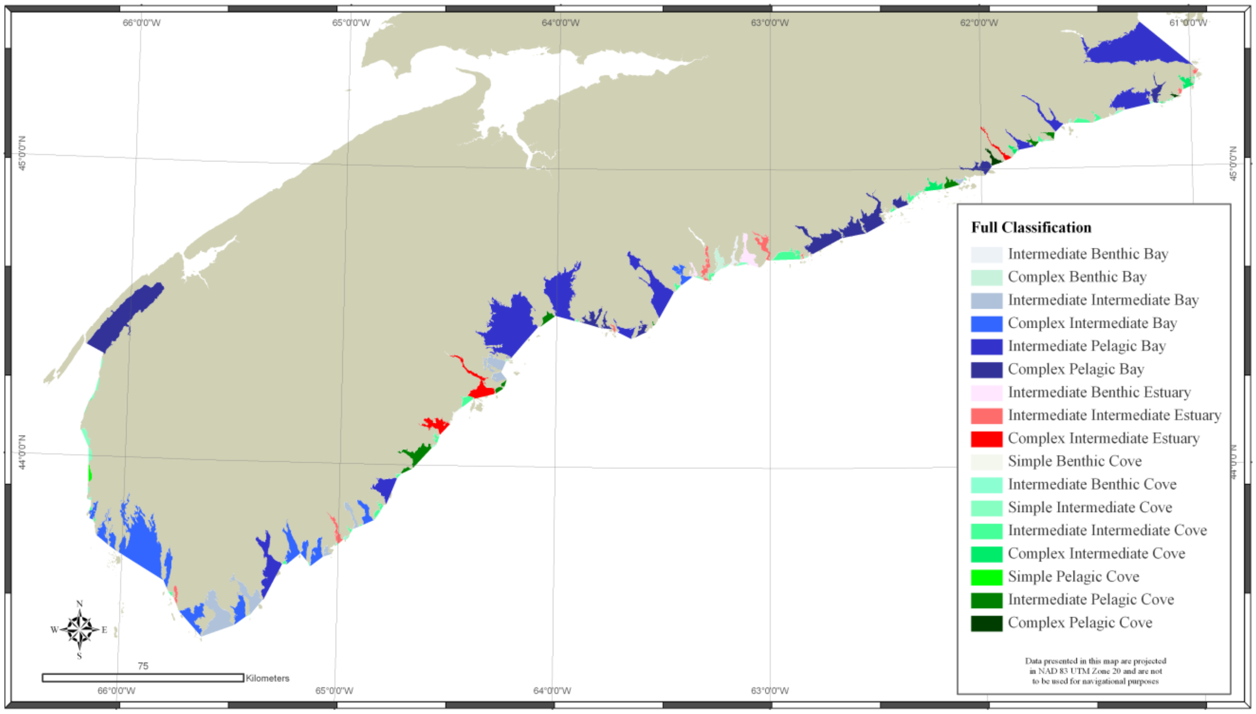

Figure 9c. Classification of inlets by complexity and type of productivity regimes (Greenlaw 2009).

4.1.1. Types of Shoreline

The marine environment may also be described as a collection of habitats such as rocky exposed shore, pebble, cobble or sand beaches, salt marsh, eelgrass, mudflats, and estuarine habitat (Hardy and Associates 1984, Davis and Browne 1996a). Sediment type and exposure of the coast to open ocean and orientation with respect to prevailing winds define the physical energy of these habitats.

4.1.1.1 Rocky Exposed Shore

Most of the exposed shoreline in Inshore Scotian Shelf is resistant bedrock (e.g. granite, quartzite) that erodes slowly and has a steep gradient. In areas where the bedrock is sedimentary, erosion results in a gently sloping coastline. Only 26% of the Atlantic coastline is open coast, but 82% of the rocky habitat is on open coast (Moore and Miller 1983). The common seaweed species on the exposed rocky coast are the kelps *Laminaria longicruris, L. digitata, Sacchorhiza dermatodea*, and *Agarum cribrosum*. Rockweed (*Fucus spp*) and Irish Moss (*Chondrus crispus*) occur most commonly on the Cape Breton coast, although between Mira Bay and the Great Bras d'Or Channel, the sandstone coast is less suitable for attachment of seaweeds. Much of the research in the rocky shore has focused on depth zonation of macrophyte communities and sea urchin grazing and the development of urchin barrens.

4.1.1.2 Beaches

Pebble and cobble beaches result mainly from the erosion of glacial till. These beaches are present along entire coast but are more prominent near drumlins (e.g. St. Margaret's Bay to LaHave). The drumlin erosion separates the till components (sand, mud, gravel and cobbles and boulders) and redistributes them according to wave and current energy; sand is generally transported to the relatively sheltered beaches and the adjacent deeper water. Neither pebble nor cobble supports seaweed in exposed areas, although in lower energy environments they can be stable and thus suitable substrate for encrusting algae, macrophytes and sessile invertebrates. Sand is highly unstable and supports little phytoplankton growth other than filamentous algae.

4.1.1.3 Mud Bottom

Mudflats form from the deposition of fine grained sediments in sheltered tidal water. They are usually associated with estuaries that have large sediment supply. However, on the Atlantic coast, the mud is also the result of the low-energy depositional component of the till erosion; that is, it is fed by constant erosion and accelerated by sea-level rise. Mud is common in the innermost harbours, but outside of the sheltered areas the mud occurs only in the deeper basins where it has collected at a diminishing rate since the sea-level low-stand between 10-15,000 years ago. Mudflats are generally more stable than sand and may have a film of diatoms and blue green algae, and the green seaweeds *Ulva* spp. and *Enteromorpha* spp. may also grow. In very sheltered areas mud can be anaerobic, but in more exposed areas may be well aerated and well drained.

4.1.1.4 Eelgrass

Eelgrass occurs in deeper waters on soft bottom, while chord grass can establish in more shallow waters. In sparse eelgrass beds, diatoms and filamentous algae may also contribute to primary production.

4.1.1.5 Tidal or Salt Marsh

Tidal marshes occur where sedimentation exceeds submergence, that is, in sheltered areas where mud and silt can accumulate (Figure 10). The accumulation of organic material in sediments can lead to anaerobic conditions, which limits the types of plants that can survive in this habitat. There is transition of plants with depth, as lower marsh plants experience distinct seasonal cycle with ice damage. Salt marshes play an important role in the life cycles of many species, including commercially important fish (Mann 2000; Section 11.2.5).

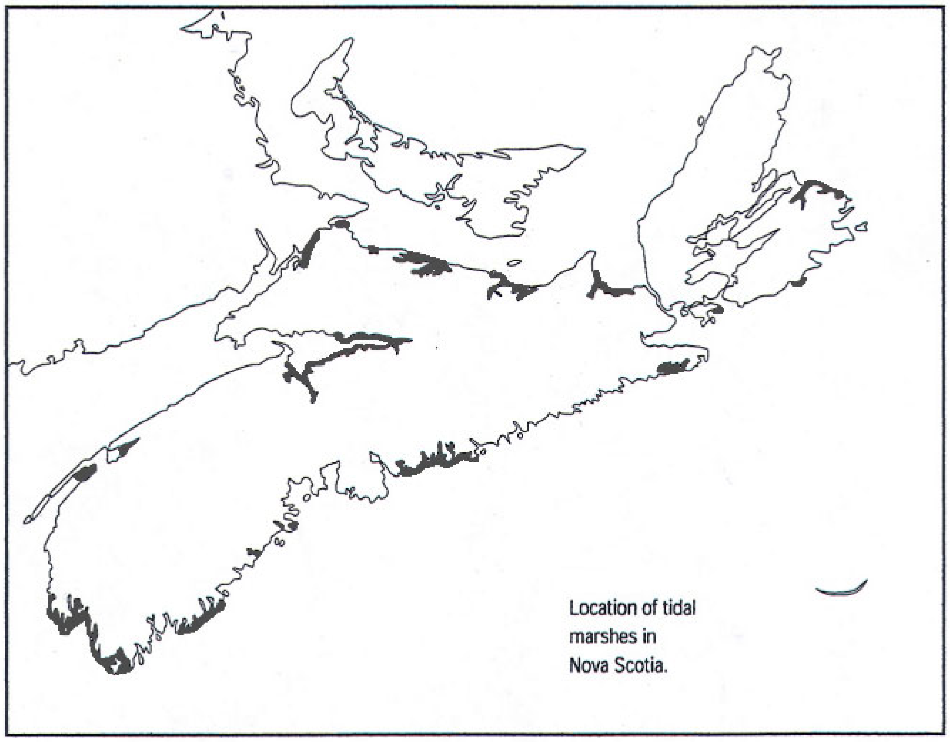

Figure 10. Location of tidal marshes in Nova Scotia (adapted from CBCL Limited 2009).

4.1.2. Coastal Erosion

Relative sea level has been rising and drowning the coastline of Nova Scotia for more than 10,000 years; it is not new. Shaw et al. (1993) provide an overview of the impacts of rising sea level during the Holocene, Late Holocene and past century. Just east of Halifax along the Eastern Shore, fragmentary evidence of former coastal environments have been found farther offshore. At about 10,000 radiocarbon years BP the average position of the coastline was 10 km seaward of its present location and by 5,000 years BP the shores were at 1.5 km. Therefore, shoreline retreat has decreased from about 2 m to 0.3 m per year (m/a). As sea level rose, it was like an erosional front passing over the outer coast into the bays and estuaries (Piper et al.1986; Carter et al. 1992; Forbes et al. 1995). Coastal retreat can often be counterbalanced by local shoreline stability or even progradation where relatively large volumes of sediment are supplied to the littoral zone either by erosion of glacial deposits or from the disintegration of older beach systems. A similar situation exits today tempered by human activities. The factors that have the most impact on the health and status of marine and coastal habitat are: (a) the continuity of barrier beach shores, their breakdown and leakage of sediment into the inner bays and estuaries; (b) large scale temporal variations in shoreline change at a given location and its evolutionary stage of development; and (c) human impacts on sediment supply and abundance and their interference with natural sediment pathways (see Section .4.4).

4.1.2.1 Shoreline Reformation and Continuity

Barrier beaches along Nova Scotia can be subdivided into a variety of types (Table 5) based mainly on their physical character, composition, sediment supply and abundance (Forbes et al.1990). Type 1 - prograded beach ridge complexes have in the past, or are presently, building seaward because of an abundant sediment supply. Type 2- high gravel barrier beaches and Type 4 and 6 - high sand barriers maintain a fairly stable position because waves and winds have built a higher beach crest on gravel barriers and a foredune on sand beaches which prevent waves from overwashing them. Sediment packages can vary slightly within each coastal compartment but there is little chance of significant sediment losses or transfers from a shoreline unless tidal channels or large wave overwash channels form. Tidal channels have more potential of cutting through sand than gravel barrier beaches because of their decreased barrier porosity. Type 8 - pocket beaches are also generally more stable because sediment is trapped in a small compartment and the beach can only migrate slowly landward across a rising backshore. Physical changes are greatest along Type 3 and 7 - low barrier beaches because they are frequently overwashed by waves and cut by channels which promote the transfer of sediment landward into coastal ponds, lagoons and wetlands. Type 5 - drift-aligned shores, e.g. spits, are also more susceptible to shoreline retreat and breakdown as sediment supplies decrease and they become detached from their headland or bedrock anchors.

Table 5. Examples of beach types, their physical size and rate of change in seaward position since the 1980s. Rates of landward beach migration are least for pocket beaches and barrier beaches with a width >50 m, and a crest/foredune elevation >4 m.

Barrier Beach Type and Location	Barrier Width* (m)	Beach Crest / Foredune Elevation (m)	Rate of Beach Change (m/a)
Type 1 - Multiple Ridges Sh. Harbour, Aspy Bay	80 to 90	4.0	+ 0.4
Type 2 - High Gravel Miseners-Long Beach	28 to 37	3.3 to 4.5	-0.2 to -0.7
Type 3 - Low Gravel Cow Bay	11 to 36	1.9 to 3.9	-1.2 to -2.3
Type 4 – Sand Martinique	61 to 142	3.1 to 5.2	-0.0 to -0.3
Type 5 - Drift-aligned St. Anns	34 to 90	2.2 to 3.5	+ 0.4 to + 1.0
Type 6 - High-mixed Lawrencetown	44 to > 60	4.4 to 6.2	-0.2 to -1.9
Type 7 - Low-mixed Hirtles	> 48	3.4 to 3.9	-0.2 to -0.4
Type 8 - Pocket Beach Arties Cove	25	4.5	-0.02
Type 9 - Artificial Crescent	37 to 51	3.4 to 6.7	-0.2

* Barrier width where beach intersects 1 m elevation.

Type 3 - low gravel barrier beaches can migrate hundreds of metres landward in a span of 50-70 years through a rollover process where waves overwash the barrier transferring sediment from the ocean to landward side of the barrier. Much of the beach sediment is reused and transferred landward in the cyclic reformation and breakdown of the beach. Therefore human-built structures which interrupt natural sediment pathways should be discouraged. Rates of complete barrier beach rollover recorded along the Eastern Shore ranged from 23 years at Cow Bay Beach to four beach rollovers in 13 years at the mouth of Chezzetcook Inlet. Rollover accelerates with time as the sediment core of the beach becomes more mobile and less compact. As the barriers migrate landward, soft lagoon muds become squeezed out by the weight of the beach moving across it and dispersed by wave motion. Compacted estuarine mud is all that remains seaward of these barrier beaches (Figure 11). The mud substrate is cut back by breaking waves forming pits and large craters which become new fish habitat. With time the craters are infilled by sand and gravel carried seaward from the mobile barrier beach. The low barrier beaches can become stalled in their landward migration if they become flattened by waves to below high tide level. They then become a coarse sediment shoal only exposed at low tide (e.g. Figure 2, year 2000). Loss of a barrier beach above high tide causes less protection to inner shores from waves and initiation of shore erosion.

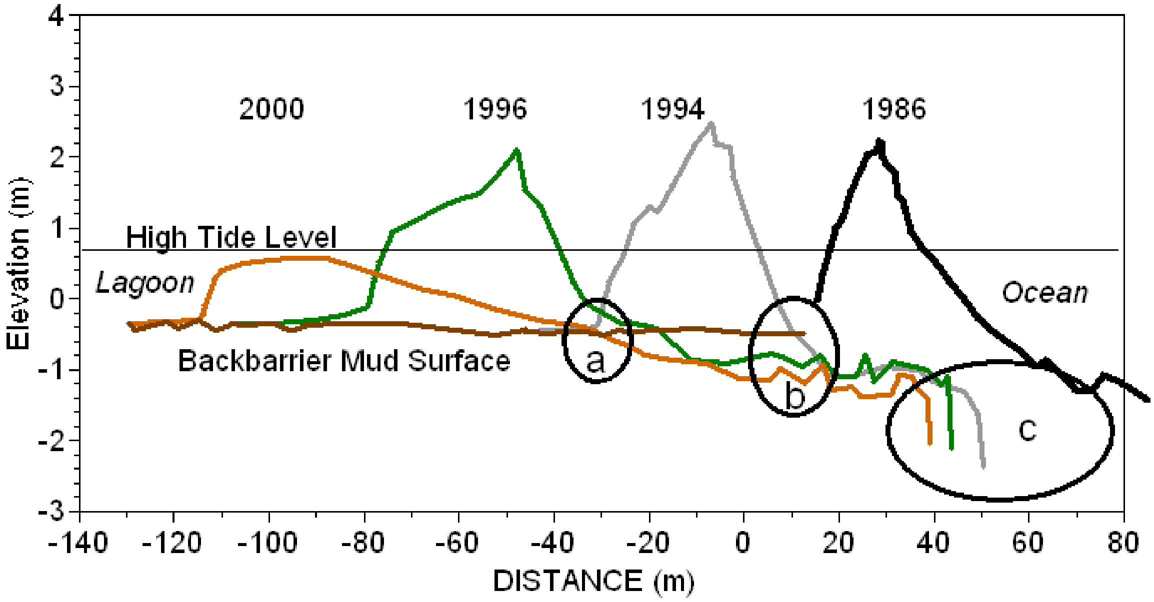

Figure 11. Sequence of Type 3 barrier beach landward migration at the mouth of Chezzetcook Inlet showing the net loss of soft estuarine mud between 1994 and 1996 (a-b) where the beach/mud surface intersects the ocean and the development of a crater (c) forming new habitat just offshore where the beach existed in 1986.

In contrast, the landward migration of sand and mixed sand and gravel barrier beaches is through the intermittent formation of wide, wave overwash channels. The landward thrusts are a natural mechanism for widening beaches over a period of 5-10 years so dune building can resume (Taylor and Frobel 2003). Sediment used to rebuild the backshore is derived from adjacent shores which weaken them and make them more susceptible to the next landward thrust. This natural sequence allows the barrier beaches to retreat landward and maintain their swash-alignment. Localised changes across the barrier beaches provide opportunity for some biological species such as

Piping Plovers but may result in the loss of other species buried by the washover and new dune deposits within the inner estuary.

In Aspy Bay, Cape Breton Island, two shore cliffs measured from 1991-1998 lost a maximum of 5.5 m of cliff top and the mean rate of cliff top retreat was 0.5 m/a (Table 6). In the early 1980's the rate of retreat along a low till cliff increased to 1.9 m/a over a three year period. Large sand barrier beaches at the head of Aspy Bay vary from a single dune ridge across North Harbour to a wide barrier with more than 30 beach ridges across South Harbour (Taylor et al.1991). Although not the only source of sediment, shore cliff retreat has contributed to beach building and the accumulation of sediment off South Harbour where the beach is prograding (Table 5) and the tidal channel into the harbour is frequently closed off. The closures negatively impact water circulation and salinity in the harbour and the local oyster operations (A. Dunphy, pers. comm.). Maintaining tidal circulation into bays and estuaries and safe passage of fishing vessels into community harbours is an ongoing issue, particularly where the coastal compartments narrow requiring less sediment reserves to rebuild a shoreline as it retreats landward.

4.1.2.2 Temporal Shore Changes / Evolutionary Stages

Shorelines do not always erode or change at the same rate over time because of changes in their physical conditions or changing processes which in turn can be triggered by changes along adjacent shorelines. Shoreline changes measured at decadal intervals along shore cliffs and barrier beaches since the first vertical air photos in the 1930's illustrate the magnitude of temporal variations that can occur at the same shores (Figure 11). Landward barrier beach migration ranged from less than 2 to 15 m per year and shore cliff retreat varied from less than 0.3 to nearly 13 m per year (Covill et al.1995). These large scale differences in shoreline change occurred within a small geographic area at the mouth of Chezzetcook Inlet.

Drumlin headlands are a finite length and increase in elevation toward their centre. It was found that cliff retreat was fastest in the early and late stages of the drumlin erosional cycle. Rates of shore cliff retreat were commonly less than 3 m/a and could be more than 10 m/a in the early and late stages of retreat and less than 1 m across the higher mid-sections of a drumlin (Table 6). The abundance of boulders in a cliff was also important. A high abundance contributed to the build-up of a natural boulder ramp along the base of the cliff which protected the cliff from wave attack. Cliff retreat was also slowed or halted where a foreland develops in front of a cliff, e.g. Lawrencetown Head. During the period 1981-2007 field measurements of till cliff retreat along the Eastern Shore varied from a maximum of 0.3 m/a to 9.9 m/a (Table 6). Excluding one rapidly eroding site, which was in an early phase of retreat, the mean and maximum rate of cliff top retreat for the remaining sites was only 0.3 and 0.8 m/a, respectively.

Table 6. Shore cliff (till) erosion rates observed within the study area since the late 1970s.

Location (no. of sites)	**Time Interval (no. years)**	**Max. Retreat Distance (m)**	**Erosion Rate (m/a)**	
			mean	**max.**
Aspy Bay (1)	1980-83 (3)	5.0	1.3	1.9
Aspy Bay (2)	1991-98 (7)	5.5	0.4	0.9
Louisbourg Outer (9)	1995-05 (9)	5.3	0.2	0.9
Louisbourg Harbour (2)	1995-05 (9)	4.2	0.3	0.5
Kennington Cove (3)	1995-05 (9)	0.7	0.0	0.1
SE. Cape Breton Is (4)	1992-01 (9)	2.2	0.2	0.4
Chedabucto Bay (1)	1981-98 (17)	3.2	0.2	0.2
#Eastern Shore (8)	1980-06 (26)	12.6	0.3	0.9
*Eastern Shore (1)	1988-05 (16)	71.0	4.4	9.9
Blandford Head (1)	1976-92 (16)	4.4	0.1	0.3
Hartling Bay (1)	1986-07 (21)	6.3	0.3	0.5

Note: Erosion of drumlin cliff site in early (*) and mid phase (#) of life span.

With rising sea level, shores at the mouths of larger bays and estuaries are reshaped and rearranged which can impact wave propagation into the bays. Sediment eroded from the outer shores attaches to and between closely spaced drumlin islands within the bays forming new beaches and tidal flats, e.g. Mahone Bay, Chezzetcook Inlet. Wave attack is focussed on the drumlin headland and sediment is swept along the sides and back of the headland creating pathways for further sediment transport landward. Many shores are left with submerged shoals perpendicular to the coastline which can impact both sediment transport alongshore and onshore offshore.

Louisbourg is an example of how changes at Rochfort Point, at the mouth of the harbour, impacted an inner harbour. Retreat of shore cliffs and shorelines along Fortress of Louisbourg National Historical Site are of great concern because of the loss of archaeological resources and a protective buffer for park infrastructure. Shore cliffs surveyed were less than 10 m elevation. From 1995 to 2005, maximum cliff top retreat was 5 to 5.3 m along the outer coast near the Fortress and within the wave-exposed parts of the harbour. However when retreat rates are combined for all other cliff sites, the loss was much less. Mean and maximum retreat rates were only 0.2 m/a and 0.4 m/a, respectively, and even less along Kennington Cove (Table 6).

4.1.2.3 Global Warming

Sea level rise as a result of global warming is predicted to have a major impact on the Atlantic coastline. Rising sea level will result in more coastal erosion as storm surges will inflict greater damage. An additional concern in Cape Breton is that the extent and duration of sea ice will be reduced as the climate warms, thus allowing storms to flood and erode the coast more frequently. Most of the coastline in the Inshore Scotian Shelf has been assessed as highly sensitive to the expected sea level rise (Figure 12; Shaw et al. 1998). This assessment is based on a sensitivity index describing the impact of the expected sea level rise on seven variables: relief, geology, coastal landform, sea-level tendency, shoreline displacement, tidal range, and wave height.

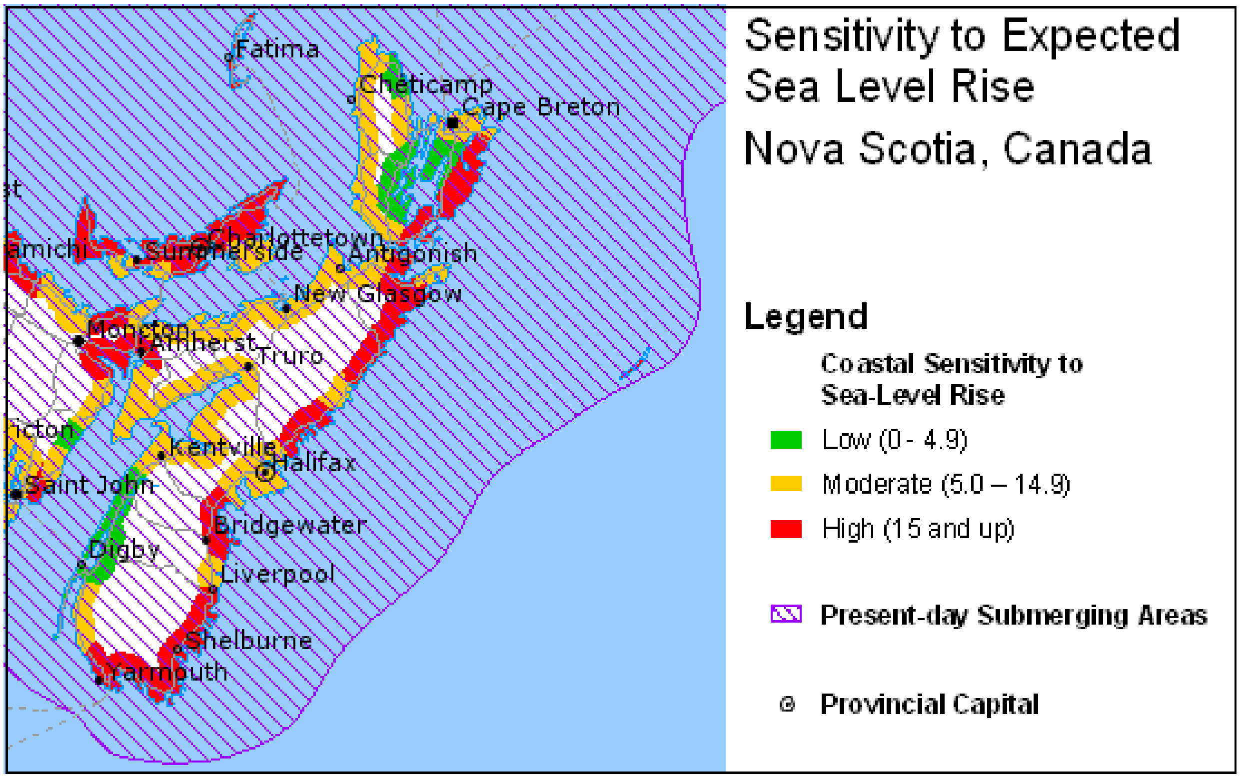

Figure 12. Sensitivity of the coastline to the expected rise in sea level. Sensitivity is defined as the degree to which a coastline may experience physical changes such as flooding, erosion, beach migration, and coastal dune destabilization. Also shown on this map are the expansions of the submerging areas.

4.2. Hydrography and Watersheds

Nova Scotia has a temperate climate, with an average annual precipitation of 1300 mm (Davis and Browne 1996a, see Section 6.a.ii). Eight of the province's eleven monitoring sites for stream water flow are located in watersheds that drain into the Inshore Scotian Shelf (Davis and Browne 1996a). The mean monthly discharge plots for these stations show high sustained flow during the winter months, with maximum flow in April, and low flow from June to September.

A watershed refers to the land area from which surface water (plus sediments, nutrients and contaminants) drains into a common stream, river and ultimately into the sea. This land area can include all water and water-dependent land features, such as wetlands, forests and towns[1].

The system used to classify watersheds in Canada was developed by the Water Resources Branch of the Water Survey of Canada (formally known as the Dominion Water Power Branch of Canada, Department of the Interior) in 1914. The classification system was designed for the storage of such information as the location of waterpower sites, waterpower developments, storage reservoirs, stream measurement stations, and

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[1] For more information, see Davis and Browne (1996a) and http://www.gov.ns.ca/nse/water.strategy/resources.asp

meteorological stations. The system involved dividing and subdividing the country into suitably sized areas based on drainage .Under this classification system, Canada was divided into eleven major groups of river basins. The first three groups apply to eastern Canada: the Maritime Provinces were assigned to Group 1; the watersheds of the St. Lawrence River were assigned to Group 2 - the island of Newfoundland was also assigned to Group 2 after joining Canada in 1949; and all the rivers in Quebec and Labrador draining into Hudson Bay and the Labrador Sea, were assigned to Group 3. These river basins were then further divided into sub-groups, which were designated with letters[2].

The Maritime Provinces (Group 1) were divided into the following three sub-groups: 1D, which represents all mainland watersheds draining into either the Bay of Fundy or the Northumberland Strait; 1E, which represents all mainland watersheds draining into the Atlantic Ocean; and 1F, which represents all watersheds on Cape Breton Island.

Sub-groups (e.g., 1D, 1E, and 1F) were then further divided using additional letters and numbers to designate primary, secondary, tertiary, and sub-tertiary watersheds[3]. The original coding and river allocations for primary watersheds in Nova Scotia were conducted by the Maritime Resource Management Service for the Department of Environment in 1981[4]. This classification system is still in use today. Under this classification system, there are 250 secondary watersheds in Nova Scotia (Appendix A), which are grouped into 45 primary watersheds (plus Isle Madame and Missaguash River at the Nova Scotia/New Brunswick border). Of the 46 primary watersheds in Nova Scotia, 23 have drainages that flow into the Atlantic Ocean within the study area (1EB to 1ER, 1FA, and 1FD to 1FJ[5]) and comprise roughly half of the area of Nova Scotia (Figure 7). The two largest primary watersheds in the province are 1ED (which contains the Mersey River) and 1FJ (which contains the Salmon and Mira Rivers) (see also Davis and Browne 1996, and CBCL Limited 2009). The ten largest secondary watersheds that drain into the Atlantic Ocean within the study area include the Mersey, LaHave and Medway rivers (Figure 13, Table 7).

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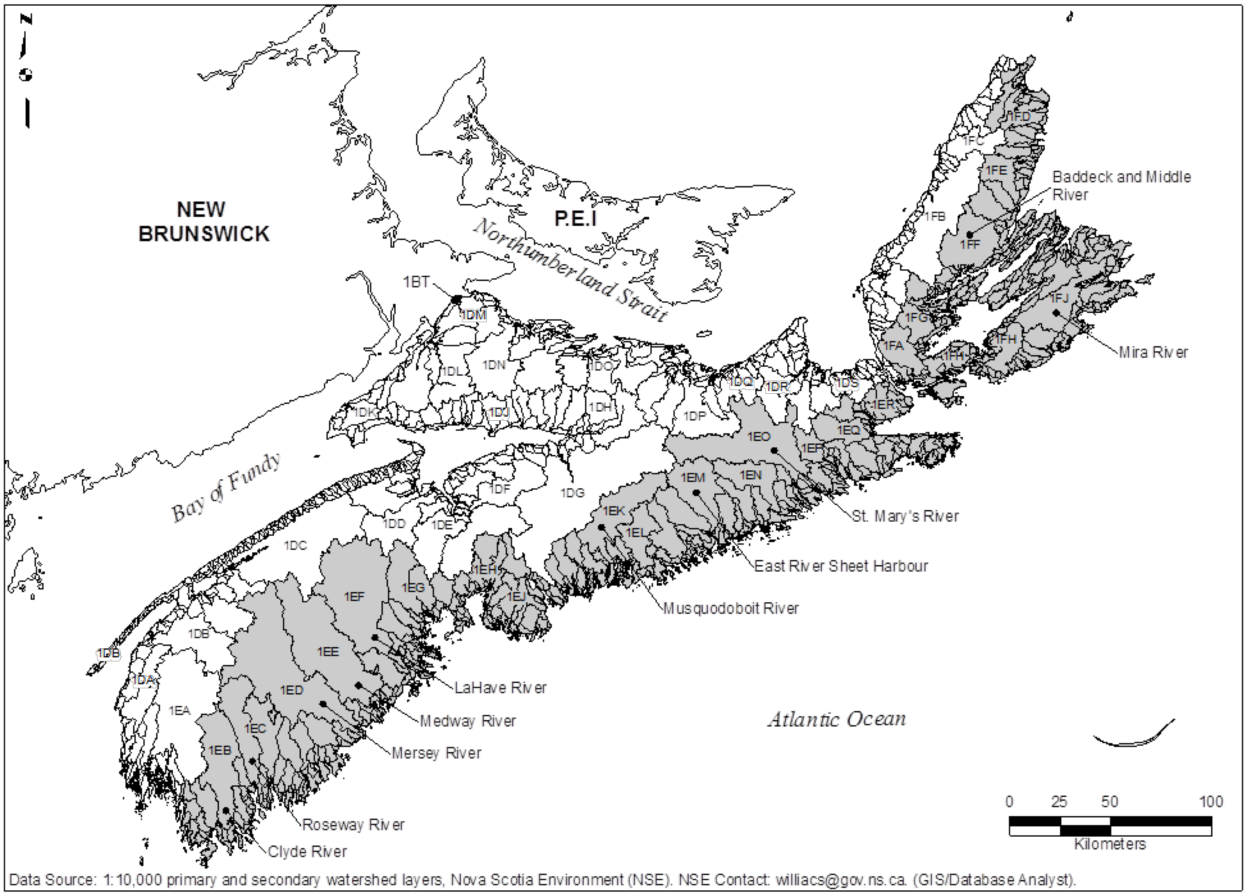
[2] See http://www.gov.ns.ca/nse/water.strategy/docs/WaterStrategy_NSWatershedMapExplanation.pdf

[3] See http://www.gov.ns.ca/nse/water.strategy/docs/WaterStrategy_NSWatershedMapExplanation.pdf

[4] See http://www.gov.ns.ca/nse/water.strategy/docs/WaterStrategy_NSWatershedMap.pdf

[5] 1EA is not included, as it is not within the study area for this report. A portion of 1FA is included as it drains into the Atlantic Ocean. The remainder of 1FA that is not included drains into the Gulf of St. Lawrence or the Strait of Canso.



Data Source: 1:10,000 primary and secondary watershed layers, Nova Scotia Environment (NSE). NSE Contact: williacs@gov.ns.ca. (GIS/Database Analyst).

Figure 13. Primary and secondary watersheds of Nova Scotia. Adapted from Natural History of Nova Scotia. Map provide by Alex Levy, Fisheries and Oceans Canada.

Table 7. Top ten secondary watersheds in Nova Scotia that drain into the Atlantic Ocean within the Study Area.

Secondary Watershed	**Area (km^2)**	**Primary Watershed #**
Mersey River	1936	1ED
LaHave River	1524	1EF
Medway River	1519	1EE
St. Mary's River	1337	1EO
Clyde River	777	1EB
Musquodoboit River	719	1EK
Baddeck and Middle River	618	1FF
Mira River	605	1FJ
East River Sheet Harbour	577	1EM
Roseway River	550	1EC

The inshore areas of the ocean can be affected by activities that occur in the watershed. Terrestrial vegetation can influence export as well as the capture of atmospheric contaminants and nutrients (Carpenter et al.1998). Increased nutrients, specifically nitrogen, can lead to eutrophication in coastal waters that may result in hypoxia and harmful algal blooms (Section 8.5). Dissolved organic carbon (DOC) also plays an important role in a number of ecosystem processes (Section 8.4). Clair et al. (1994) developed models to predict DOC export from the watershed area, slope and local precipitation. Arguably, slope is a surrogate variable that may be representing the importance of wetlands or soil carbon to nitrogen ratios (Aitkenhead-Peterson et al. 2005), which itself may be integrating a number of watershed characteristics.

Detailed analysis of watersheds along the Atlantic coast, including a summary of the land use, terrestrial vegetation, soil type, fire history as well as population and industrial development could help predict the export of sediments, dissolved organic matter, nutrients and pollution. Recently, the Nova Scotia Watershed Assessment Project, a joint project between the Nova Scotia Department of Natural Resources and Dalhousie University, has conducted an initial assessment of the watersheds of Nova Scotia.[6]

4.3 Bathymetry and Seascapes

While coastal wetlands can be classified from aerial photography (Hanson and Calkins 1996), a systematic survey of the subtidal zone is more challenging. Moore and Miller (1983) present the largest systematic survey of hard bottom. Their transect survey relied on SCUBA diving to document the distribution of macrophytes, fish and invertebrates. Further, photography and video surveys are also used to assess the benthic habitats and communities. Most of the research conducted with underwater video on the Scotian Shelf is in waters deeper than the scope of this EOAR, but there are a large number of videos of various sites associated with impact assessment in the marine environment and video from six bays collected as part of the DFO/FSRS Inshore Ecosystem Project (Heyer 2007). There have also been periodic studies of fish and invertebrates in the inshore that rely on trap and trammel nets (for review see Hardy and Associates 1984) and bottom trawl (Simon and Campana 1987).

Remote sensing technologies are currently being validated and used to map macrophyte distribution in the very shallow water (Theriault et al. 2006). There are also a number of tools such as multibeam bathymetry, sidescan sonar and seismic mapping that are currently being used for high-resolution remote mapping of the ocean floor (Figures 5, 9). Some of this technology, specifically multibeam bathymetry, has been developed in Nova Scotia (Courtney 1993, Courtney et al. 1993, Courtney and Fader 1994). The advantages of technology include 100% coverage of seabed morphology, portrayal of subtle aspects of deposition and erosion, and details on the seabed texture, roughness and lithology at a large enough scale to provide data for the interpretation of regional processes (Section 3.1). In addition to providing important information on marine sediments to understand the geology, these technologies can also be used to map living marine resources such as scallops and lobsters (Smith et al. 2009; Tremblay et al. 2009a), and to plan aquaculture sites and other coastal development (Pickrill and Todd 2003).

4.4. Human Impacts on Geomorphology

4.4.1. Sediment Extraction

One of the greatest human impacts on shoreline stability over the past 50 years is beach sediment extraction which has removed reserves of sediment built up over hundreds and possibly thousands of years. The removal of sediment and more importantly the coarse core of many beaches resulted in large scale readjustments and retreat of the impacted and adjacent shores. The best documented case is at Silver Sands Beach (Cow Bay Beach) near Halifax, but a similar situation arose along many shores near Sydney as well (Bowen et al. 1975). Many of the changes we observe today along barrier beaches are the consequence of this sediment depletion. Sediment extraction still occurs along the backshore along some shores, e.g. Cap

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[6] http://www.novascotia.ca/nse/water.strategy/docs/Nova.Scotia.Watershed.Assessment.Program_Part-A_Phase-1_Summary.Report.pdf

Ronde, Isle Madame. Excavations of large pits across the backshore are naturally refilled as storms push the beaches landward, which further depletes the sediment available for beach building.

4.4.2. Coastal Development

Removal of small cottages and replacement by large permanent homes, and increased residential development, especially along the South Shore and near Halifax, has resulted in the construction of shore protective structures. Such structures protect the backshore but reduce the natural supply of sediment to adjacent shores and marshes. Similarly, the construction of causeways across water bodies can also interrupt sediment pathways and accelerate local sediment deposition at the causeway. Barrington Passage is an example. Highways crossing the back of barrier beaches slow the natural landward migration of beaches and the natural coastal succession into bays. The rebuilding of barrier beaches using an armour stone core buried by local beach sediment is a new technique being tested at the mouth of Ingonish and Pictou Harbours. The structures reduce shoreline erosion and protect inner bays but alter the natural coastal succession. Another activity that is common in Nova Scotia is the artificial dredging of barrier beaches to alleviate flooding of roads along inner ponds and lakes. The full impacts of this activity are unknown but it does have an impact on barrier beach stability and the transfer of sediment into the lake. It is unknown whether the openings exist long enough to impact the passage of migratory fish or other marine species.

4.4.3. Dredging

Harbour dredging and marine disposal of spoils is a common phenomenon. Natural Resources Canada has observed evidence of either or both practices in Shelburne, Liverpool, Lunenburg, Halifax, and Canso. These are wharf and nearshore operations, mainly for safe navigation and generally involve muds. Spoils are generally dumped locally, usually beyond the harbours but within the headland areas. They typically involve several tens of thousands of cubic metres. It is likely most harbours and ports have seen some form of dredging activity in the past (E.L. King, pers. comm.). The dredge spoils are commonly transported offshore (Parrott 2000).

4.4.4. Trawl Marks

Trawl marks are recognized from sidescan sonograms in a wide range of water depths. Individual drag marks are very common across most of the offshore muds in waters deeper than about 80 m. These represent the cumulative total of occurrences as their healing/infilling is anticipated to be at very low rates in this area of low sedimentation rate. Some areas are so trawled as to have left little area untouched. Sometimes hydraulic, otter, or scallop trawl marks can be differentiated.

5. SEDIMENTOLOGY

Contributed by T. Milligan

Sediment is one of the most fundamental factors affecting habitat and habitat utilization in the coastal zone. Sediment texture largely controls the flora and fauna that inhabit the benthos by providing structure and refuge, and for many organisms, food. Sediment in suspension limits light transmission and in some instances provides protection for the larval stages of some species. Sediment transport and deposition represents a critical part of the natural evolution of coastal environments but is sensitive to perturbations whether natural or as a consequence of development.

The transport and deposition of sediment is controlled primarily by turbulence and particle flocculation. Sediment eroded from land masses is transported by rivers and streams to the coastal zone where it can eventually deposit and accumulate. For coarse-grained sediment (medium silt and larger), erosion and sedimentation are directly linked to the overall energy of the environment. In simple terms this means that the greater the energy the larger the particle which can be transported. The erosion, deposition, and transport of mud are fundamentally affected by the tendency of fine sediment particles to clump into large agglomerations of particles called flocs. For fine-grained sediments the formation of these large, fast sinking particle aggregates effectively increases the settling velocity of the constituent grains by up to several orders of magnitude, confounding the simple relationship to turbulence.

The formation of flocs in a suspension depends on the collision rate of particles, the likelihood that particles remain attached after collision, and the rate at which the flocs are broken up by turbulence. Flocculation rate increases with particle concentration due to higher probability of contact. It also increases with higher sticking efficiency resulting from, for example, the excretion of long chain polysaccharides by diatoms. Up to a certain level of turbulence, aggregation processes are favoured due to increased particle encounter rate, but once that level of turbulence is exceeded, floc breakup by energetic shear will occur. Floc size, and therefore the settling velocity of fine particulate material, is controlled by concentration, turbulence and particle composition. Changes to any of these controlling factors will have an immediate effect on the transport and deposition of sediments that can lead to habitat alteration.

An abrupt change in sediment texture from well sorted sands to poorly sorted mud is a feature found on most continental margins. The depth of this boundary scales with wave energy and represents the transition between floc settling and settling by individual sand and silt sized particles. Seaward of the sand-mud transition, the accumulation of mud exceeds its removal by wave re-suspension. This change in sediment size and sorting makes the sand-mud transition an important ecological boundary.

5.1. Sources

The primary source of sediment is the erosion of land masses. The rate of erosion and the size of the material being produced during erosion are affected by the type of rock. Resistant granites tend to produce coarser grains than softer sedimentary material. Differences in resistance are reflected in the shape of shorelines with the less resistant coastline retreating more rapidly. Much of the Atlantic shoreline of Nova Scotia consists of unconsolidated glacial moraines (see Section 3) that are easily eroded, leading to rapid retreat and the formation of large amounts of sediment. The erosion of headlands often provides the source rock for the formation of barrier beaches, a common feature along the Atlantic Coast.

Estuaries are key sedimentary environments where river borne sediment undergoes rapid deposition when fresh and salt water meet. A decrease in turbulence leads to deposition of coarse material and the presence of salt initiates flocculation of the fine sediment. Coupled with estuarine circulation driven by the mixing of salt and fresh water, concentrations in suspension can get very high in a region called the turbidity maximum. The increased concentration in this region leads to enhanced flocculation that in turn helps to maintain this zone of highly suspended sediment. Due to lack of relief and glaciation, rivers in Nova Scotia tend to be small and do not have large sediment loads, compared to rivers such as the Saint John River which discharges into the Bay of Fundy, or the St. Lawrence River which discharges into the Gulf of St. Lawrence. Turbidity maxima are present but on a smaller scale than those found in areas of high sediment discharge.

Glaciation of Nova Scotia led to the formation of many fjords along the Atlantic Coast. These inlets are narrow and deep and often feature a sill that restricts exchange with the offshore. As a result, sediment grain size ranges from coarse at the river or stream mouth, to fine grained in the central part of the inlet to coarse again in areas exposed to waves from offshore. Within the inlets the sand-mud transition tends to be at shallow depths due to low wave energy in these protected environments. Offshore, the sand-mud transition on the high energy Scotian Shelf is at about 100 m depth.

Organic material provides a significant source of "sediment" particles. Although normally small and of low density, organic material can achieve high settling velocities due to its incorporation into flocs. Stickiness associated with bacterial degradation enhances flocculation making organic material one of the major components of muddy sediments. During the late stages of blooms phytoplankton undergo rapid flocculation increasing their settling velocity to the order of mm s^{-1} (Kranck and Milligan 1989; Cranford et al. 2007). In bays with restricted exchange of water, such as those with sills, the rapid flux of organic material to the bottom can lead to oxygen depletion.

5.2. Association with Contaminants

Trace metals and other surface-active contaminants can be found in areas where flocculated mud accumulates. The large surface area of fine particles, both organic and inorganic, and the coatings on them incorporate transition and heavy metals and several persistent organic compounds into flocs. Substantial contamination of sediments and biota is limited to Halifax and Sydney Harbours and the Strait of Canso with a few other isolated incidents of localized contamination. An illustration of the extent of metal contamination of sediments is shown in Figure 14. Industrial centers such as Halifax, Lunenburg and Sydney have localized areas of contamination some of which exceed levels of probable effects. Extensive surveys of contaminants have been carried out in Halifax Harbour (Winters et al. 1991) and Sydney Harbour (Stewart et al. 2001). In the mid 1990s, Loring et al. (1996) also mapped grain size and metallic contaminant concentrations for nine Nova Scotia inlets. The metals residing in the sediments within these and other inlets are composed of both naturally occurring metals and those from anthropogenic sources resulting from both past and present depositional conditions.

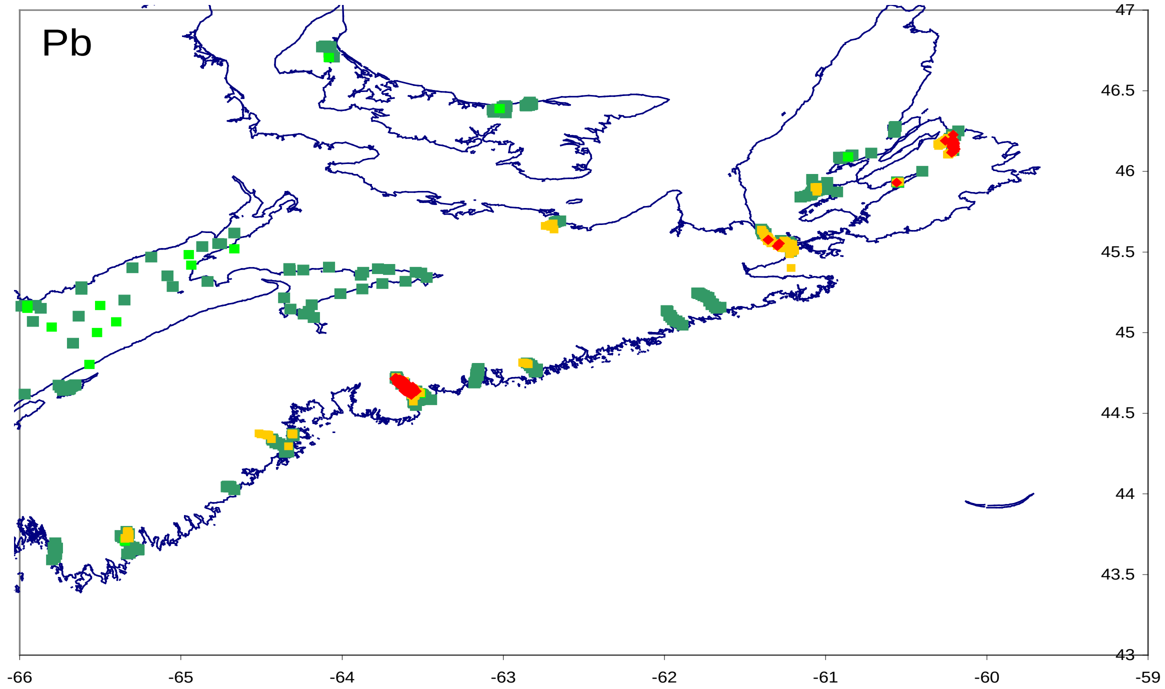


Figure 14. Traffic light Marine Environmental Quality (MEQ) map for lead in surficial sediments: dark green = background; light green > background but less than the Canadian Council of Ministers of the Environment threshold effects level (TEL); yellow > TEL and background, but less than the probable effects level (PEL); and red > PEL (Phil Yeats, pers. comm.).

Because of the relationship of trace metals and other surface-active contaminants with the surface area of particles, a method to discern natural levels from elevated levels is required. To assess the anthropogenic input the contribution of naturally occurring metals to the total content due to the textural and major element chemistry of the sediment must be determined. Elevated levels of metals can occur in areas where the source rock has high natural concentration. Normalization with lithium can provide a method to discriminate both qualitatively and quantitatively among contributions from natural and anthropogenic sources (Yeats et al. 2005).

5.3. Sediment and Light

Light penetration through the water column is a critical factor controlling biological processes in the nearshore due primarily to its influence on photosynthesis. Water clarity influences the behaviour of aquatic organisms that rely on visual cues for life processes and has a significant effect on the human perception of water quality. With the exception of waters with very high concentrations of coloured substances, sediment particles are the dominant influence on light transmission.

In the coastal ocean, optical properties change in response to both the concentration of suspended particles and their particle size distribution forced by particle aggregation and disaggregation. Aggregation and disaggregation rates depend on sediment concentration and turbulence in the water column, which in turn are functions of wave and current generated shear stress, the distance from the bottom, and water column stratification (Curran et al. 2002). Essentially, aggregation and disaggregation rates are controlled by sediment concentration and turbulence. When turbulence intensity is weak to moderate, concentration controls the degree of aggregation, with high concentrations associated with a high degree of packaging within flocs (Curran et al. 2002). Eventually, however, increasing turbulence causes disaggregation rate to increase to the point where it overwhelms the aggregation rate, and floc sizes fall abruptly (Hill et al. 2001; Agrawal and Traykovski 2001). Resultant changes in floc packaging affect fundamentally the optical properties of the water column. Flocs tend to remove small particles with high scatterance leading to greater light transmission. An analogy that can be used to explain the effect of flocculation on light transmission is the difference between rain drops and fog.

5.4. Issues

Sedimentation patterns in the coastal zone can be considered at an equilibrium between supply and removal. Alterations to this balance will inevitably lead to changes to the sedimentary environment and can lead to significant changes in habitat. One of the most obvious alterations is the creation of barriers such as causeways and breakwaters that change flow patterns and intensities. A decrease in wave height and/or currents leads to sediment infill and acceleration of currents or exposure to waves will result in the removal of sediment. The creation of stress refuges, areas where bottom stress is low, will result in infill, the rate of which will depend on sediment concentration. In the extreme, such as the Upper Bay of Fundy, rapid deposition can lead to the formation of fluid mud which can regulate the transmission of stress to the bottom leading to even greater accumulation.

Less well understood and often ignored in coastal planning is the effect of altering flocculation dynamics. Increasing fine grained sediment concentration, reducing turbulence or increasing stickiness can lead to rapid deposition of mud. In addition to the effect of barriers, land use practices such as clear cutting, the dredging of channels, and increased organic loading can all lead to changes in fine grained sediment dynamics. Increased sediment erosion in watersheds and along the coast can lead to the deposition of fine grained sediment in areas of sand and vice versa. Dredging of channels can affect sedimentation patterns by decreasing the flow velocity in the channel, increasing sediment concentration in suspension and depositing the spoils in areas of different grain size. In some areas this has lead to the unexpected rapid infill of the new channel leading to more dredging (Kranck and Milligan 1989). The introduction of organic material can lead to increased fine sediment deposition in areas of intense aquaculture

(Milligan and Law 2005). Alterations to fine grained sediment concentration and packaging also affect light transmission. This can lead to changes in both primary and secondary productivity. Although not always detectable as a change in the texture of the bottom sediment, transient accumulations of fine-grained sediment can alter benthic habitat by affecting the feeding efficiency of suspension feeding organisms (Wildish and Pohle 2005).

5.5. Resource Potential

Contributed by T. Worcester

Nova Scotia has a rich geological history. While this has led to prospecting and exploration for gold, iron, copper, coal and more recently coalbed methane (Figure 15), there has been only minor commercial exploitation of geological resources along the coastal zone of eastern Nova Scotia from Cape Sable Island to Cape North (sand and gravel extraction not discussed here).

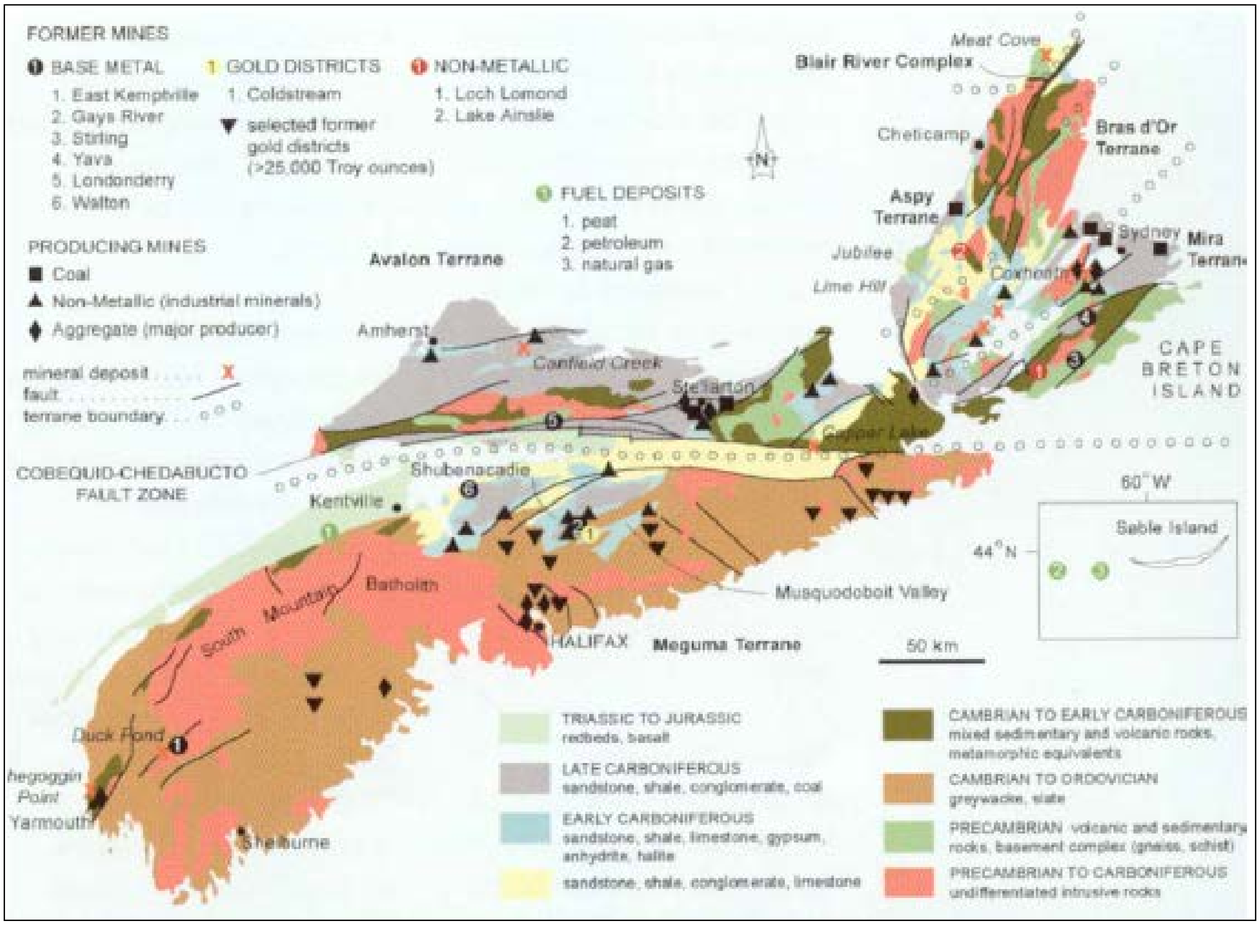


Figure 15. Simplified geological map of Nova Scotia showing locations of selected mineral, fuel deposits and former mines (NSDNR 1996).

The primary resource exploitation in the study area has been the development of coalbeds in Cape Breton, which began in the 1720s, declined in the 1960s, and was renewed with the development of the Prince, Lingan, and Phalen Mines from 1975 to 1995. Cape Breton Development Corporation's last underground coal mine (Prince Mine at Point Aconi) closed in 2001 (Nova Scotia 2001). At present, there are approximately seven privately-owned surface mines active in Nova Scotia, including a surface coal mine in Florence, Cape Breton (NSDNR 2006). Donkin Mine has received approval to reopen and continue exploitation of coal deposits that extend underneath the nearshore environment. Issuance of coalbed methane rights for the Donkin block offshore Cape Breton is also pending. Contact Exploration Inc, an Alberta-based company, has exploration rights for a license block that extends from the Canso Straight to St. Peters, including Isle Madame (NSDOE 2007; Figure 16).

Oil exploration in Nova Scotia has focused on the offshore environment, with successful development of oil and gas reserves on Sable Bank. The closest exploration wells to the study area were drilled by Shell in 1971 (Eurydice P-36) and by Murphy et al. in 1974 and 1976 (P-05 and F-24), but they found nothing of commercial interest (Figure 16). However, there has been some recent seismic exploration of nearshore areas around Cape Breton, and onshore activity appears to be increasing. No commercial discoveries have yet been made onshore Nova Scotia, but discoveries have been made in New Brunswick in similar geological formations.

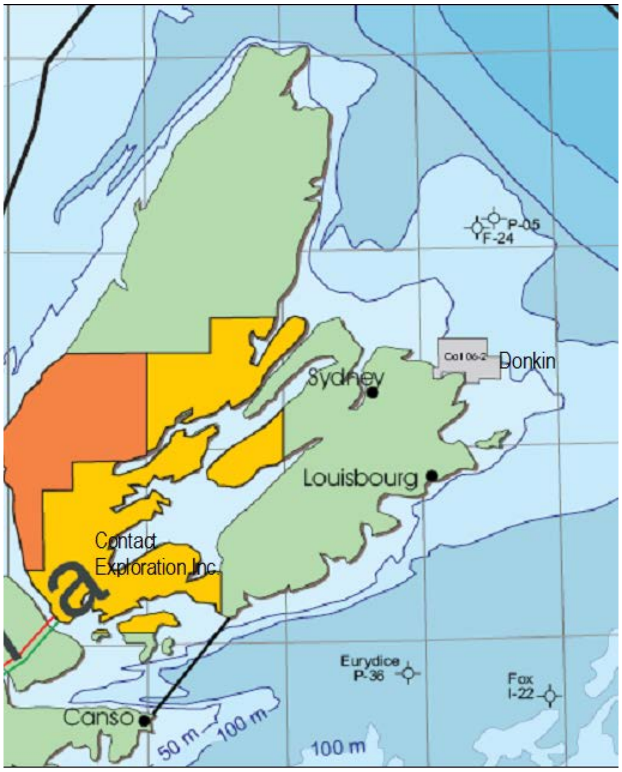


Figure 16. Energy exploration off Cape Breton (adapted from NSDOE 2007).

Additional geological resource exploitation in the study area includes an active gold mine in Port Dufferin (near Sheet Harbour along eastern Nova Scotia) and a limestone quarry in Kellys Cove (near New Campbellton, Cape Breton). Iron deposits have been found on Isle Madame, and several places in eastern Cape Breton (Manchester, Lynch’s River and near Louisburg). Copper has been found onshore in Chedebucto Bay.

PART B – OCEANOGRAPHIC SYSTEMS

6. ATMOSPHERE / OCEAN EXCHANGE

Contributed by G. Bugden

6.1. Seasonal Climatic Patterns

6.1.1. Air Temperature

Coastal Nova Scotia is subject to both continental air masses, which arrive from the west, and the maritime influence of the Atlantic Ocean. The region thus experiences rather wide fluctuations in air temperatures on a day to day and season to season basis. The annual average air temperature varies little from place to place, ranging from about 4°C to 8°C. The warmest season is usually from July to early August, while the coldest temperatures usually occur between late January and mid-February. In general, the greater the degree of oceanic influence, the less extreme the air temperature range. In other words, the interior regions of the province are generally warmer than the coasts in summer, while in the winter, the temperatures are somewhat milder near the coast than further inland. Fogs are frequent along the southeast coast, particularly in the spring and summer. Figure 17 shows the monthly average air temperatures from Sydney, at the northeastern end of the study area, and Yarmouth, at the southwestern end. Also shown in Figure 17 are air temperatures from Truro, an inland location, showing the cooler winters and warmer summers experienced away from the oceanic influence.

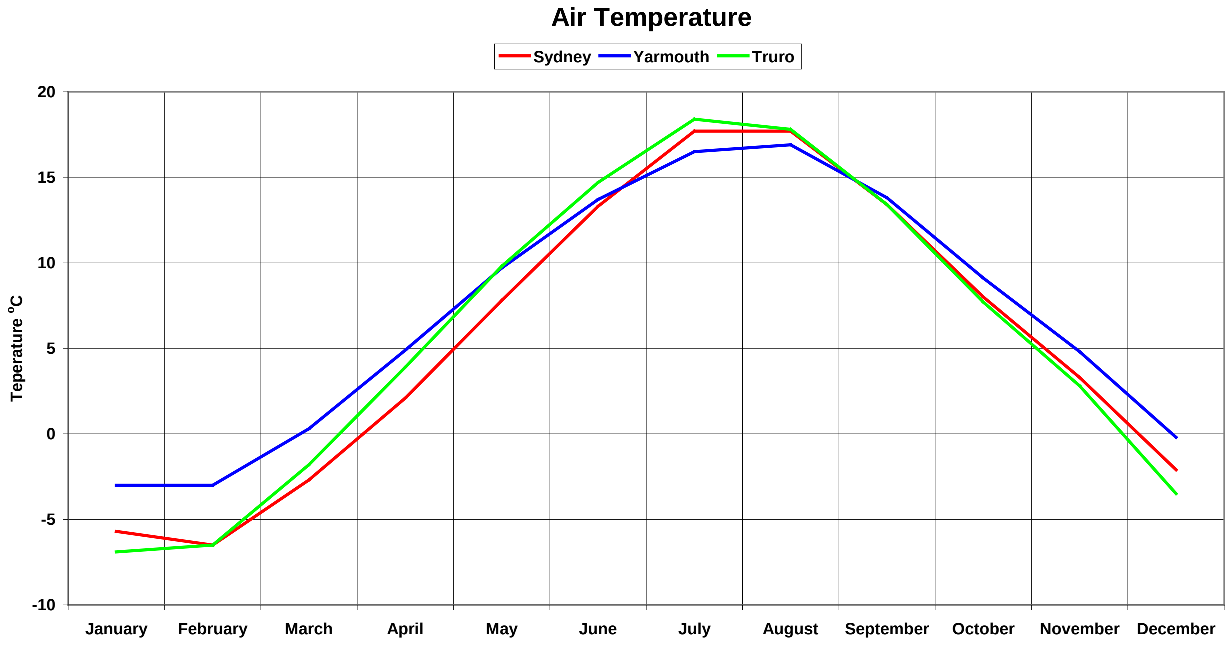


Figure 17. Air temperatures from Sydney, at the northeastern end of the region of interest and Yarmouth, just beyond the southwestern end. Also shown is data from Truro, an inland location.

6.1.2. Precipitation

Rain may occur in any month. The total annual precipitation (rain plus snow) ranges from about 1200 mm to 1500 mm. While snowfalls of small amount and brief duration are not unknown in October, the first significant amounts usually arrive between mid November and mid December. Precipitation occurs on the average of 150 to 160 days per year. Precipitation in excess of 25 mm per day occurs on an average of 12 to 17 days per year with exceptional falls usually associated with storms of tropical origin.

6.1.3. Prevailing Winds and Storms Tracks

Wind speed and direction, which influence currents and mixing in the inshore area, vary considerably throughout the year. In general, the prevailing wind direction is from the SW in summer and from the west (W) or northwest (NW) in winter (Figure 18). Wind speeds are generally greater in the winter.

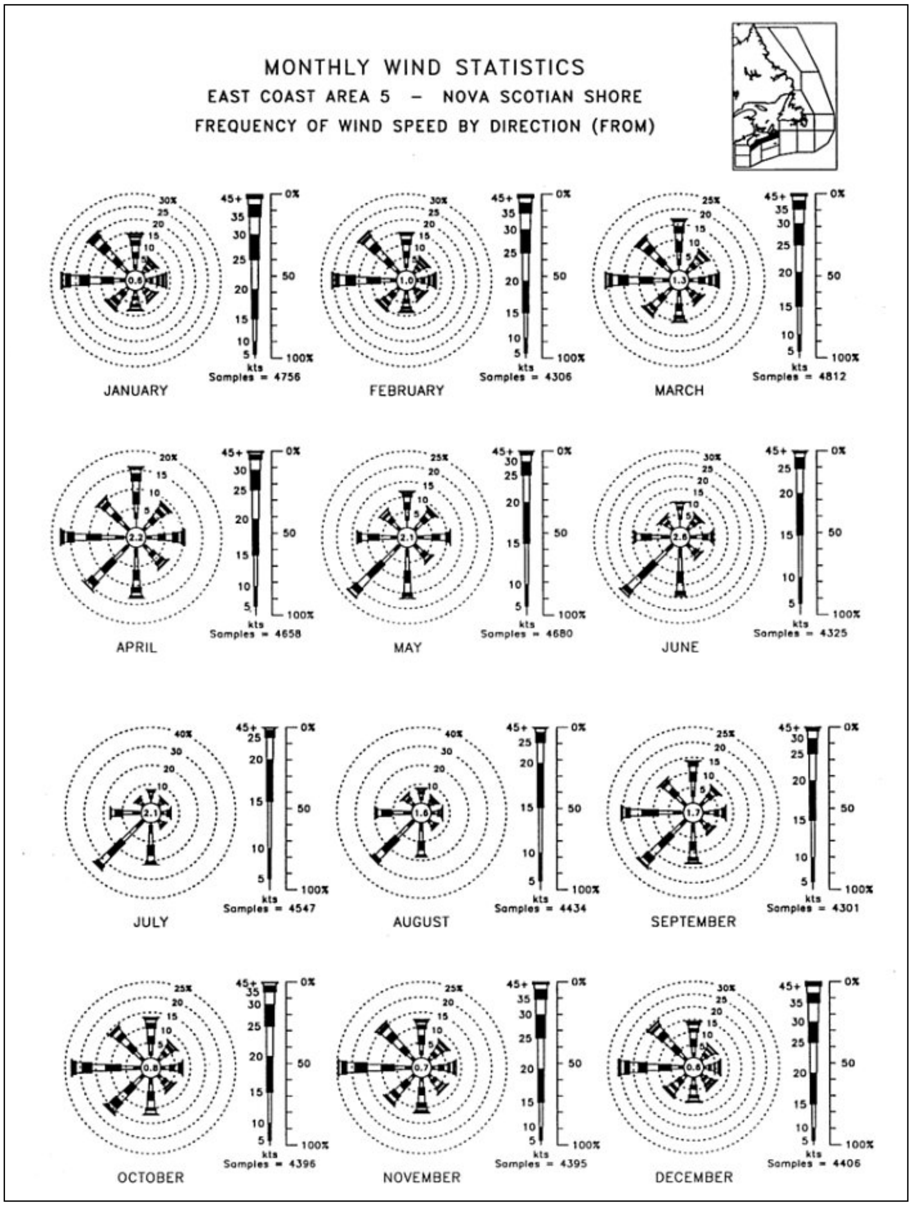


Figure 18. Monthly wind statistics for the nearshore Scotian Shelf (MacLaren Plansearch 1991).

Winds over waters near the coast can differ both in strength and direction from those over the land and those over the open continental shelf. This is due to both dissimilarities between the effective surface roughness of the land and that of the sea and variations in the rates at which the land and sea heat up and cool down. On sunny days, the sun warms the land more quickly than the water and this may cause unstable atmospheric conditions over the land. These differences in surface roughness, heating rates and atmospheric stability result in several complicated phenomena which generally occur within 15 km of the coast (Bowyer 1995). As a result, inland and offshore observing stations may seriously misrepresent wind speed and direction in inshore regions.

Along the Atlantic Coast of Nova Scotia, in the absence of any heating effects, a wind blowing from the northeast will often result in a band of stronger wind within a few kilometers of shore. This is due to convergence of the air flow because of the different surface roughness of the land and sea. This is often mistaken for a sea breeze (see below) but will persist both day and night. This effect will be diminished by preferential heating of the land. A wind blowing from the southwest will result in the opposite, a band of weaker wind near the coast. However, heating of the land can reverse this effect and result in a converging air flow with increased wind speeds near the coast. This is often observed along the Eastern Shore of Nova Scotia during the summer.

Sea breezes occur during the daytime in warm sunny weather when the air over the land is heated and rises while relatively cool air from offshore flows onshore to replace it. As the day progresses the sea breeze circulation strengthens and extends further inland and seaward. The Coriolis force, due to the rotation of the earth, causes the sea breeze to veer, that is change direction clockwise, during the day and the circulation generally ceases shortly after sunset. At night the air over the land cools faster than that over the nearby water, causing the air to circulate in the opposite direction, a land breeze. Land breezes are generally weaker than sea breezes.

In addition to the effects of surface roughness and atmospheric stability described above, irregular coastlines can also funnel and channel winds, locally changing their strength and direction.

Frontal lows track generally from southwest to northeast. The tracks tend to be further south in the summer but each low tracks according to the daily location of the air masses. The official Atlantic hurricane season occurs from the beginning of June to the end of November. On average, only two or three tropical storms affect Atlantic Canada each year. On occasion, these storms can maintain hurricane strength until landfall in Nova Scotia causing widespread destruction. Generally, this occurs during August-September when the surface water temperatures are highest. Recent modelling studies indicate that storm-induced horizontal dispersion of passive particles in bays during a hurricane may be equivalent to 20-days of dispersion associated with pure tidal currents (Sheng et al. 2008).

6.2. Heat Exchange and Budgets

The extent of vertical mixing in the ocean will often determine how much the sea surface warms for a given amount of heat input. If a quantity of thermal energy is put in at the surface and mixed over a large depth, the temperature rise will be smaller than if the same quantity of heat energy is mixed over a smaller depth. The depth of the mixed layer is generally determined by a balance between the mixing energy provided by the wind or tides and the buoyancy input from freshwater discharge or surface heat flux. Water that is warmer and/or fresher is lighter and takes more energy to mix downward into the denser sub-surface waters. The Inshore Scotian Shelf is supplied by buoyancy at the northeastern end by the fresher, warmer surface waters of the southern Gulf of St. Lawrence. The southwestern end is strongly mixed by the large tides of the Bay of Fundy. This is reflected in the sea surface temperatures and subsequently in the air temperatures. Figure 19 shows surface water temperatures and salinities from the northeastern end (Scatarie Island) and the southwestern end (Cape Sable).of the region of interest. The moderating influence of the increased vertical mixing on the water temperatures and subsequently on the air temperatures (Figure 19) is readily apparent.

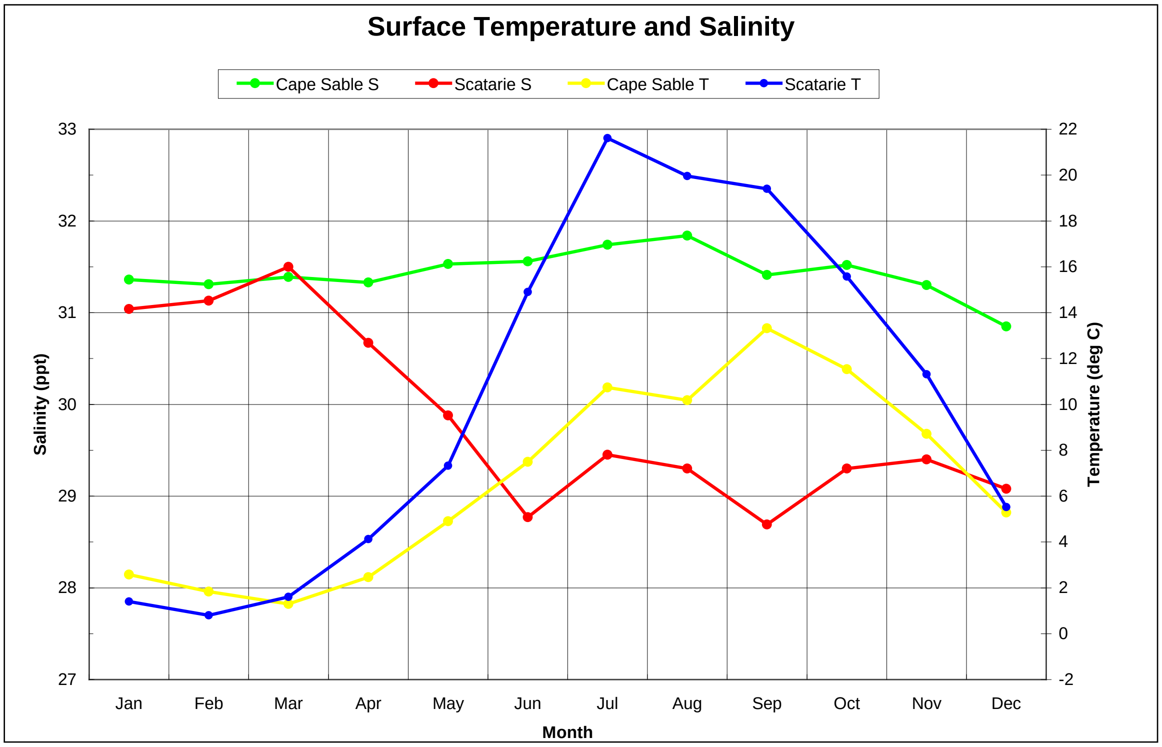


Figure 19. Surface water temperature and salinity from areas at the eastern (Scatarie) and western (Cape Sable) ends of the Scotian Shelf.

7. PHYSICAL OCEANOGRAPHY

Contributed by G. Bugden

7.1. Freshwater Inputs

There are very few major rivers along Nova Scotia’s Atlantic coast, and their influence is largely limited to the estuaries into which they discharge (see Section 4.2). Figure 20 shows discharge statistics for the Sackville River which discharges into Halifax inlet. Discharge is seen to be generally highest in the spring with lesser peaks through the fall and winter. Discharge is generally lowest during the summer months of July and August. Like most Nova Scotia rivers, the Sackville River is quite “flashy”, that is, it responds quickly to precipitation events because of the limited storage capacity of the watershed and the impervious nature of the underlying bedrock.

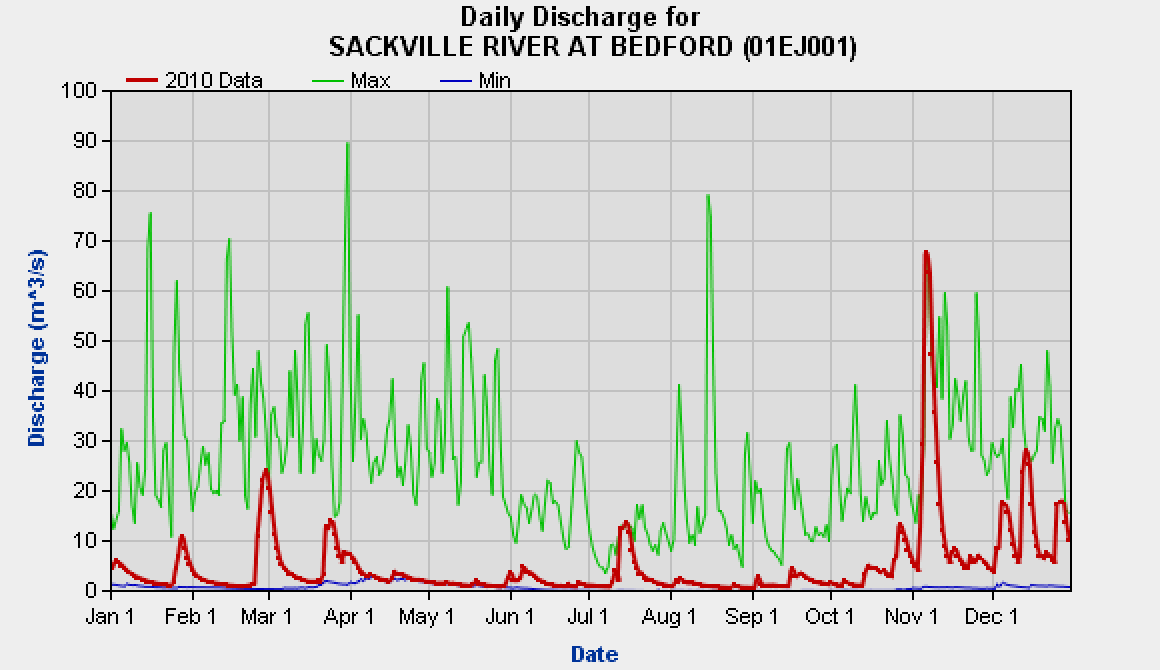


Figure 20. Discharge statistics for the Sackville River, which discharges into the Halifax Inlet based on 42 years data recorded from 1916 to 2010 (from Environment Canada).

Peak discharges are generally due to exceptional precipitation events associated with storms of tropical origin. Significant amounts of freshwater derived from the discharge of the St. Lawrence River are supplied to the northeastern end of the inshore Scotian Shelf from the southern Gulf of St. Lawrence and carried southwestward by the Nova Scotia Current.

7.2. Sea Level and Tides

Tides are a major contributor to sea level variability in the region. The inshore Scotian Shelf is situated between the Southern Gulf of St. Lawrence where relatively small diurnal (daily) tides dominate and the Bay of Fundy with its famously large semi-diurnal (twice daily) tides. Semi-diurnal tides are predominant along the Atlantic Coast of Nova Scotia. The tidal range varies from about 3.0 m at Clark's Harbour at the western edge of the region to about 1.5 m at Bay St. Lawrence at the eastern end. This may be contrasted with the Bay of Fundy where near Westport, at the mouth of the bay, the range is 5.5 m and at Hantsport near the head of Minas Basin the range is 14.5 m (see Figure 21). Atmospheric pressure variations, local wind forcing and sea level variations that propagate into the area from other regions also make important contributions. Storm surges, which are significant increases in water level associated with low pressure weather systems, can be particularly damaging to coastal infrastructure when they occur near the time of high tide.

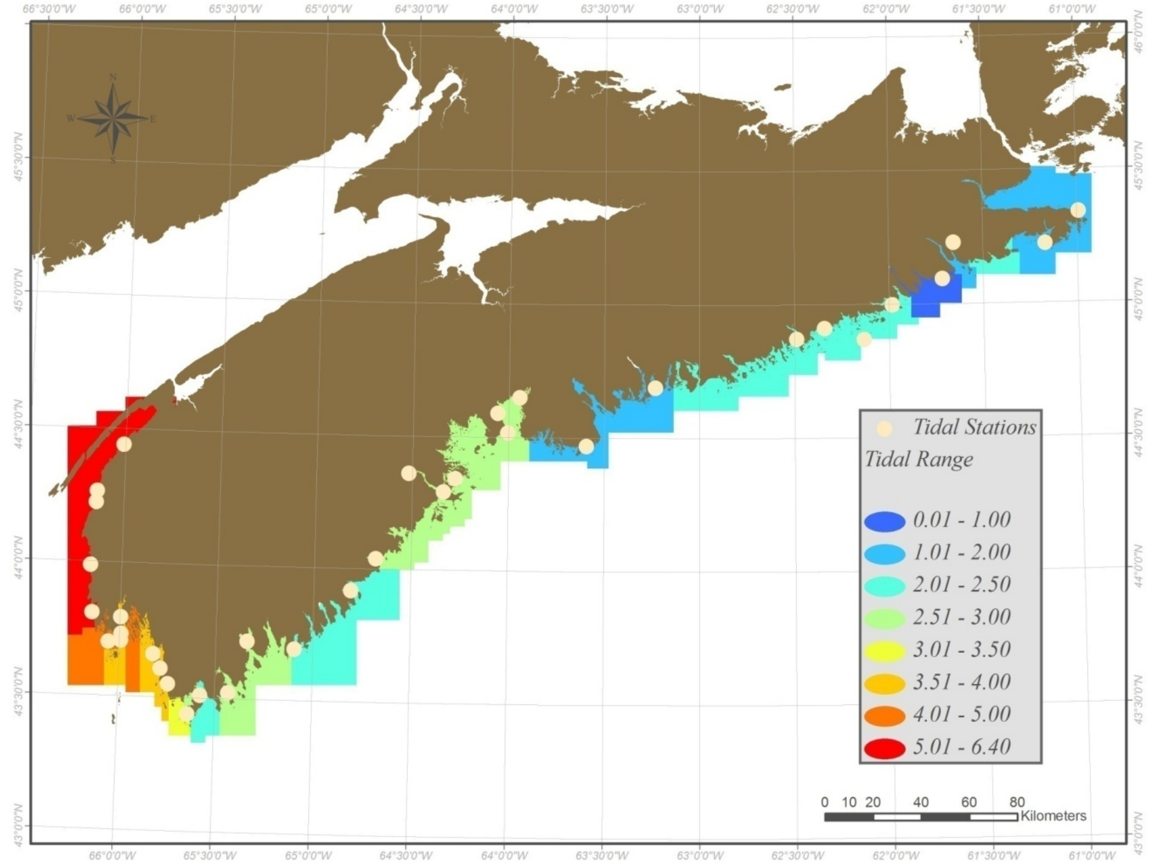


Figure 21. Tidal range at tidal stations along the coast, provided by the Canadian Hydrographic Service. Tides are in m above Low Low Water Large Tide.

In addition to these higher frequency components, relative sea level has risen quite steadily over the last 100 years. Relative sea level is the combination of absolute sea level change (resulting from changes in the volume of water or circulation of the ocean) and sinking or rising of the earth’s crust. As a result of post-glacial rebound, Nova Scotia is sinking (see also Section 4.1.2). Primarily as a result of this, at Halifax, the relative sea level has been rising at the rate of about 32.5 cm/century.

7.3. Water Masses and Currents

The Nova Scotia Current is the dominant alongshore flow on the inner half of the Scotian Shelf (Figure 22). This current originates in the Gulf of St. Lawrence, flows through Cabot Strait into Sydney Bight and is sometimes supplemented by waters from the Newfoundland Shelf that cross the Laurentian Channel. It brings generally fresher water from the Gulf of St. Lawrence that is colder in the winter and warmer in the summer onto the Scotian Shelf. The Nova Scotia Current has two branches; one which flows southwestward along the inner Scotian Shelf and an offshore branch that follows the shelf break.

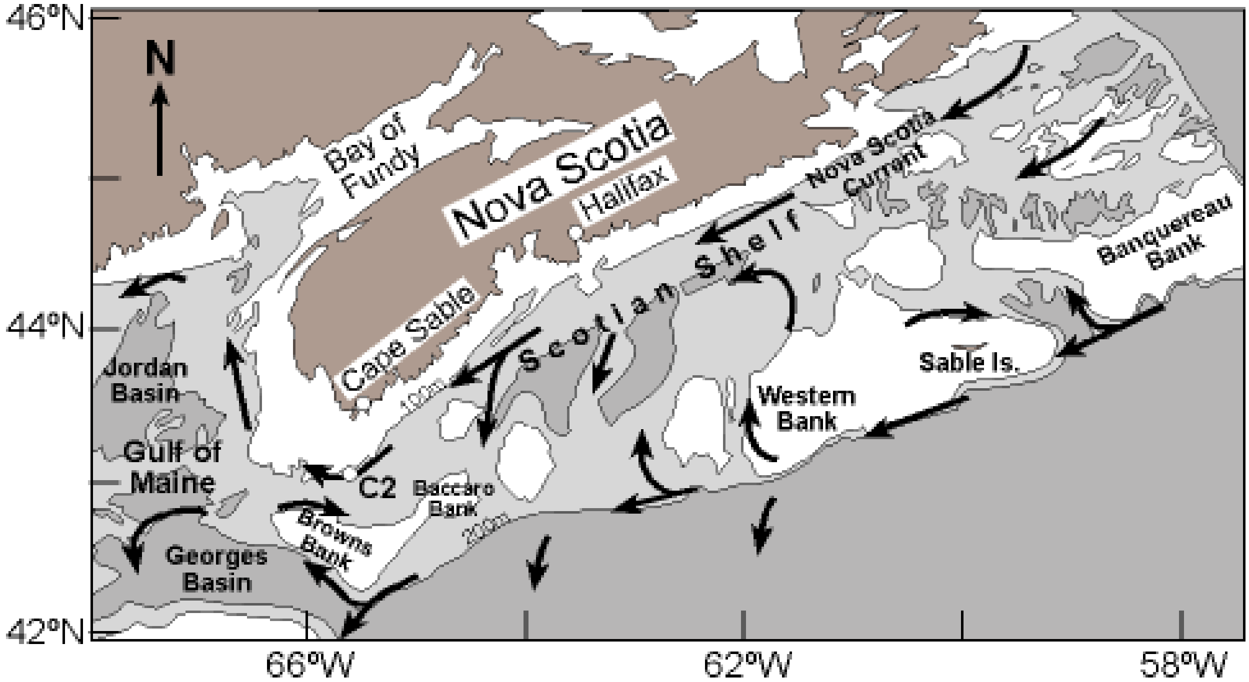


Figure 22. Schematic of the general circulation on the Scotian Shelf.

Model simulations of the mean circulation indicate that the inshore branch of the Nova Scotia Current flows generally alongshore but moves slightly offshore southeast of Halifax (Loder et al. 2003). The Nova Scotia Current has significant annual variation in volume transport (Drinkwater et al. 1979) with the strongest currents in the winter months (Figure 23). The transport and the currents are generally weaker from July to October.

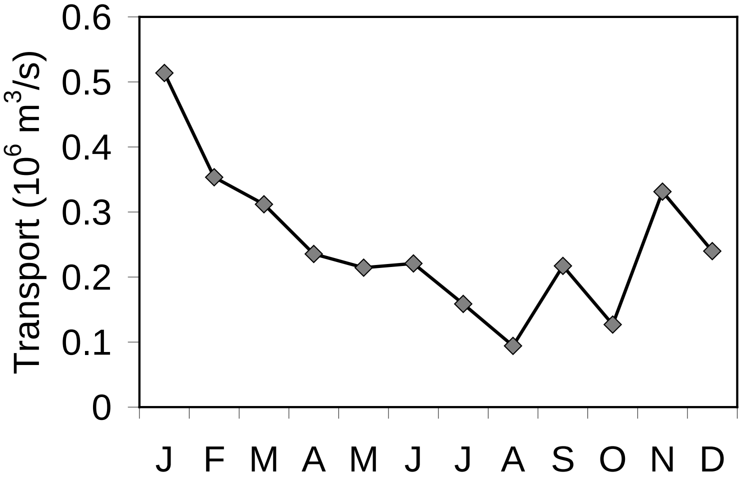


Figure 23. Monthly southwest transport of the Nova Scotia Current, 0-100 m for the inner shelf, from Drinkwater et al. (1979).

7.4. Stratification and Mixing (Fronts, Gyres and Upwelling)

The Inshore Scotian Shelf is supplied by buoyancy at the northeastern end by the fresher, surface waters of the southern Gulf of St. Lawrence. The southwestern end is strongly mixed by the large tides of the Bay of Fundy. As discussed above, the resultant gradient in the extent of vertical mixing is reflected in the sea surface temperatures and subsequently in the air temperatures.

Wind forcing over the shelf and within the inlets can alter the temperature and salinity structure through mixing, upwelling and downwelling. Winds from the southwest, the prevailing direction during the summer months, are most effective in generating coastal upwelling; winds of the opposite direction drive downwelling (Petrie et al. 1987). Coastal upwelling causes surface waters to move offshore and be replaced by colder, saltier waters from below. This process can also cause extensive flushing of coastal inlets by offshore waters (Strain 2002). One of the most striking recorded cases of coastal upwelling on the Nova Scotia shelf occurred in July 1984 (Petrie et al. 1987). The wind had blown persistently from the southwest for about one month, favouring upwelling. Figure 24 shows the satellite-derived sea surface temperature on July 25th, near the end of the period of upwelling favourable winds. An approximately 50 km wide band of water, with temperatures as low as 4°C, is seen all along the coast and in the inlets. Coastal temperatures normally increase by about 4.1°C from June to July in the upper 10 m of the Scotian Shelf. In 1984, the increase was only 0.5°C, indicating the major impact of this upwelling event.

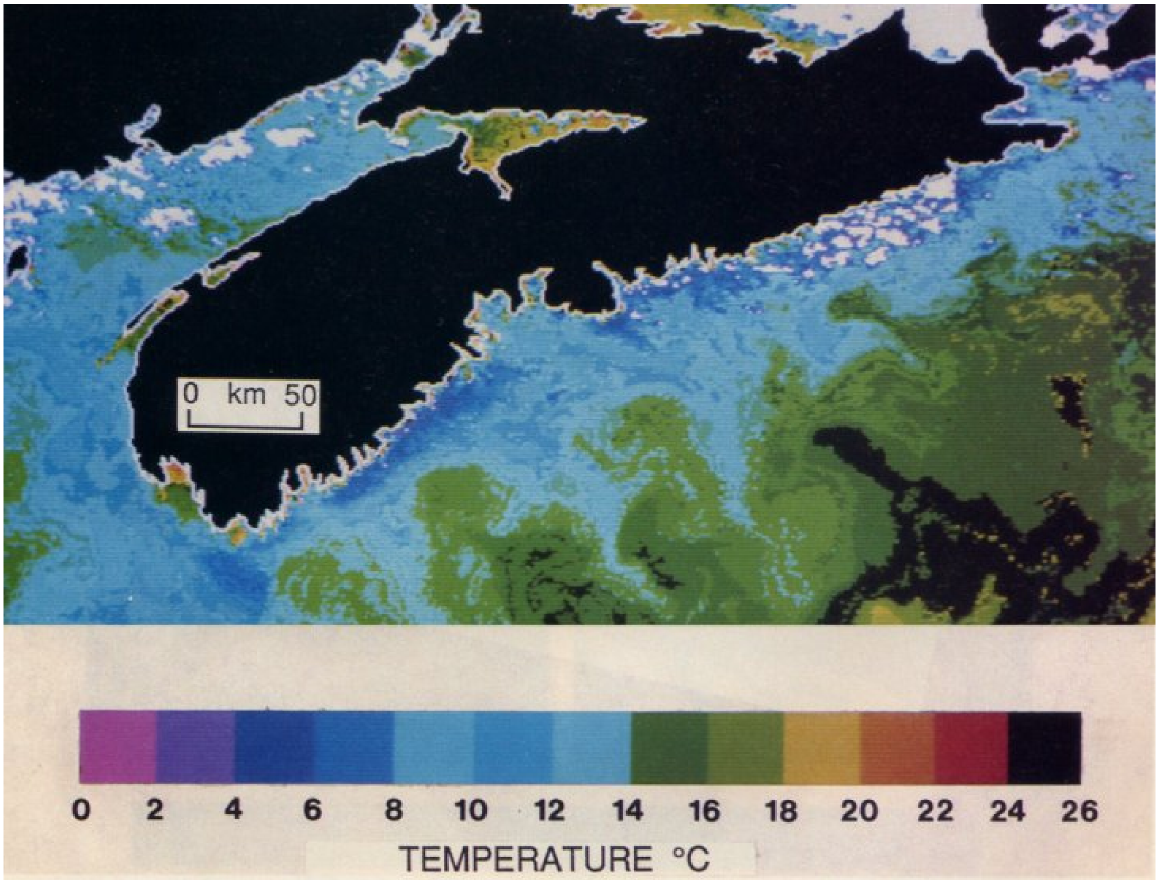


Figure 24. Sea surface temperature captured by satellite on July 25th, 1984, near the end of a period of upwelling favourable winds (Petrie et al. 1987).

Circulation and flushing in the many bays and inlets along the Nova Scotia coast is driven by many factors including the large scale upwelling just described, local wind events, tidal dispersion and estuarine circulation. The importance of each of these factors will depend on the shape and bathymetry of the inlet and the relative magnitude of each of the forcing mechanisms. Gregory et al. (1993) describe the oceanographic, geographic and hydrological properties of many Atlantic Canadian inlets and calculate an approximate flushing time based on tidal exchange approximations. The presence of a sill at the entrance of the inlet may limit exchange of the deeper waters behind the sill. This can result in anoxic conditions in the deeper waters if natural or anthropogenic organic loading is sufficiently high. This occurs in both Bedforf Basin and Ship Harbour.

Considerable amounts of oceanographic data have been collected in the inlets of this region, particularly in Sydney Harbour (Petrie et al. 2001), Country Harbour, Ship Harbour (Strain 2002), Petpeswick Inlet (Loucks and Sadler 1971), Halifax Harbour (Petrie and Yeats 1990) and St. Margaret’s Bay (Heath 1973). In addition, over the years several monitoring programs of variable duration and levels of complexity have been undertaken in various inlets along the Nova Scotia coast. Notable among these are the Phytoplankton Monitoring Program (Keizer et al. 1996b) and the Long Term Temperature Monitoring Program (Petrie and Jordan 1993).

The Phytoplankton Monitoring Program was initiated by Fisheries and Oceans Canada in response to a domoic acid shellfish poisoning event in Prince Edward Island. Part of that response included a survey conducted at five coastal sites in Nova Scotia over a period of three years from 1989 to 1992 to determine what potentially toxic species of phytoplankton were commonly present. Approximately 26 times each year samples were collected from three depths at each of the sites in Whitehaven Harbour, Ship Harbour, St. Margaret's Bay, Woods Harbour and Annapolis Basin. A vertical profile of temperature, salinity and in vivo fluorescence was obtained and discrete samples were collected for determination of chlorophyll a, suspended particulate matter, ammonia, nitrate, phosphate and silicate. Phytoplankton in these samples were identified and counted and a vertical tow was also conducted (Keizer et al. 1996a, 1996b). This data remains largely unanalyzed. The Long Term Temperature Monitoring Program began in 1987 and continues in a reduced from. This program involves the deployment of internally recording thermographs at many sites around coastal Nova Scotia, giving a relatively complete description of the temperature regime.

The Atlantic Zone Monitoring Program (AZMP) has sampled Station 2 on the Halifax Line approximately biweekly since 1998 (Therriault et al. 1998; Harrison et al, 2003). This station, located approximately 30 km SSE of Chebucto Head at the entrance to Halifax Harbour, is slightly beyond the outer limit of the region of interest but is representative of conditions at the offshore boundary. Observations made routinely at this site include vertical CTD profiles of temperature, salinity, chlorophyll fluoroesence, and dissolved oxygen, bottle samples for dissolved oxygen, nitrate, silicate, phosphate, and phytoplankton, 200-mm vertical net tows for zooplankton and Secchi depth for water clarity. This station is occupied approximately 25 times each year and the regular observations are often supplemented with additional moored instrumentation.

These contemporaneous physical and biological observations have informed our understanding of the dynamics of seasonal phytoplankton blooms on the Scotian Shelf (Greenan et al. 2002, 2004, 2008). The onset and evolution of blooms on the inner Scotian Shelf has been found to be a complex process in which nutrient inventory, vertical mixing, and coastal upwelling play roles of varying importance throughout the bloom lifetime.

7.5. Waves and Turbulence

Wave statistics for the coastal zone of Nova Scotia are based largely on the observations made by a wave rider buoy moored off Halifax since 1970 (MacLaren Plansearch 1991). Monthly significant wave height statistics are shown in Figure 25. A strong annual cycle is apparent with the largest values in winter and the smallest in summer (Figure 26), the magnitude and direction closely mirroring the annual variations in wind strength and direction, as expected.

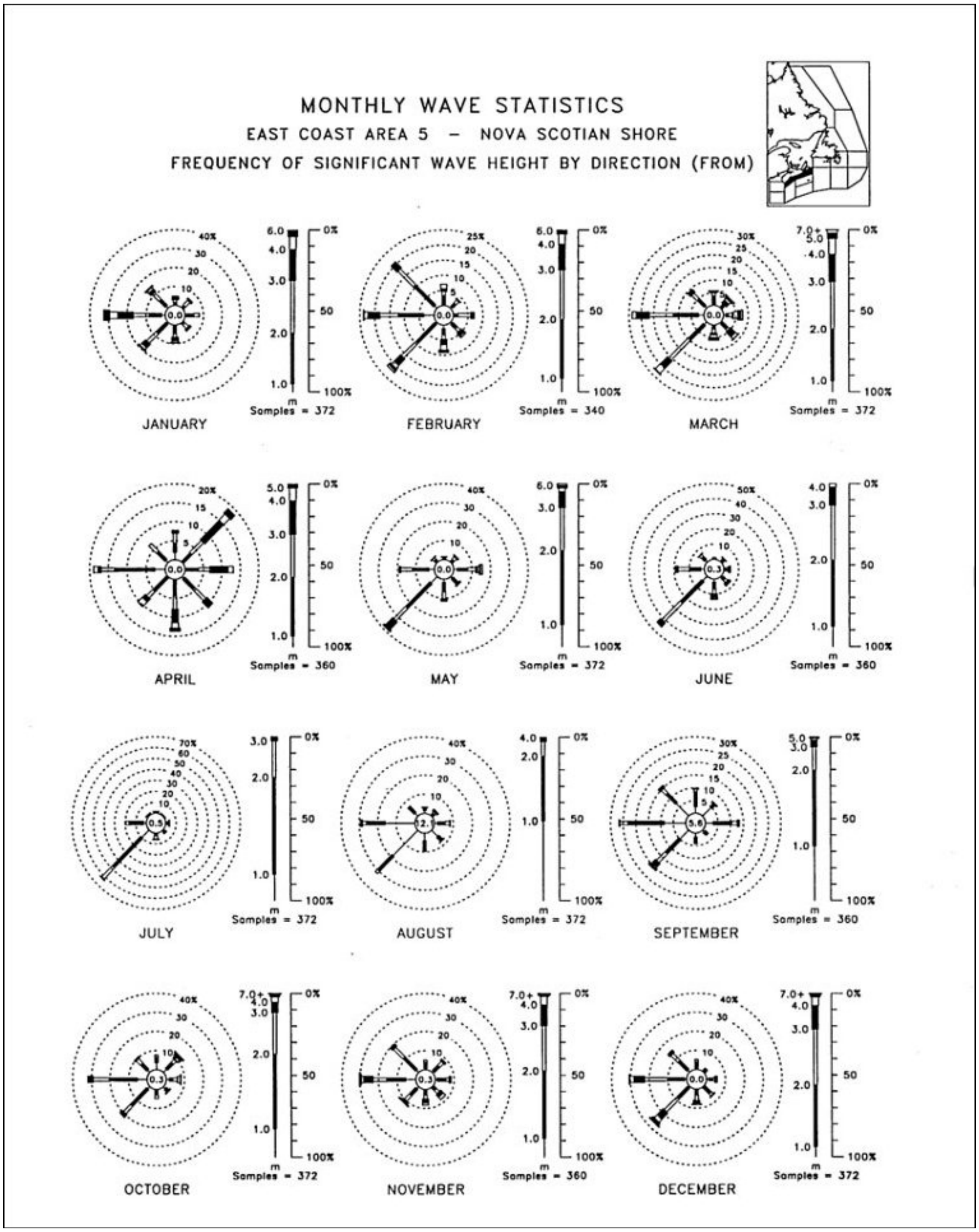


Figure 25. Significant wave height statistics derived from a buoy just off Halifax (MacLaren Plansearch 1991).

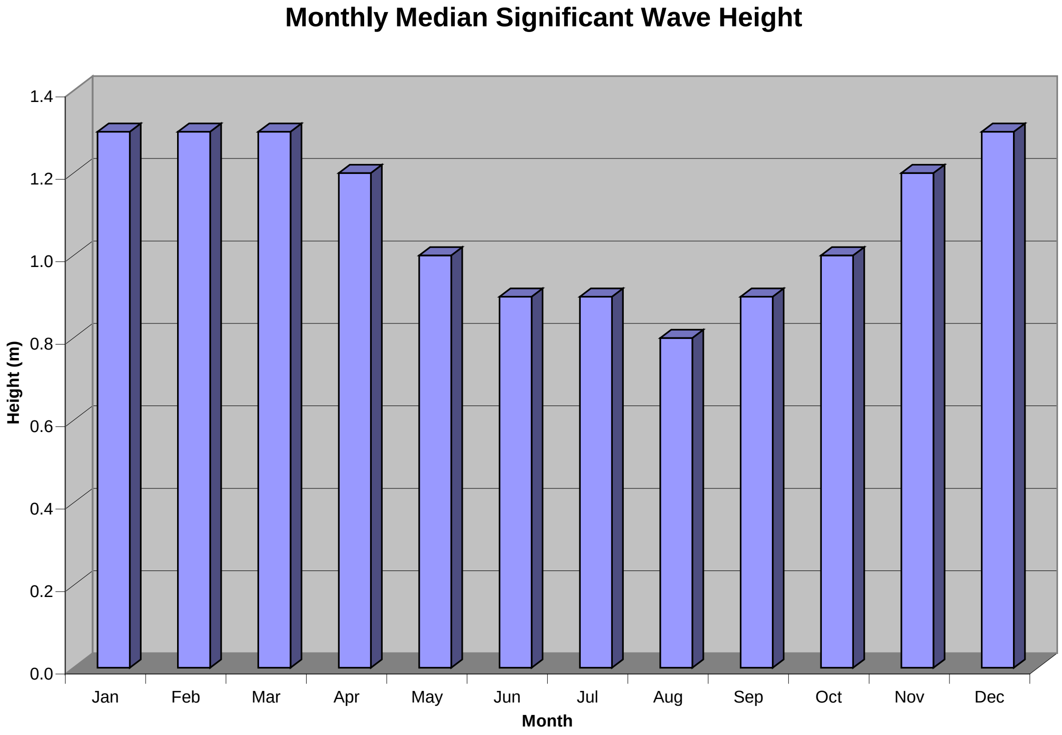


Figure 26. Monthly median significant wave height for the Nova Scotia Shore (MacLaren Plansearch 1991).

7.6. Ice (Permanent and Seasonal Coverage)

Landfast ice generally forms in the upper reaches of the various bays and inlets during the winter months. Its extent is determined by the degree of exchange with the generally ice-free open waters. The outer portions of the harbours of the Atlantic coast of mainland Nova Scotia are generally not frozen during the winter months. Further offshore there is no locally formed ice, but ice exported from the Gulf of St. Lawrence in the early spring can be transported far to the southwest by the Nova Scotia Current. Subsequent onshore winds can then transport this ice onshore as occurred in Halifax Harbour in 1943 and 1987. This phenomenon is highly variable from year to year.

7.7. Underwater Sound – Sources and Propagation

Contributed by N. Cochrane

The acoustic environment of the Inshore Scotian Shelf is largely characterized by generally deepening waters to the vicinity of the 100 m isobath about 25 km offshore. Inshore depths to about 200 m occur in the approaches to Chedabucto Bay, the adjacent south coast of Cape Breton, and near Cape North. From Cape Sable to Cape Canso, inshore waters are underlain by superficial, variable, but generally acoustically hard sands and gravels, typically less than 10 m thick with frequent hard bedrock exposures which become the norm in the outer reaches of the inshore zone (Forbes et al. 1991; Section 3). Scotian Shelf acoustic noise levels are highly variable in the short term but display seasonal trends related to both average wind speeds and systematic physical oceanographic changes affecting noise propagation. Increasing marine traffic, especially near the approaches to the Port of Halifax, Chedabucto Bay, and the Cabot Strait, coupled with a modern tendency toward larger ships, introduces increasing noise at local to regional scales. Seismic surveys associated with offshore oil exploration occasionally can constitute a source of noise which can propagate inshore. A highly irregular coastline characterized by partially enclosed harbours and embayments of varying water depths make the very nearshore acoustic environment one of high spatial (as well as temporal) complexity.

Inshore acoustic noise levels are best characterized by comparison with corresponding deep open ocean levels, classic references for the latter being Knudsen et al. (1948) and Wenz (1962); Urick (1983) provides an accessible overview. The deep ocean acoustic noise spectrum is markedly frequency and wind speed dependent. Below 10 Hz ocean noise is dominated by turbulence and little dependent on local wind speed. From about 10 Hz to 200 – 500 Hz, ocean ship noise dominates, often originating from the hundreds of km range. Above about 500 Hz, wind correlated noise from ocean spray and surface micro-bubble generation dominates, with decibel spectral levels falling with the logarithm of increasing frequency in a highly linear and reproducible fashion. Another high level acoustic noise source is precipitation. Inshore measurements in Long Island Sound by Heindsman et al. (1955) and reproduced in Urick (1983), show “heavy rain” to result in acoustic levels from 1 – 10 kHz about 7 to 18 dB higher than “rain-free” conditions at 40 to 80 km wind speeds.

Most studies of Scotian Shelf ambient acoustic noise have been national defence-related (Piggott 1964, Zakaraukas et al. 1990, Desharnais and Collison 2001). The best separable inshore measures are probably the 1-year dataset of Piggott (1964) spanning 8.4 to 3100 Hz gathered from bottom hydrophones at 37 and 51 m more than five kms from the coastline at exposed sites now known to be near Halifax (DFO 2007a). While displaying expected spectral trends in the higher frequency regions dominated by wind, important seasonal variations were observed at equivalent wind speeds. January - April spectral levels were about 3.5 dB higher than May - December levels over a broad frequency range. The favoured explanation is better winter-spring propagation conditions enhancing the non-locally generated noise component. The effect was first demonstrated by MacPherson and Fothergill (1962) from propagation studies off Hartlen Point, near Halifax. Winter – spring oceanographic conditions produce a negative sound speed gradient in the upper water column, refracting horizontally propagating sound upward, thereby minimizing attenuating interactions with the bottom. In summer and fall, sound is refracted downward with higher bottom absorption. Davis et al. (1998) have modeled seasonal propagation effects over a wide frequency range in connection with noise originating from outer Scotian Shelf exploration seismic surveys. Piggott’s (1964) inshore noise measurements below 150 Hz are systematically lower than the wider area Scotian Shelf measures summarized by Zakaraukas et al. (1990) – at least 15 dB lower at 50 Hz (an effort was apparently made to exclude local ship noise). This may be consistent with the observations of Staal et al. (1986) who measured unexpectedly high propagation losses below 100 Hz over granitic sea beds which may characterize significant areas of the Atlantic inshore.

Lack of abundant published data forces speculation about the acoustic character of the nearshore largely from inference. Ship origin noise would be expected to dominate the acoustic noise spectrum from about 20 Hz to at least several hundred Hz - and in calm weather to at least 1 kHz within perhaps 10 km of ship traffic, and would appear especially important near high traffic routes such as the approaches to Halifax Harbour. Urick (1983) showed that average noise levels near the approaches of New York Harbour were 10 – 15 dB higher than in comparative low traffic inshore areas in the 100 Hz – 1 kHz range with some enhancement persisting to at least 10 kHz. Wilson et al. (1985) pointed out the importance of noise related to shoreline breaking surf. While it is uncertain precisely how Californian measurements might translate to Nova Scotia, data reproduced from Elles (1982) showed a 10 – 15 dB enhancement in omnidirectional noise levels between 50 and 700 Hz moving from 8.5 to 2.8 km offshore in “heavy surf” conditions. Discontinuous brashy pack ice, as may seasonably occur along the Cape Breton coastline, might be expected to raise noise levels 5 – 10 dB over levels observed in ice-free waters in similar sea-states (Urick 1983). Noise also originates from biological sources, the most important for the Scotian Shelf inshore probably being the fin whale which vocalizes with a narrow-band signal near 20 Hz which can be very prominent over wide areas of the Shelf in fall and early winter months (see literature overview of Davis et al. 1998).

Important constraints also arise from basic acoustic theory: In extremely shallow nearshore areas sounds propagating from afar can be inhibited by water depth alone, propagation becomes very inefficient for acoustic wavelengths greater than four times water depth over a hard bottom (Jensen et al. 2000). For instance, in 5 m of water, sound frequencies below 75 Hz will not propagate efficiently. Therefore, the littoral zone should be largely protected from very low frequency sound of non-local origin.

8. PHYSICAL-CHEMICAL PROPERTIES OF SEAWATER

8.1. Temperature, Salinity and Water Density

Contributed by G. Bugden

The long-term temperature, salinity and sigma-t (density) averages in the 0-100 m depth range for the region outside the coastal headlands in the central portion of the study area are shown in Figure 27. An extensive layer of cold water develops in the winter with temperatures less than 1°C. In spring and throughout the summer as heat exchange from the atmosphere to the ocean increases, a shallow warm layer forms with temperatures that exceed 15°C. During summer and fall, vertical diffusion and mixing deepen the warm layer.

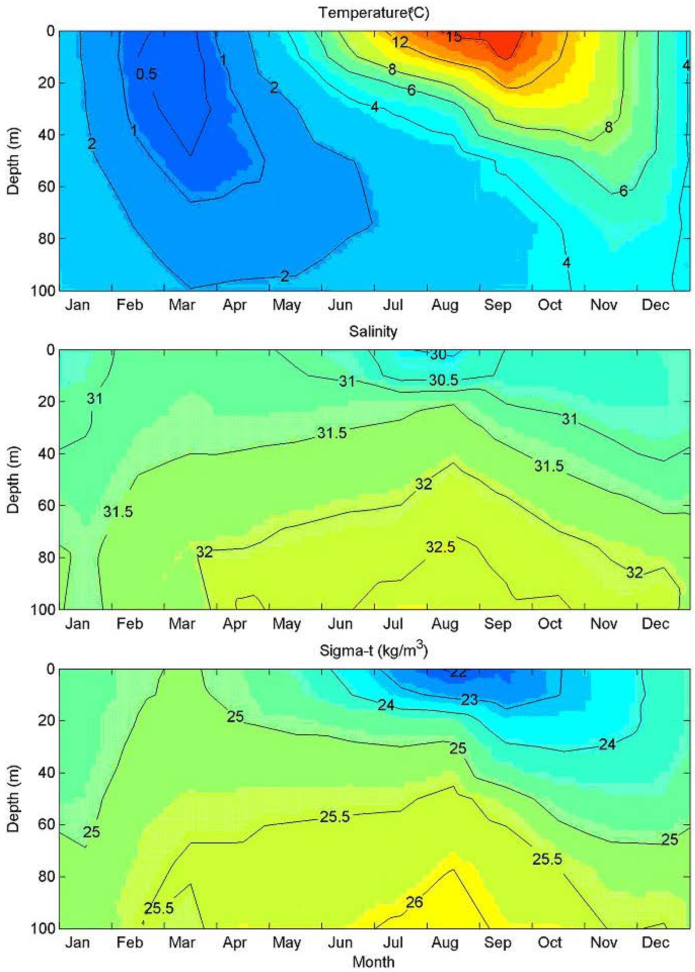
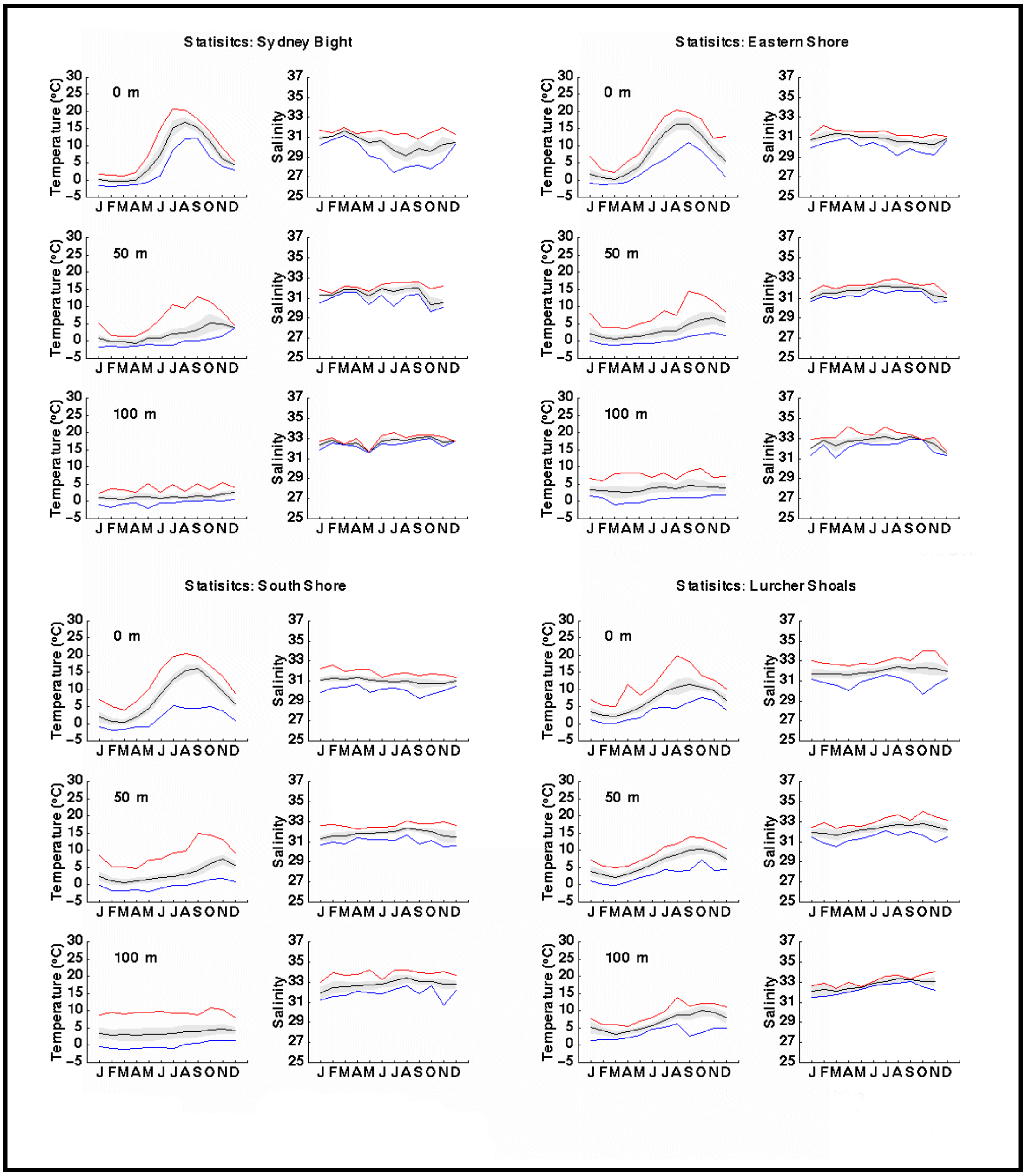


Figure 27. Vertical structure of long-term monthly averaged temperature, salinity and sigma-t (density) for the central portion of the study area (McCullough et al. 2005).

Figure 28 shows the monthly mean hydrographic properties and their statistics at 0, 50 and 100 m from four polygons in the inshore waters of the Atlantic coast of Nova Scotia. The standard deviations are based on monthly mean values of each variable; the maximum and minimum values are based on individual observations. In summer, the difference between the minimum and maximum observed temperatures can reach ~15°C.


Statisitcs: Sydney Bight

Statisitcs: Eastern Shore

Statisitcs: South Shore

Statisitcs: Lurcher Shoals

Figure 28. Annual cycle of temperature and salinity from four regions of the study area. The blue line is the minimum monthly value and the red line the maximum monthly value. The black line is the mean and the grey shading shows +/- 1 standard deviation about the mean.

The influence of the fresher waters of the southern Gulf of St. Lawrence at the northeastern end and the strong mixing by the large tides of the Bay of Fundy at the southwestern end discussed previously is seen to result in a horizontal gradient in both temperature and salinity at all depths. Wind forcing over the shelf and within the inlets can alter the temperature and salinity structure through mixing, upwelling and downwelling. In fact, the latter two processes are major contributors to the large differences between maximum and minimum property values shown in Figure 28.

8.2. Dissolved Oxygen – Areas of Hypoxia

Contributed by P. Yeats

Oxygen is introduced into surface waters by exchange across the air-sea interface and by photosynthesis. As a result, concentrations in inshore waters are generally near saturation; in fact, they are often slightly supersaturated. Oxygen depletion occurs naturally as a result of decomposition of organic matter, a process that releases nutrients (N and P) to the water and consumes oxygen. This build-up of nutrients and depletion of oxygen is called eutrophication. In most coastal waters wind and tidal mixing ensures adequate contact with the atmosphere to replenish oxygen consumed by the decomposition of organic matter. In some deeper basins and other areas with poor water circulation, the bottom waters are sufficiently isolated from exchange with the atmosphere that significant depletion of dissolved oxygen can occur. This happens most frequently in late summer to fall when water temperatures are high, net accumulation of organic debris from spring/summer plankton growth is high, and water mixing is low.

Inputs of organic matter from sewage, fish plant wastes or other discharges can contribute to the organic matter build-up, but eutrophication does occur naturally in numerous harbours. A study of the eutrophication situation in the Maritime provinces (Strain and Yeats 1999) indicated that the deepest waters in several harbours on the Nova Scotia Atlantic coast (Ship Harbour, Petpeswick Inlet, Wine Harbour and Bedford Basin) had <50% saturation concentrations of oxygen in the fall. These samples also had elevated levels of nutrients and dissolved iron and manganese, two metals that have high solubility in anoxic waters. Other areas, including some with substantial inputs of anthropogenic organic matter (e.g. Sydney Harbour and Halifax's Northwest Arm) showed little or no reduction in oxygen saturation. The critical factor was the presence or absence of a sill that could limit circulation and mixing in the bottom waters.

In a two year long study of nutrient and oxygen dynamics in Ship Harbour, one of the Nova Scotia harbours with a eutrophic inner basin, Strain (2002) modelled the physical, chemical and biological processes that control the eutrophication process. He found oxygen consumption rates of 10 to 30 mmol/m^2/d during the August to November period when stress on the oxygen supply is greatest, which are similar to those seen in other harbours and bays. This similarity indicates that the very low levels of oxygen observed in Ship Harbour are a result of the poor flushing characteristics, not excessive oxygen demand.

There are currently no data available to assess inter-annual trends in oxygen concentrations in bottom waters. The project (Li and Dickie 2001) has collected oxygen data since 1999 but they are not yet available. An alternative approach to the assessment of bottom water trends would be to monitor molybdenum concentrations in dated sediment cores. Solubility of molybdenum is significantly reduced in anoxic waters and changes in anoxia in bottom waters or surficial sediments will be reflected in changes in sedimentary molybdenum concentrations (Adelson et al. 2001).

8.3. Suspended Matter – Light Availability

Suspended matter and light availability are discussed in Section 5.3.

8.4. Organic Carbon in the Coastal Zone (DOC/POC)

Contributed by P. Kepkay

As in most marine ecosystems, the majority of total organic (or biogenic) carbon load in coastal waters is carried as dissolved organic carbon (DOC) and the rest is particulate organic carbon (POC). The bioreactivity of DOC in seawater is not easy to define because most of the carbon is regarded as semi-labile or refractory (Carlson et al. 1994) and cannot be directly utilized by micro-organisms without a nutrient (ammonia, nitrate, phosphate) supply. Even then, the majority (> 80%) is refractory (i.e, slow to degrade). There are also wide variations in the organic carbon load carried by coastal ecosystems. For example, the concentration of DOC in tidally-dominated SWNB surface waters can be as low as 100 µM C (1.2 mg C L^{-1}) and as high as 6800 µM C (81.6 mg C L^{-1}) during the summer (Kepkay et al. 2005). In addition, the concentration of organic carbon cannot be related in any simple way to commonly-accepted indices of ecosystem health, such as primary production by the phytoplankton and biological oxygen demand by community respiration. Instead, carbon load is regulated by additional complex interactions between the sedimentation of phytoplankton detritus, the tidal resuspension of natural and anthropogenic organic material, and the influx of terrestrial carbon carried by local rivers rich in dissolved humic material (Kepkay et al. 2005).

8.5. Nutrients – Flux and Budgets

Contributed by P. Yeats

The main source of nutrients (nitrogen, phosphorus and silicon) to inshore waters is water exchange with the adjacent coastal waters. Even in Halifax Harbour with its substantial inputs of domestic sewage, the offshore source of phosphate is twice that of sewage and for nitrate it is much higher (Petrie and Yeats 1990). Input from the offshore generates high concentrations of nutrients in inshore surface waters in winter. In most harbours, these are depleted by the spring phytoplankton bloom and remain low through the spring/summer period to be replenished in the fall when mixing increases. Nitrate is the most rapidly and extensively removed, usually to levels that would limit primary productivity during most of the spring/summer period. This is the normal seasonal cycle of nutrient concentrations that is seen in temperate waters. A few locations along the Atlantic coast of Nova Scotia show elevated nutrient concentrations that can be attributed to anthropogenic sources but more show elevated concentrations in bottom waters in summer and fall that are related to natural sources (see above).

The annual nutrient cycle has been characterized over a period of at least two years for Bedford Basin, Ship Harbour, Whitehead Harbour, Sambro, St. Margaret's Bay (two locations), Mahone Bay and Woods Harbour. Results from the Bedford Basin study are available on the Bedford Basin monitoring project , those from one of the St. Margaret's Bay studies in the Biochem Database, and from the remaining sites in two reports of the results from the Phytoplankton Monitoring Project (Keizer et al. 1996a, b). A plot of nitrate concentrations vs. time for the Phytoplankton Monitoring Project St. Margaret's Bay site (Figure 29) is representative of the plots for nitrate, phosphate and silicate at all of the non-eutrophic sites. These plots can be used to characterize the levels of nutrients in winter (horizontal blue lines on plot), timing of the nitrate or silicate depletion in spring (phosphate doesn't really get depleted) and extent of nitrate depletion in spring and summer (time with concentrations below horizontal yellow line on plot), illustrating that a number of factors that contribute to nutrient status.

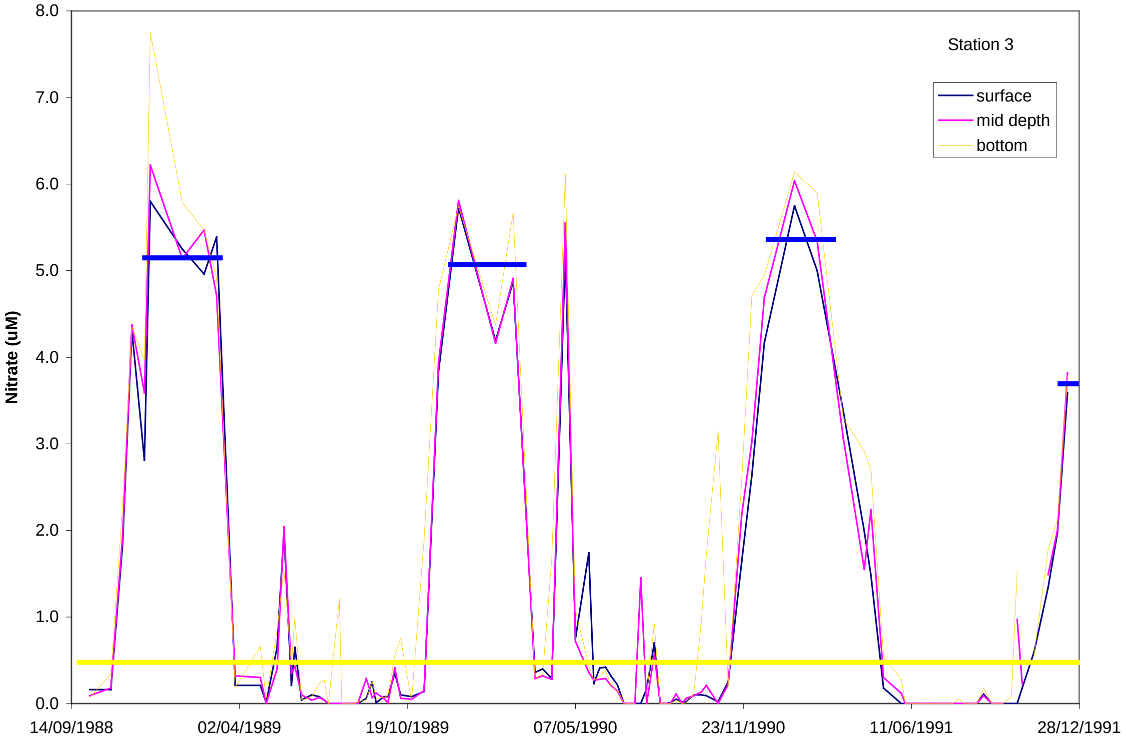


Figure 29. Nitrate concentrations versus time for the Phytoplankton Monitoring Project St. Margaret's Bay site. Blue lines = levels of nutrients in winter.

Winter nutrient concentrations give us a measure of the magnitude of, and temporal trends in, the supply of nutrients for the spring phytoplankton bloom. Trends in time of the winter phosphate concentrations are shown for the eight time locations noted above (Figure 30). The pictures for nitrate and silicate are very similar. It appears clear from this plot that winter phosphate levels in Bedford Basin are higher than those in the other harbours and that the levels are increasing with time. Sewage inputs to the harbour must be a factor here and increasing population in the Halifax area will be contributing to the temporal trends. But, there is coherence (r^2=0.27) between the Bedford Basin data and measurements made at the Wolves site off St. Andrews Biological Station (another location with a long time series), so this is not just a Halifax Harbour sewage story. Winter concentrations can also be used to investigate spatial patterns and trends. For example, analysis of the BioChem database indicates that concentrations of phosphate, nitrate and silicate decrease from high concentration in coastal waters of Cape Breton to lower concentration off southwest Nova Scotia. The differing concentrations appear most influenced by the low salinity, nutrient enriched discharge from the Gulf of St. Lawrence. Higher concentrations are found in the extreme southwest (Cape Sable area) where lower stratification and contributions of deeper oceanic waters with relatively high nutrient concentrations provide another nutrient source.

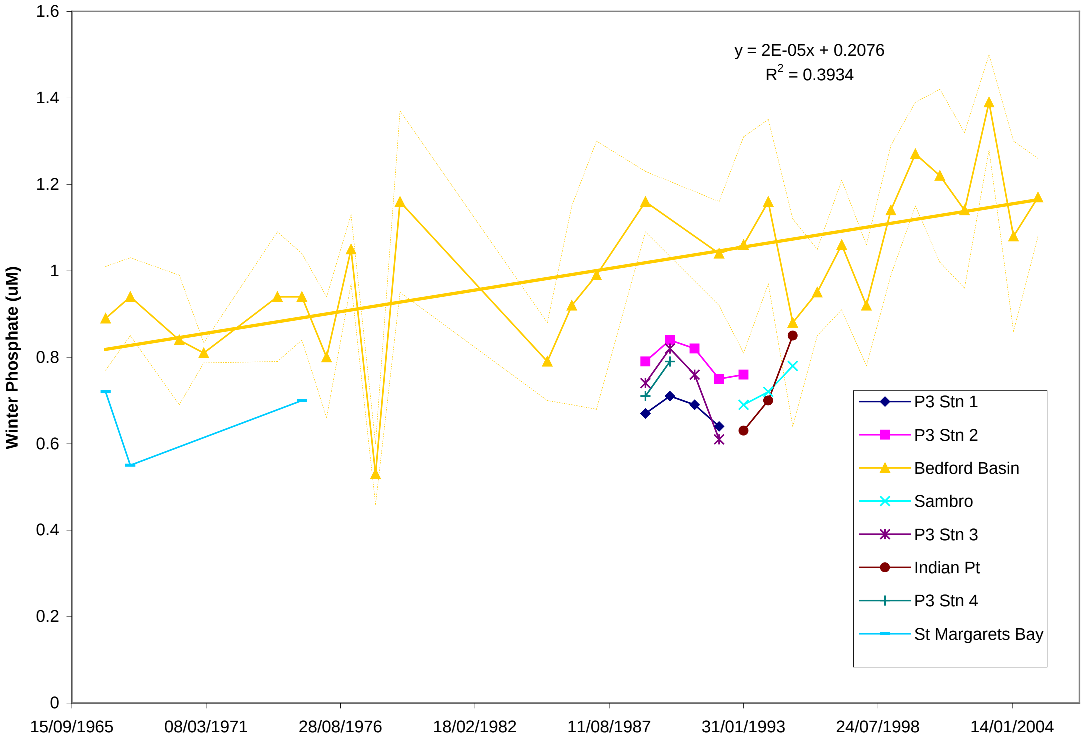


Figure 30. Temporal trends in winter phosphate concentrations. Bedford Basin data show the average concentrations from mid December until the start of the spring depletion; dashed yellow lines are the ± standard deviations, solid yellow line is the regression line. The other sites are represented by average concentrations. (P3 Stn 1: Tor Bay; P3 Stn 2: Ship Harbour; P3 Stn 3: St Margarets Bay; P3 Stn 4: Woods Harbour).

Elevated near-bottom concentrations of phosphate, ammonia and silicate in summer/fall resulting from eutrophication are clearly evident in the seasonal cycles in Ship Harbour and Bedford Basin. The other six sites show little or no indication of eutrophication. In both Bedford Basin and Ship Harbour, concentrations in the deep waters isolated behind sills increase through summer and fall to levels that are as much as 10 times those in the offshore supply water. The total inorganic nitrogen to phosphate ratios, however, are similar to those in the offshore supply.

Although the measurements are insufficient to describe the annual nutrient cycles in the harbours, they do give some indication of nutrient “health” of the harbours. Our understanding of nutrient dynamics generated in the larger ecological studies has been used to generate a traffic light Marine Environmental Quality (MEQ) framework for assessment of nutrient health. The framework that has been developed (Yeats 2006, 2007; Ryan et al. 2006, 2007) is based on two premises. First, the maximum concentrations that are expected in harbours will be determined by the wintertime concentrations in near-surface coastal waters that supply nutrients to the inshore areas. Second, uptake and regeneration of nitrogen and phosphorus will be governed by the Redfield ratio. Concentrations that deviate from those predicted based on these two premises will indicate additional anthropogenic inputs or eutrophication.

For the purposes of this report, available data including those collected in the 2006 Inshore Ecosystem Project (Bundy 2007b) have been assessed against two environmental management criteria (thresholds). These are expected background concentrations that are based on the two premises described above, and a potential harmful effects threshold that is based on the Canadian Council of Ministers of the Environment (CCME) marine water quality guideline for oxygen. Two maps are used to describe observed concentrations versus these thresholds; the first (Figure 31) is based on surface water concentrations from all seasons and is used to identify areas with additional inputs, and the second (Figure 32) is based on bottom water concentrations in fall and is used to assess eutrophication. In both cases, green is used to indicate concentrations that are within the expected normal range, yellow is used for those that are outside the normal range but less than the water quality guideline, and red is for concentrations that are above the water quality guideline. Figure 31 shows mostly green dots with isolated occurrences of yellow and red. The exception is Sydney Harbour where there is a high density of yellow and red dots, presumably reflecting the input of nutrients in sewage discharged to the harbour. It is surprising that there are not more yellow or red dots in Halifax Harbour, but this may be because the BioChem database has rather few ammonia measurements for Halifax Harbour (nitrate, ammonia and phosphate measurements are needed for the assessment). Figure 32 shows a number of red dots mostly for the harbours identified as sensitive to eutrophication in Strain and Yeats (1999). It is interesting that the red dots in Halifax Harbour are restricted to Bedford Basin.

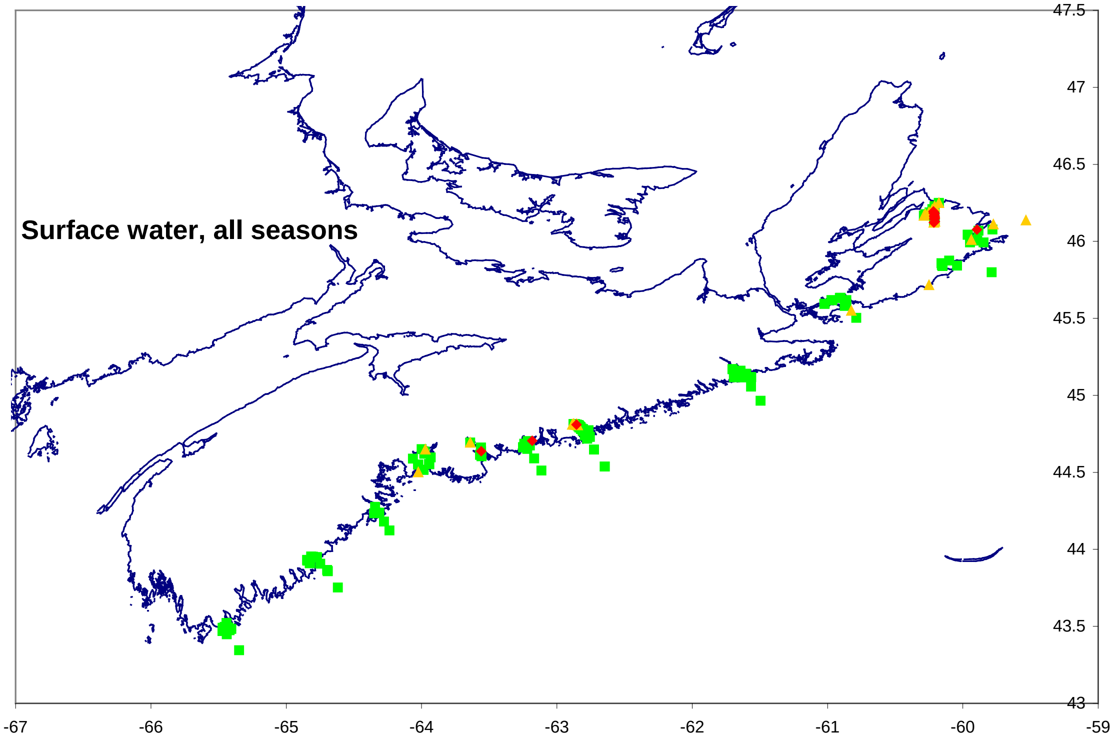


Figure 31. Traffic light Marine Environmental Quality map based on N:P ratios in surface waters. Green = concentrations within the expected normal range. Yellow = concentrations outside the normal range but less than the water quality guideline. Red = concentrations that are above the water quality guideline.

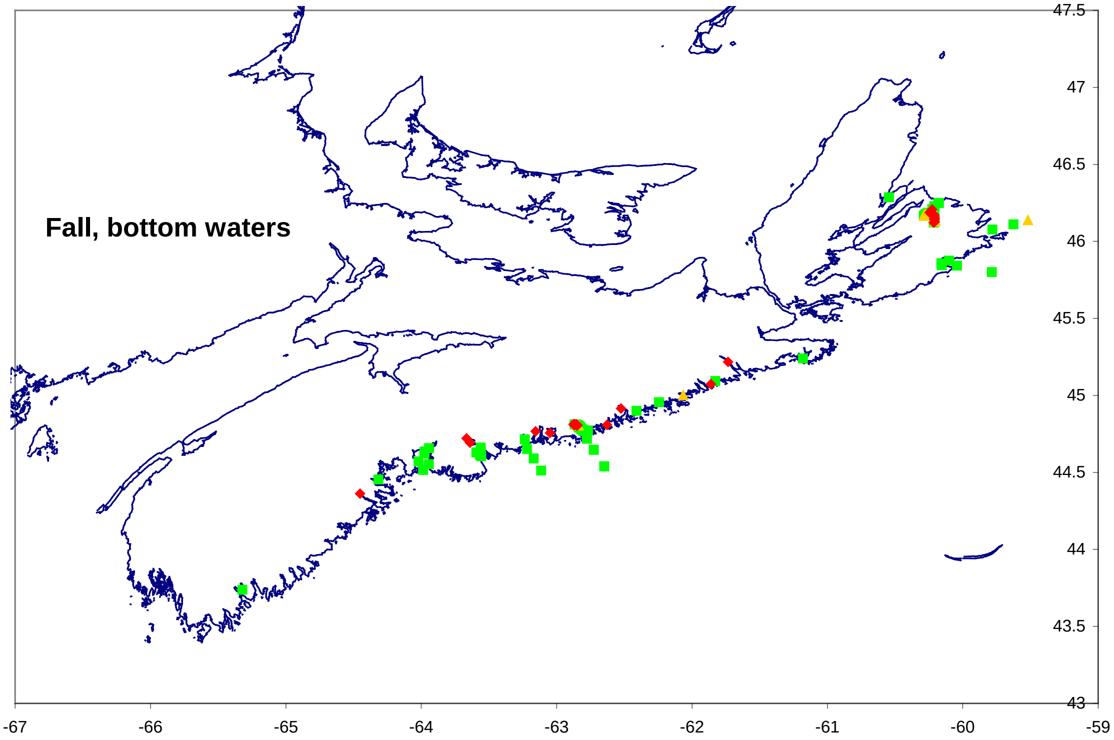


Figure 32. Traffic light Marine Environmental Quality map based on N:P ratios in bottom waters. Green = concentrations within the expected normal range. Yellow = concentrations outside the normal range but less than the water quality guideline. Red = concentrations that are above the water quality guideline.

8.6. Biogeochemistry (Dissolved Trace Metals and Natural Hydrocarbons)

Contributed by P. Yeats

Trace metals, like nutrients, are ecosystem parameters that have both natural and anthropogenic sources. For most of the metals that might be important for ecosystem functioning either as secondary nutrients or as pollutants, the freshwater sources (rivers and atmospheric precipitation) will dominate. Distributions reflect this and dissolved metal concentrations in inshore areas generally decrease with increasing salinity. Partitioning of metals to particulate phases that are subject to gravitational settling is an important biogeochemical process that will cause the relationships with salinity to be non-linear. Oxidation reduction reactions can also be important and high concentrations of iron and manganese are frequently observed in hypoxic waters and/or above anoxic sediments.

Dissolved trace metal distributions have been studied most extensively in Halifax Harbour in 1988/89 (Petrie and Yeats 1990; Dalziel et al. 1991) and 2001/02 (unpublished data), and Sydney Harbour in 1999/01 (Lee 2002), where concerns about metal pollution were the impetus for the studies. More limited measurements have been made in Medway Harbour in 1987/88 (Windom et al. 1991), Ship Harbour in 1991/92 (Ship Harbour, Bras d'Or and Pictou data are from Strain and Yeats 2002) and in the eutrophication status project (Strain and Yeats 1999). Average concentrations from these harbours plus two other nearby areas are shown in Table 8 (samples with salinities <15 have been excluded from the means). The numbers show that the three relatively pristine areas (Medway Harbour, Ship Harbour and the Bras d'Or Lake) have lower concentrations of the metals cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn) that are generally associated with heavy metal pollution than do the more industrialized

Halifax, Sydney and Pictou harbours, but only the differences for Cu and Ni are significant ($P<0.05$, t test for differences between means).

Table 8. Dissolved metal concentrations (conc.) in Nova Scotian harbours.

Conc.	Medway	Halifax1989	Halifax2002	Ship	Sydney	Bras d'Or	Pictou
number	n=20	n=63	n=38	n=42	N=32	n=13	n=19
Cd (ng/l)	29±14	36±11	25±6	22±6	23±6	21±10	33±10
Cu (μg/l)	0.23±0.09	0.42±0.15	0.49±0.19	0.22±0.04	0.46±0.11	0.29±0.03	0.60±0.24
Fe (μg/l)	40.1±42.2	2.3±1.2	1.8±0.9	2.7±1.6	3.3±3.3	1.2±0.9	6.9±4.4
Mn (μg/l)	10.4±8.9	1.8±1.0	2.6±1.2	2.9±1.8	7.1±3.9	1.5±1.1	2.7±1.8
Ni (μg/l)	0.33±0.04	0.47±0.17	0.40±0.09	0.30±0.10	0.43±0.19	0.22±0.04	0.36±0.06
Pb (ng/l)	39±33	57±64	26±26	15±10	28±13	11±8	46±23
Zn (μg/l)	1.3±0.7	3.1±1.9	1.8±1.0	1.0±0.9	1.0±1.0	0.83±0.69	1.2±0.6

Where temporal studies exist, the data indicate that heavy metal concentrations have decreased over time. Lead (Pb) concentrations decrease with time, where older data sets show higher concentrations regardless of whether they are from pristine or industrialized areas. Long range atmospheric transport, an important input mechanism for lead that would not differentiate between harbours, has been decreasing over the last few decades, so the observations are consistent with what we know about lead transport. The two sample sets from Halifax Harbour (6 surveys from 1988/89 and 3 from 2001/02) show lower concentrations in the more recent surveys for cadmium (Cd), nickel (Ni), lead and Zinc (Zn) and higher concentrations for copper (Cu) but only the difference for cadmium is statistically significant. Decreasing inputs of most industrial heavy metals to Halifax Harbour over the past few decades have been recorded in dated sediment cores (Buckley et al. 1995). The counter trend for copper is not surprising since the main anthropogenic source for copper is sewage, not specific industrial discharges, and sewage inputs have not been decreasing. Temporal or spatial concentration differences for iron (Fe) and manganese (Mn) will be less related to direct industrial discharges and more to differences in pH or oxygen concentrations because the chemical reactivity of these two elements makes them much more soluble at low pH and low oxygen concentrations. The high levels of iron and manganese in Medway Harbour result from very high concentrations in the low pH Medway River. In the eutrophication status project (Strain and Yeats 1999) high concentrations of iron and manganese were invariably associated with very low oxygen concentrations.

PART C – MAJOR ECOSYSTEM COMPONENTS

9. FLORA AND FAUNA

9.1. Planktonic Communities

Plankton are aquatic micro-organisms, plant, animal and bacterial, ranging in size from less than 200 nm to over 2 mm. They can be free-swimming or suspended in the water, but both forms rely on ocean currents for movement. Plankton comprises a diverse group: species that spend their whole life history as plankton are holoplankton, while species whose life cycle has a planktonic stage, such as fish, crustaceans and echinoderms are meroplankton. Here, plankton are discussed as 6 main groups: 1. virioplankton, 2. protist plankton, 3. bacterioplankton, 4. phytoplankton, 5. zooplankton (including some meroplankton) and 6. ichthyoplankton.

Plankton communities in the inshore areas of the Scotian Shelf have not been well studied spatially or temporally, with a few important exceptions (Figure 33):

1. The Bedford Basin Plankton Monitoring Program (Li et al. 1998) has sampled one station in the Bedford Basin weekly since 1991, making observations of the biological, physical and chemical properties of the Bedford Basin.
2. The Atlantic Zone Monitoring Program (Pepin et al. 2005) has collected biological, physical and chemical data at a network of fixed stations in eastern Canada since 1998. One station, Station 2 off Halifax, is just outside the 25 km outer bounday of the study area.
3. DFO Phytoplankton Monitoring Program (PMP) collected biological, physical and chemical data from Whitehaven Harbour, Ship Harbour, Sambro, St. Margaret's Bay, Indian Point and Woods Harbour between 1989 and 1994 (Keizer et al. 1996a, 1996b). The PMP was a DFO response to several deaths due to amnesic shellfish poisoning in the late 1980s.
4. Historical Studies in St. Margaret's Bay (e.g. Platt and Irwin 1968; Therriault et al. 1978; Paranjape and Conover 1973), Petpeswick Inlet (Platt and Irwin 1972), Bedford Basin (Platt et al. 1973; Taguchi et al. 1975).

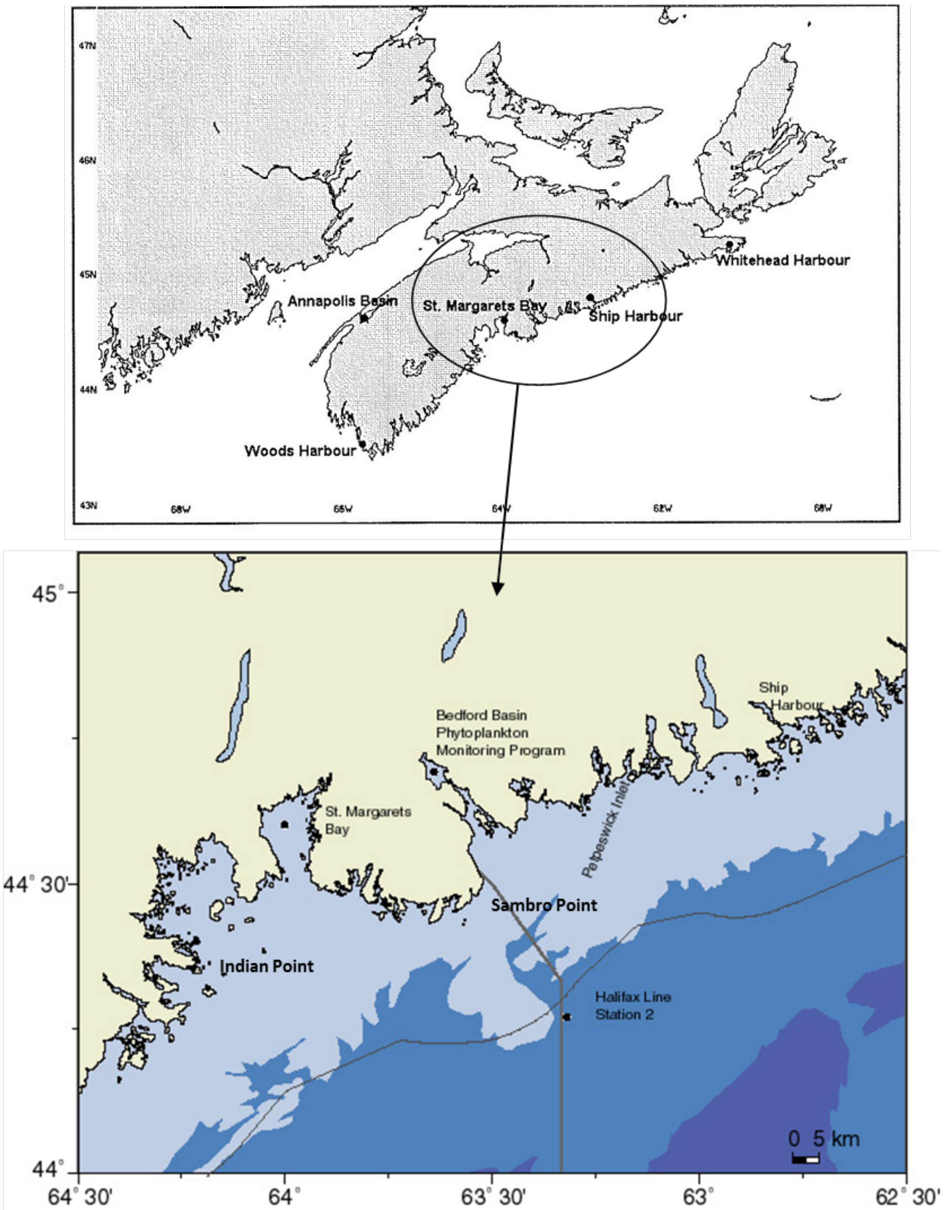


Figure 33. Location of some current and historical Nova Scotia phytoplankton sampling sites, including the DFO Phytoplankton Monitoring Program stations, the Bedford Basin Plankton Monitoring Program station, and Station 2 of the Atlantic Zone Monitoring Program.

9.1.1. Virioplankton

Contributed by W. Li

Viruses are the smallest and the most abundant biological entities in the plankton. These particles are so small (less than 200 nm long) that they are operationally misconstrued as a component of the dissolved organic material in seawater. Yet they are so abundant (concentrations of order 10^7 mL^{-1}) that in bulk, ocean virioplankton contain more carbon than 75 million blue whales (Breitbak et al. 2007). Viruses consist of genetic material (nucleic acid) surrounded by a protein coat, but have no intrinsic metabolism. They are obligate parasites of cellular hosts (bacterioplankton, phytoplankton, protistan plankton) which they infect in modes variously leading to immediate host death (lysis), delayed host death (lysogeny) or non-lethal parasitism (chronic infection).

As an agent of host mortality and gene transfer in the plankton, viruses play crucial ecological and evolutionary roles in the ocean: nutrient recycling, carbon flux, selective community structuring, and maintenance of biodiversity (Suttle 2007). It is estimated that viral lysis can remove up to 40% of prokaryotic (*Bacteria* and *Archaea*) standing stock each day, and that this approximates the impact of grazing as a source of microbial mortality. Dissolved organic material released from lysed cells enters into the biogeochemical cycles of nutrients and carbon. A plausible tenet yet to be generally confirmed is that because lytic infection is strain specific, species diversity of the putative host community is kept even by a selective killing of the most abundant hosts, simply because of higher encounter rates. There are likely hundreds of thousands of viral genotypes in the world's oceans. The facile movement of genes in the plankton community through mechanisms of lateral gene transfer allows viruses to act as genetic reservoirs for their hosts. It is not inconceivable that viruses may represent the storehouse of all genetic information on Earth (Suttle 2007).

In Bedford Basin, the annual cycle of virioplankton (Figure 34) is similar to that of bacterioplankton (Figure 37), abundance being about 10 times higher in summer than in winter. The ratio of virus to bacteria varies between 4 in the winter to 17 in the summer, averaging 7 for the year (Li and Dickie 2001). Although the ecological and evolutionary roles of virioplankton have not been assessed in the inshore waters of Nova Scotia, they might be expected to be similar to other coastal waters.

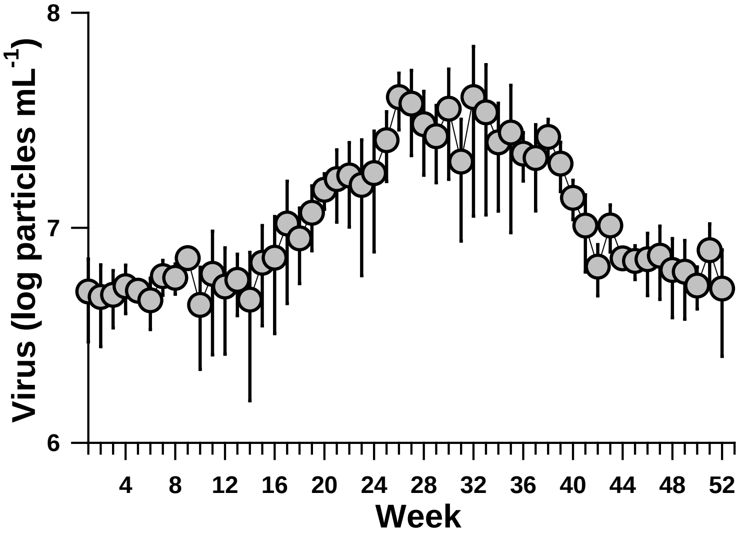


Figure 34. Annual cycle of virioplankton in surface waters of Bedford Basin, 1996-2000.

Seasonal variations in bacterioplankton and virioplankton reflect the trophic dependence of these microbial partners on each other and on the phytoplankton. Viral infection of bacteria or algae proceeds very quickly, causing host mortality that may be as high as about 50% per day. In the course of these short-term events, there can be an inverse relationship between host and parasite abundance. However, at longer time scales, the trophic phasing between bacteria and virus leads to parallel annual cycles that exhibit summer maxima and winter minima (Li and Dickie 2001).

9.1.2. Protist Plankton

Contributed by W. Li

Protists are unicellular eukaryotic microbes that have photosynthetic, heterotrophic or mixotrophic nutritional modes. Photosynthetic protists (phytoplankton) are discussed in Section 9.1.4. Heterotrophic and mixotrophic protists have no permanent chloroplasts (i.e. are aplastidic) and usually engulf their prey by phagotrophy. These protists include non-pigmented dinoflagellates, chrysomonads, bicosoecids, pedinellids, choanoflagellates, bodonids, ciliates, radiolarians, foraminiferans, acantharians and heliozoans. A familiar ciliate in Nova Scotian waters is *Mesodinium rubrum* which, when abundant, imparts a red coloration to the water but the cells remain non-toxic. This large protist ingests cryptophyte algae and robs the latter of their plastids to form a chimaera that is functionally photosynthetic (Gustafson et al. 2000).

It is known, but generally not well-appreciated, that heterotrophic protists account for the major portion of phytoplankton mortality, even in coastal ecosystems (Landry and Calbet 2004). Furthermore, protists can form a major portion of mesozooplankton nutrition, either as a supplement to phytoplankton, or in fact represent the primary food resource. A recent review concludes that heterotrophic dinoflagellates are likely to be more important consumers of bloom-forming diatoms than copepods and other mesozooplankton (Sherr and Sherr 2007). As a result of the feeding activities of protists, a large amount of dissolved organic matter is made available to bacterioplankton. Heterotrophy by protists lengthens the food chain from primary production to fish production, with consequent losses in ecological efficiencies.

In Bedford Basin, the abundance of heterotrophic protist plankton (Figure 35) peaks in late summer for the larger forms, and in early autumn for the smaller forms, consistent with the annual cycle of various tintinnid species in Bedford Basin (Paranjape 1987). Although the ecological roles of protist plankton have not been systematically assessed in the inshore waters of Nova Scotia, they might be expected to be similar to other coastal waters. The annual cycles of photosynthetic protists in Bedford Basin are well established from long record of observations (Figure 36; Li and Dickie 2001; Li et al. 2006a).

Figure 35. Annual cycle of protist plankton in surface waters of Bedford Basin. Microplankton (left panel): Taguchi and Platt (1978); nanoplankton (right panel): Li and Dickie (unpublished).

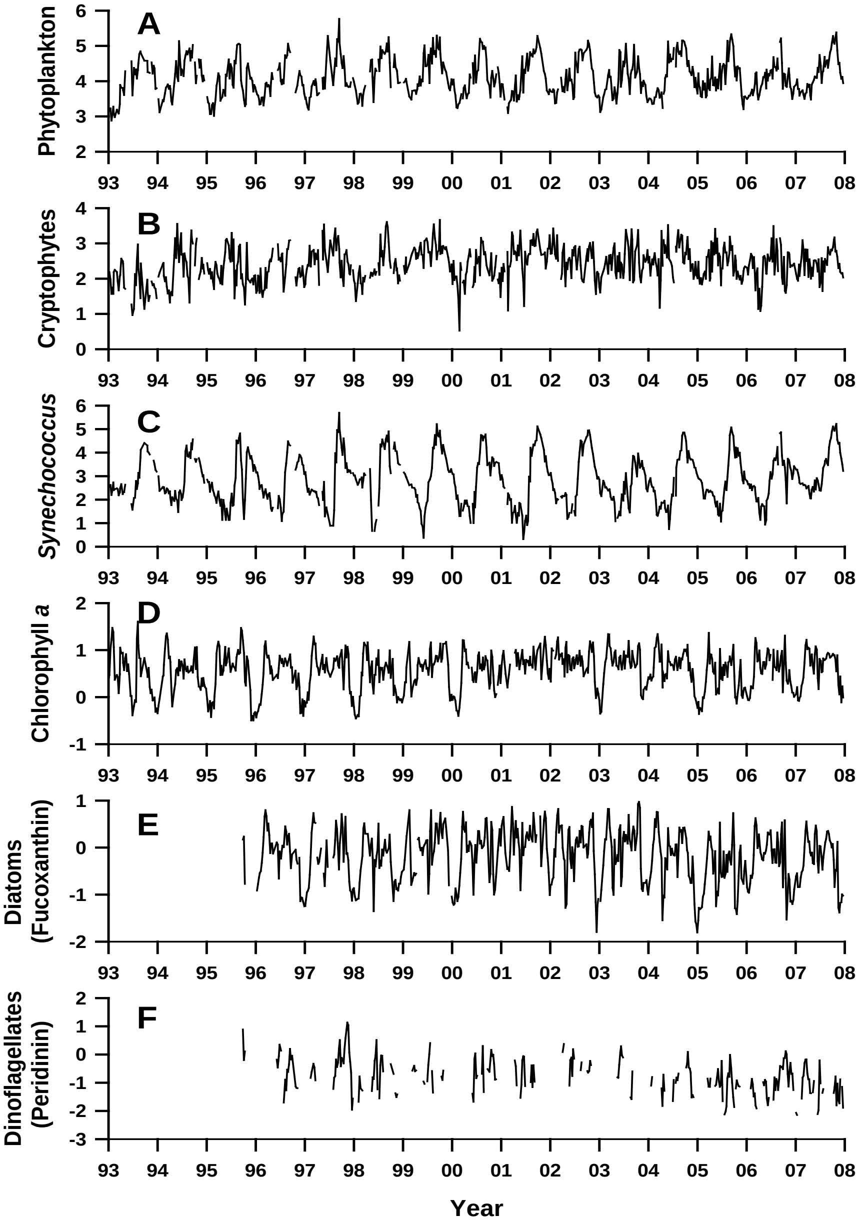


Figure 36. Fifteen year weekly record of photosynthetic protists in Bedford Basin. (A) phytoplankton cell concentration, (B) cryptophyte cell concentration, (C) Synechococcus cell concentration, (D) chlorophyll a pigment concentration, (E) fucoxanthin pigment concentration, (F) peridinin pigment concentration. Units are log cells mL-1 (A,B,C) and log mg m-3 (D,E,F).

9.1.3. Bacterioplankton

Contributed by W. Li and J. Sperl

Bacterioplankton are the smallest free-living planktonic organisms. They play a central role in the carbon flux of aquatic ecosystems by taking up dissolved organic carbon (DOC) and remineralizing the carbon (Ducklow et al.1993). They are unicellular prokaryotes belonging to the domains of Bacteria and Archaea and are preyed on by zooplankton. By size, they are usually 0.5 to 1 μm in the longest dimension, placing them in the picoplankton, a very diverse group.

Bacterioplankton include both primary producers (photoautotrophy and chemoautotrophy) and secondary producers (heterotrophy). The heterotrophic processes are the processes important in transferring, mineralizing and mobilizing dissolved organic carbon (DOC), nitrates and phosphate (Caron 1984, Azam and Hodson 1977, Ducklow et al.1993). Up to fifty per cent of primary production may be assimilated or commensurately respired by heterotrophic bacterioplankton, thus routing the products of primary production through the microbial loop (Ducklow 2003). As much as 80% of primary production routed through bacterioplankton has been recorded in the open Northwest Atlantic, highlighting an important component of the ecosystem that was overlooked decades ago (Ducklow et al.1993, Williams 1981), but now firmly accepted in contemporary views of marine microbial ecology (Kirchman 2000). In coastal inshore waters, the flux of primary production through the microbial loop is usually proportionately less than in deep ocean waters. Nevertheless, bacterioplankton play an important role in regulating the oceanic carbon sink, which is greater than the atmospheric carbon sink of CO_2 (Sharp 1993).

Heterotrophic bacterioplankton respond to phytoplankton blooms even deep below the euphotic zone (Ducklow et al. 1993). They vary in time along the same scale, though at a slower rate of growth than those bacterioplankton in the euphotic zone (Ducklow et al. 1993). This tandem variation is thought to result from the sinking phytoplankton and phytodetritus breaking down into its consumable constituents at that depth. Other sources of DOC exploited by the bacterioplankton include DOC released by zooplankton and viruses, and POC (particulate organic carbon) (Ducklow et al.1993). The coherence of multiyear trophically-linked changes in the standing stocks of phytoplankton and heterotrophic bacterioplankton have been noted at large spatial scales (Li et al. 2006b). At times, bacterioplankton populations are controlled by bottom-up factors such as the supply rate of organic or inorganic nutrients; at other times, bacterioplankton are controlled by top-down factors such as grazing by heterotrophic microflagellates (Caron 1984), and lytic mortality by viral infections.

The most intensive time series of bacterioplankton observations in the coastal zone of Atlantic Canada is associated with the weekly plankton monitoring program in Bedford Basin of Halifax Harbour (Li and Dickie 2001). Here, the observed maximum quantity of bacterioplankton supported by prevailing phytoplankton is higher than in offshore open ocean ecosystems (Harrison et al. 2005), and approaches the limit constrained by primary production (Li et al. 2004). In Bedford Basin, the significant influence of phytoplankton on bacterioplankton, a form of bottom-up control, can be discerned when the weekly measurements (Figure 37) are coarse-grained to the annual time scale. The positive rank correlation between normalized annual anomalies of the two microbial groups (Figure 38) indicates that long term changes in phytoplankton concentration can be propagated to the bacterioplankton.

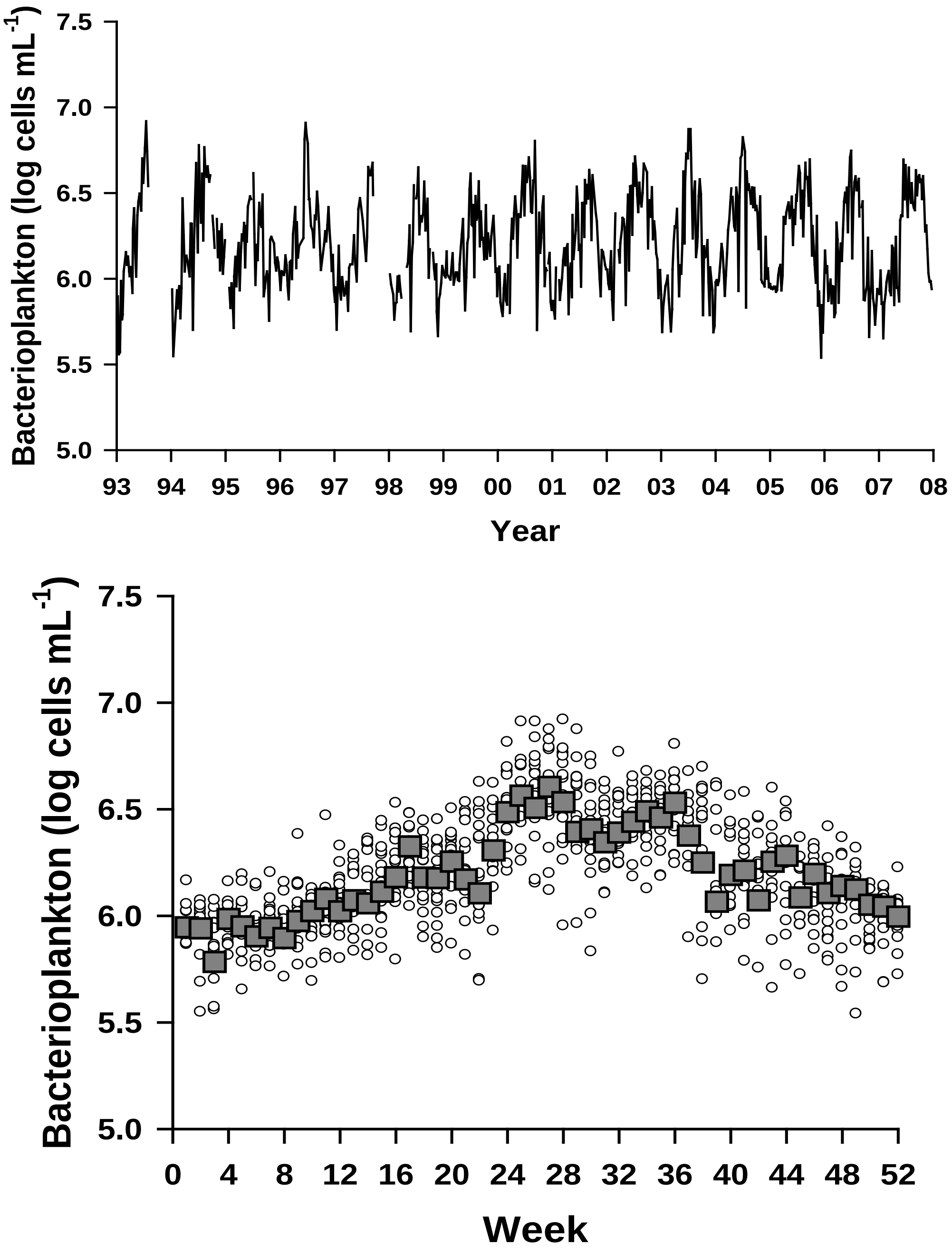


Figure 37. Fifteen year time series (line, upper panel), seasonal variation (circles, lower panel), and 1993-2000 climatology (squares, lower panel) of surface bacterioplankton numerical abundance in Bedford Basin.

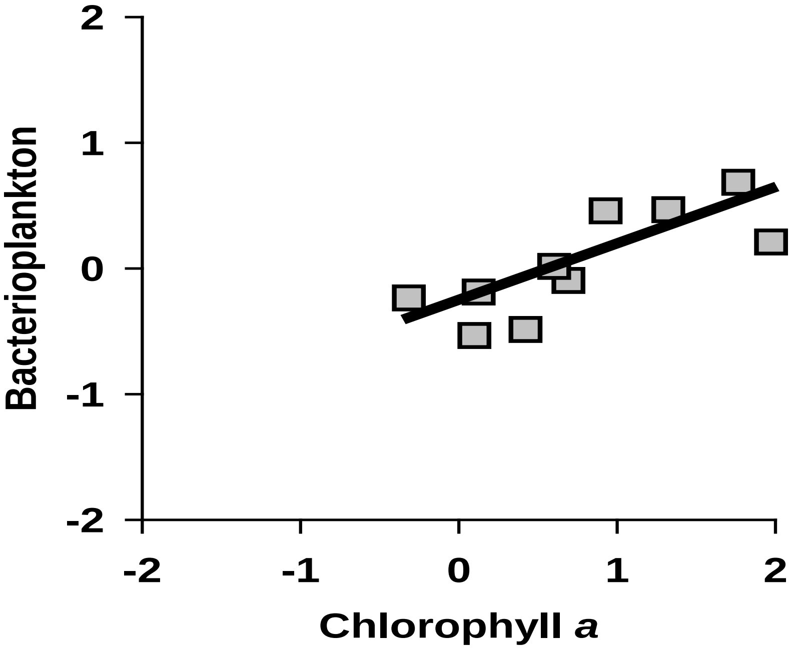


Figure 38. Rank correlation between normalized annual anomalies of bacterioplankton abundance and chlorophyll a concentration in Bedford Basin.

9.1.4. Phytoplankton

Contributed by J. Sperl, T. Platt and C. Caverhill

Phytoplankton are the primary producers of the oceanic ecosystem, providing the essential energy on which marine ecosystems are based. They are responsible for up to half of global photosynthesis (Barsanti and Gualtieri 2006) and like land plants, produce energy (sugar) from carbon dioxide and water, thus forming the base of the marine food web. This conversion process, photosynthesis, requires light and a photosynthetic pigment that functions to capture the light. There are several photosynthetic pigments, including chlorophyll a, b, c_1, c_2, phycobilins, xanthophylls and carotenoids that exploit different wavelengths of the photosynthetically-active radiation (PAR). The pigments can also protect the organism from intense light. In addition to light and carbon dioxide, phytoplankton also require phosphate and nitrate which often occur at concentrations limiting to growth.

Phytoplankton include diatoms, cyanobacteria, dinoflagellates and coccolithophores, euglenids and other single celled and colonial algae (Li et al. 1998; Graham and Wilcox 2000). Phytoplankton have been well studied on the larger Scotian Shelf, but in recent years there has been less emphasis on the inshore areas where primary producers include marine plants (see Section 9.2.2) in addition to phytoplankton. The principal environmental factors that affect inshore primary production are: surface irradiance, wind direction and intensity, topography of the inlet, and community structure and biomass of phytoplankton (Platt 1971, 1975; Platt et al. 1972). Surface irradiance can be depressed by coastal fog, and this in turn reduces primary production (Platt 1971). Intense wind will break down stratification of the water column and entrain nutrients from below the mixed-layer depth into the surface water, thus increasing primary production. The direction of the wind also plays a role through Ekman transport – bringing either nutrient-rich deep water inshore or warmer surface water, depending on the direction of the wind. If the wind is very intense, the inlet is flushed and whatever community structure has built up may be replaced with that of offshore water (Platt 1971). The topography of the inlet is also important. Deep basins with a high sill have more protection from offshore forcing than inlets with a less-pronounced sill (Platt et al. 1972).

Nova Scotia has many inlets parallel to each other along the coast and joined to the continental shelf. Observations show that these inlets experience the same perturbations as the shelf (Figure 39), but they do have some autonomy, especially in the spring when the biological forces are strong (Platt et al. 1972). In each inlet there is a seasonal cycle to unfold, but the effect of the weather on the shelf may perturb it. The trophic status of these inlets varies greatly with time. One study of the f-ratio (ratio of nitrate-based production to total production) in Bedford Basin showed the f-ratio to vary from values characteristic of eutrophic waters to those characteristic of oligotrophic values over the space of a few weeks from the start to finish of the spring bloom (Platt and Harrison 1985).

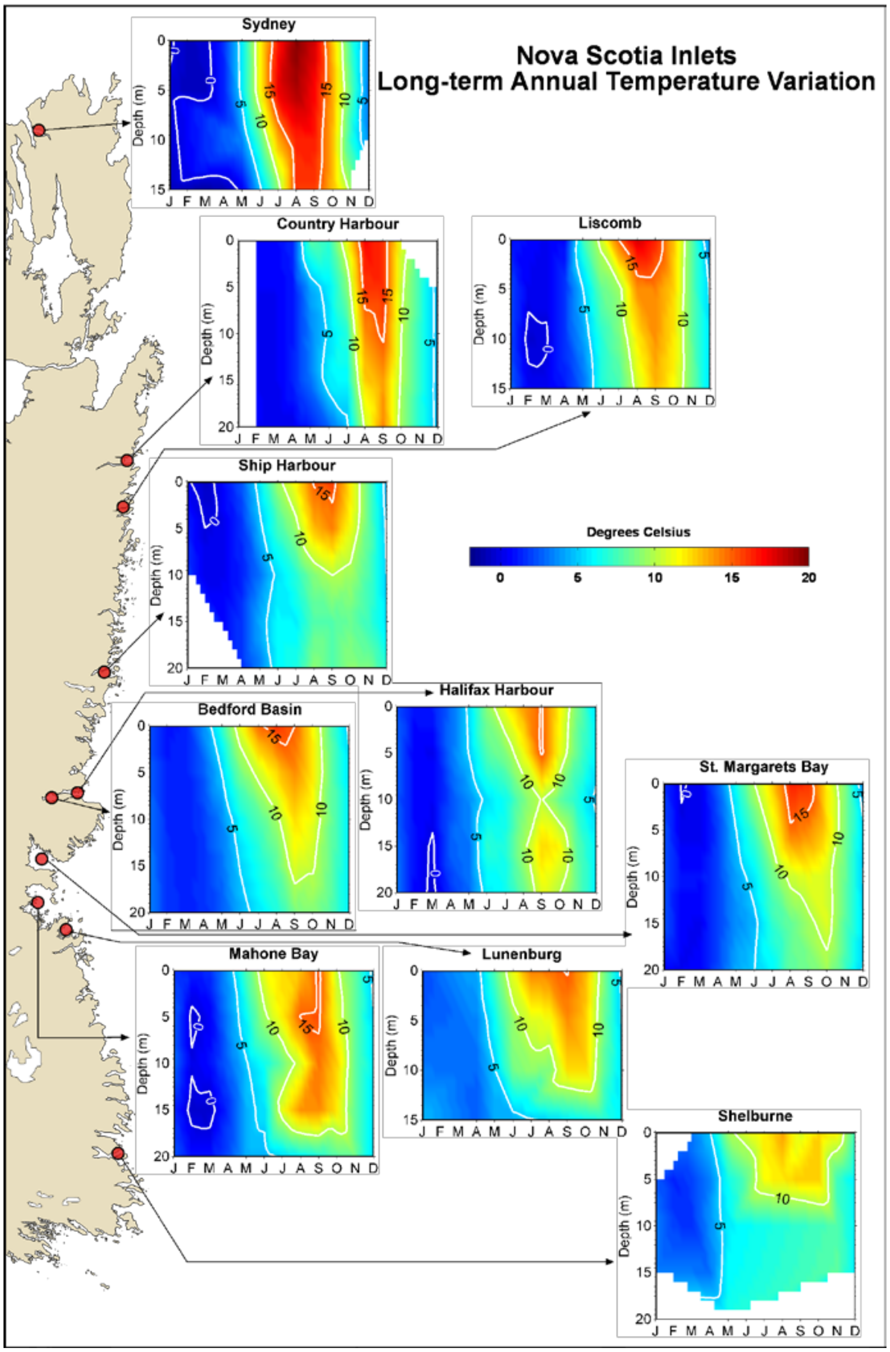


Figure 39. Temperature structure in various inlets along the Nova Scotia coast in late summer, 1924 (constructed by R. Pettipas, B. Petrie and L. Petrie) from data accessible from Bedford Basin Monitoring Prohect, Centre for marine Environmental Predictian and Ocean Sciences Division databases.

The annual cycle of phytoplankton occurrence is dominated by a strong peak in the early part of the year (the spring bloom). This phenomenon is so important and consistent that many organisms (fish and invertebrates) time their reproduction to take advantage of the increased biomass of phytoplankton (Cushing 1990, Platt et al. 1973). Usually the bloom, which may persist for several weeks, is brought to an end by exhaustion of nutrients (nitrate, phosphate). Consequently, during summer there is often a lull in phytoplankton production. However there is usually a second bloom in the autumn.

Canada has been estimating primary production along the Scotian Shelf since 1997 from chlorophyll fields produced by the NASA Sea viewing Wide Field-of-view sensor (SEAWIFS). The Bedford Basin also has a monitoring station that has been set up since 1991, where cell density, chlorophyll concentration, salinity, oxygen, nutrients, fluorescence, temperature and biomasses of phyto and zooplankton classes are recorded (McCullough et al. 2005). In the inshore areas of the Scotian Shelf, waters are optically-complex, and further research is recommended on the optical properties of inshore waters, community succession and photosynthetic response with a focus on flushing times of the inlets.

Hazardous algal blooms (HABs) are frequently associated with diatoms and dinoflagellates (Anderson et al. 2000; Graham and Wilcox 2000). Blooms are the rapid reproduction of a microscopic algal species and can be the result of an influx of nutrients or of unusual environmental conditions. The resulting high biomass of phytoplankton alters the habitat, depleting oxygen, tinting the water due to high cell density, and even shading the benthos (Anderson et al. 2000) and depleting oxygen when the phytoplankton cells die and decompose. The toxins that some algae produce can be taken up by filter-feeding shellfish, other herbivores, and accumulate up the food chain resulting in fish kills, and mass die offs in the benthos, birds, and marine mammals (Anderson et al. 2000). If shellfish containing toxins are consumed by humans, sickness may result, for example, neurotoxic, paralytic, amnesic, and diahrretic shellfish poisoning (Anderson et al. 2000). Many of the causative organisms of toxic phytoplankton blooms have been detected on the Scotian Shelf (Table 9).

Table 9. List of potentially toxic or harmful phytoplankton species detected at monitoring stations on the Atlantic coast of Nova Scotia (adapted from Bugden et al. 1992, McCullough et al. 2005).

Location	Species
Woods Harbour	*Alexandrium* spp., *Dinophysis* spp., *Prorocentrum* spp., *Nitzschia pungens* forma *multiseries*[1]
St. Margaret's Bay	*Alexandrium* spp., *Dinophysis* spp., *Prorocentrum* spp., *Nitzschia pungens* forma *multiseries*[1], *Nitzschia pseudodelicatissima*[2], *Chaetoceros concavicornis*
Ship Harbour	*Dinophysis* spp., *Prorocentrum* spp., *Nitzschia pungens* forma *multiseries*[1], *Nitzschia pseudodelicatissima*[2]
Tor Bay	*Dinophysis* spp., *Prorocentrum* spp., *Nitzschia pungens* forma *multiseries*[1], *Nitzschia pseudodelicatissima*[2]

[1] Present name is *Pseudo-nitzschia multiseries* (Bates, pers. comm. as cited in Stewart and White 2001).
[2] Now referred to as *P. delicatissima* group (J. Martin, pers. comm.).

The Phytoplankton Monitoring Program, mentioned previously, included a survey conducted at five coastal sites in Nova Scotia over a period of three years from 1989 to 1992 to determine what potentially toxic species of phytoplankton were commonly present. Approximately 26 times each year samples were collected from three depths at each of the sites in Whitehaven Harbour, Ship Harbour, St. Margaret's Bay, Woods Harbour and Annapolis Basin (Figure 33). Phytoplankton were sampled, identified and counted (Keizer et al. 1996a;1996b). This data remains largely unanalyzed.

9.1.5. Zooplankton

Contributed by J. Sperl, E. Head and A. Bundy

Zooplanktonare heterotrophic plankton that transferr energy from primary producers to higher trophic levels. As such, they are a critical component of aquatic ecosystems, including the inshore. They are the prey of many species at different life stages, including the many commercial species that are exploited in Scotian Shelf waters, as well as cetaceans and other fish and invertebrates. They exhibit a large size range, with the smallest group (20-200µm) including single-celled protozoans, such as ciliates, copepod eggs and larvae and the copepodite and adult stages of smaller copepod species. Large zooplankton (>200 µm) include the adults of many copepod species and the copepodite stages of the larger species, euphausiids, larval fish, larger larval mero- and holoplankton, jellyfish and ctenophores. Based on data collected by the Atlantic Coastal Monitoring Program at Station 2 on the Scotian Shelf (Figure 40, DFO 2004a), copepods dominate the abundance of the zooplankton.

Zooplankton data exist from the Bedford Basin for two time periods, 1969-1971 (Sameoto 1971b) and 1989-present (Bedford Basin Plankton Monitoring Program (Li 2000)). These data indicate that the species composition of zooplankton has not changed, and that species commonly found include *Acartia clausii, Calanus finmarchicus*, *Centropages* sp., *Eurytemora herdmani*, *Oithona similis*, *Pseudocalanus* spp., and *Temora longicornis*. Several of these species are found at Station 2 on the Halifax line outside Halifax Harbour, although their relative abundances are rather different in St. Margaret's Bay (Paranjape and Conover 1973). In the latter area, *Calanus* and euphausiid species densities were higher than in the Bedford Basin (McCullough et al. 2005).

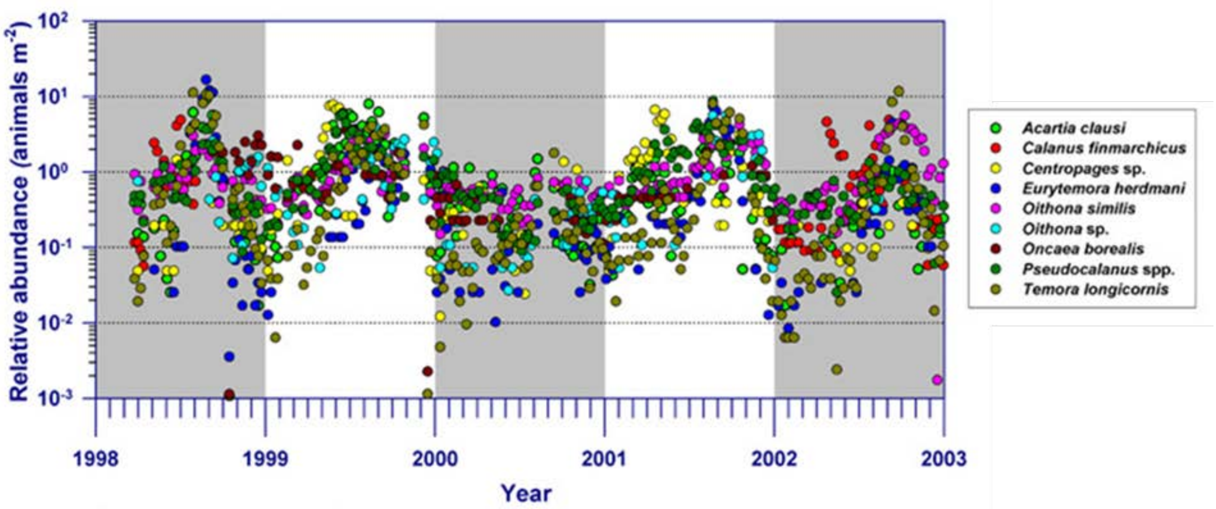


Figure 40. Relative abundance of all zooplankton crustacean in Bedford Basin (Bedford Basin Phytoplankton Monitoring Project database).

Zooplankton community composition was found to be relatively consistent around the coast of Nova Scotia in a study conducted during the summer of 2004 in 15 bays and estuaries around the coast of Nova Scotia from Chedabucto Bay to the Minas Basin (Beveridge 2005)[7]. This indicates high connectivity around the coast (see also Section 11.1.1), regardless of shoreline configuration. Community composition and abundance was explored in relation to bay size,

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[7] Beveridge notes that with further taxonomic resolution of samples, this conclusion many require modification.

depth, geographic distance and salinity, and was shown to be related to depth in bays and salinity in estuaries. Species found consistently at all sites included *Pseudo/Paracalanus*, *Temora*, *Acartia, Calanus*, *Centropages*, *Eurytemora*, *Oithona*, and *Tortanus.*

The abundance of zooplankton changes seasonally both in absolute terms and in species composition. Abundance peaks in late summer/fall in the Bedford Basin (Figure 40) and St. Margaret's Bay (Sameoto and Jaroszinski 1973). Sameoto (1971b) showed, in terms of biomass, that the main species changed from *Pseudocalanus* in May, to *Acartia* and *Pseudocalanus* in early July, to *Pseudocalanus*, *Acartia* and *Oithona* in September and to *Acartia* and *Pseudocalanus* in November. However, data from the AZMP program at Station 2 shows that *Oithona* spp. comprise about 40% of copepod abundance, although they only account for 10% of the biomass due to their small size.

Zooplankton include meroplankton which spend only part of their life in the planktonic form. They are abundant, diverse and include the larvae of many commercial species such as cod, haddock and lobster and non-commercial groups such as annelids, polychaete and nemertine worms, molluscs, echinoderms and crustaceans. Commerically important crustacean larvae such as American lobster (*Homarus americanus*) and crab have received some attention in the inshore (e.g. Dibacco and Pringle 1992, Miller 1997, Miller and Boudreau 2004). Molluscan species, such as oysters, mussels and scallops, are commercially important as harvest and aquaculture species. In addition to the harvesting of adults, their larvae (spat) are harvested for the aquaculture industry in inshore areas of the Scotian Shelf (Nova Scotia Ministry of Agriculture 2002).

9.1.6. Ichthyoplankton

Contributed by T. Lambert

A number of reproductive strategies are used by fish. Broadcast spawners release their eggs into the water where fertilization occurs externally (Chambers 1997; Scott and Scott 1988). The eggs are pelagic and are retained by hydrographic or geographic features so that they can mature. Species such as cod and haddock use this method. Other species, such as wolffish, mummichog and sticklebacks deposit their eggs in a mass on the bottom where they are fertilized (Scott and Scott 1988). After the eggs hatch the larvae remain close to the bottom. A few species undergo internal fertilization, and some, as in the case of the redfish, bear live young (Chambers 1997; Scott and Scott 1988). Skate produce an egg capsule (purse) which remains on the bottom and may take greater than 2 years for the egg to hatch. Whether eggs are released into the water column for wide dispersal, at a protective site, or live born, environmental conditions, food availability, parental health, and egg composition are all variables that determine the early life history of fishes (Chambers 1997).

In the marine environment most fish eggs range in diameter from about 0.7 mm to 2.5 mm. Eggs that are spawned demersally are generally larger than pelagic eggs and larvae that hatch from demersal eggs are also larger. No matter the size of the larvae, all possess a yolk sac when they hatch and become motile, which nourishes the larva until it is large enough to feed on small juvenile stages of copepods. This transition from endogenous nourishment to exogenous feeding is a critical stage in the life of marine fish, for if the larva fails to find food soon after depleting its yolk reserve, it will die of starvation.

Marine fish species do not release eggs all at the same time; there is rather a succession of spawning by species, with most of this activity occurring between about April to July. Along the Nova Scotia coast the earliest spawning is by Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*). The eggs of all these species are at the larger end of the size spectrum.The eggs of herring are demersal and generally attached to seaweed, whereas cod and plaice eggs are pelagic. As water temperatures increase, more species begin to spawn. By summer on the Scotian Shelf up to

15 species are producing pelagic eggs in contrast to four in early spring (Markle and Frost 1985). Typical mid-summer spawners are Atlantic mackerel (*Scomber scombrus*), Cunner (sea perch, *Tautogolabrus adspersus*) and Yellowtail flounder (*Limanda ferruginea).* Some species such as Atlantic herring and Atlantic cod have (or had, see Section 10.1.1) a complex stock structure with some contingents spawning in the spring and others in the autumn.

Data are scarce for coastal Nova Scotia since most plankton surveys were conducted offshore on the Scotian Shelf (see Breeze et al. (2002) for descriptions). However, there is some published information on herring and cod; their spawning areas were much more extensive in the past when they spawned in the fall and spring (Section 10.1.1). Although they spawned all along the coast, Chedabucto Bay and the approaches to Halifax Harbour appear to have been important areas for both species.

Other species that occur along the coast of Nova Scotia and are likely to spawn there include: pollock (*Pollachius virens*), common in inshore and offshore waters, appears to spawn from early autumn through the winter to early spring (Markle and Frost 1985); winter flounder (*Pseudopleuronectes americanus*) a shallow water species, spawns in the spring, its eggs are demersal and adhere together in clumps, hatched larvae likely to be common in plankton samples taken in the early summer; small demersals such as the four-beard rockling *Enchelyopus cimbrius,* shannies, blennies and small sculpins, such as the grubby *Myoxocephalus aeneus,* have demersal eggs but pelagic larvae; and the larvae of anadromous species such as smelt (*Osmerus mordax*) can be expected to occur in coastal waters from June through to August since the adults are caught in estuaries and rivers prior to heading upstream to spawn in freshwater during the spring (McKenzie 1964).

Mackerel are migratory visitors to Nova Scotia, en route to the Gulf of St. Lawrence, but they can spawn in coastal areas: when nearshore waters are warm, the mackerel travel close to land and some venture into bays and inlets where water temperatures are high enough to induce spawning (Section 10.1.1). Moderate numbers of eggs were collected in St. Margaret's Bay, just south of Halifax in the late 1960s by the Marine Ecology Laboratory (DFO) and low numbers were collected at scattered locations along the coastline, mostly between Yarmouth and Lockeport, during a survey conducted by the Fisheries Research Board of Canada in 1922.

9.2. Benthic Communities

The benthic community encompasses the breadth of plant and animal groups that occur in the marine environment: algae, infauna, a wide range of invertebrates and vertebrates that are closely associated with the bottom during their subadult and adult phase.

9.2.1. Microalgae

Contributed by J. Sperl and H. Vandermeulen

Algae are organisms that require submersion for their existence. They are autotrophs, able to remove nutrients from the surrounding waters through all of their outer tissues, which also contain light gathering pigments for the energy inputs of photosynthesis. The group as a whole is very morphologically and physiologically plastic, thus adaptable to a wide range of growing conditions. In some cases the form of the species can change so dramatically between environments that they were frequently defined as separate species.

Benthic microalgae consist of a variety of microscopic organisms which play a key role in the lower trophic levels of the benthos. Though large scale microalgal studies have yet to be conducted, known microalgae inhabiting the nearshore waters of Nova Scotia include filamentous algae, diatoms and bacteria (McCullough et al. 2005). Benthic diatoms can be found in and on surface sediments as a fine film (Grant et al. 1986). Even small pebbles on a shore can have a coating of microscopic algae that are only one cell layer thick or a fine uniserate filament of cells.

Benthic diatoms and filamentous cyanobacteria may have an important role in stabilizing subtidal intertidal sediments as well as shallow water sediments not regularly exposed to tides (Madsen et al*.* 1993). Stabilization is achieved on a spatial scale of centimeters and a temporal scale of days to weeks (Grant et al*.* 1986). The mucus strands from the diatom attach to the surrounding particles and help transfer organic matter from the water column and between the sediments (Grant et al. 1986).

Benthic microalgae can also be found growing on larger plants and animals as epiphytes. For example, Lyre crabs (genus *Hyas)* actively encourage algal epiphytes on their carapace as a form of camouflage. However, algal epiphytes growing on other macrophytes (seagrasses and seaweeds) can be more problematic. Blooms of epiphytes on eelgrass due to eutrophic conditions in nearshore waters can be detrimental to the eelgrass (Vandermeulen 2005). Nutrient loading increases the concentration of nitrogen and phosphorous in the water thereby enhancing the growth of annual micro- and macroalgae. The increase in phytoplankton, epiphytic, and free-floating macroalgae reduces the amount of light reaching seagrass for photosynthesis and growth, while the decomposition of dead algal matter enhances oxygen depletion and the development of anoxic sediments (Coll et al. 2008). The filamentous brown alga, *Ectocarpus*, can form very long (approximately 2 m) thick strands which can smother eelgrass and monopolize large patches in the shallows in the Bras d’Or Lakes (H. Vandermeulen, pers. comm.).

Benthic microalgae, whether growing on mud, sand, rocks or other organisms, are an important food source for a host of mesograzers such as snails, isopods and amphipods. The grazing of microalgae can have large scale effects on structure and function in the nearshore (Lobban and Harrison 1994).

Much of the information gathered on microalgae for our region is from the offshore with little effort directed at coastal waters (McCullough et al. 2005). There has yet to be a wide scale study detailing the microalgal species composition on a wide spatial distribution along the coast of Nova Scotia.

9.2.2. Macrophytes

Contributed by G. Sharp and A. Bundy

There are hundreds of species of macroalgae listed for the Atlantic coast of Canada, although 80 to 95% of the attached biomass in the photic zone is comprised of less than a dozen species (Table 10) (Novaczek and McLachlan 1989, Sharp et al. 2001).

Table 10. Common algal macrophytes on the Atlantic coast of Canada.

Species	**Common Name**
Ascophyllum nodosum	Rockweed or Knotted Wrack
Chondrus crispus	Irish moss
Palmaria palmata	Dulse
Phyllophora spp.	Dead Moss or False Moss
Ulva lactuca	Sea Lettuce
Fucus vesiculosus	Bladder Wrack
Fucus serratus	Toothed Wrack
Fucus distichus	Bladder Wrack
Saccharina longicruris	Lasagna Kelp Previously named: *Laminaria longicruris*
Laminaria digitata	Horsetail Kelp
Agarum cribrosum	Colander or Holey Kelp

Species of Atlantic coast algal macrophytes exist in a wide range of habitats from very sheltered brackish waters to the full salinity of wave-exposed outer coasts. In the most extreme case, macro algae can survive and grow as mobile unattached mats or floating material with an associated community and move with currents and winds. Attached macro algae need some degree of substrate stability relative to their ultimate mass and volume. Recruitment of ultimately large bladed kelp species can occur on very small rock or gravel substrate at the early gametophyte stage. Later, as these sporophytes grow, they offer more resistance to water movement and will be carried to deep water or the shore. Perennial kelp beds occur on more stable boulder and bedrock ledges. Some species such as *Fucus* spp have a reproductive strategy of continual summer gamete and germling production that enables them to exist in a more perturbed environment than other fucoid or kelp species. Red, green and brown algal species composed of single cell filaments in branched or unbranched forms are normally ephemeral and seasonal in their abundance. Species with long-lived holdfasts create an organic covering closely adhering to the micro crevices of rocks. Similarly prostrate species of red algae, both calcareous and fleshy, form an organic crust on the substrate. Calcareous species can actually stablize a friable substrate and allow other perennial species to develop.

The strongest environmental gradient for seaweeds is water depth for subtidal species and tide height for intertidal species. Classic zonation of the shore is defined by a gradient of species dominance (Lewis 1976) (Figure 41). The intertidal zone is one of environmental extremes, desiccation and temperature fluctuations both daily and seasonally. It is also a zone of strong inter-specific competition for space and resources. Herbivoury structures this zone because the early stages of spore or zygote settlement are very susceptible to grazing (Lubchenco 1983). Settlement stages of invertebrates including barnacles compete with the germlings of algae and in parts of the zone become the dominant cover rather than algae. These competitive dynamics can be complicated by the addition of other secondary producers preying upon settlement stages of invertebrates.

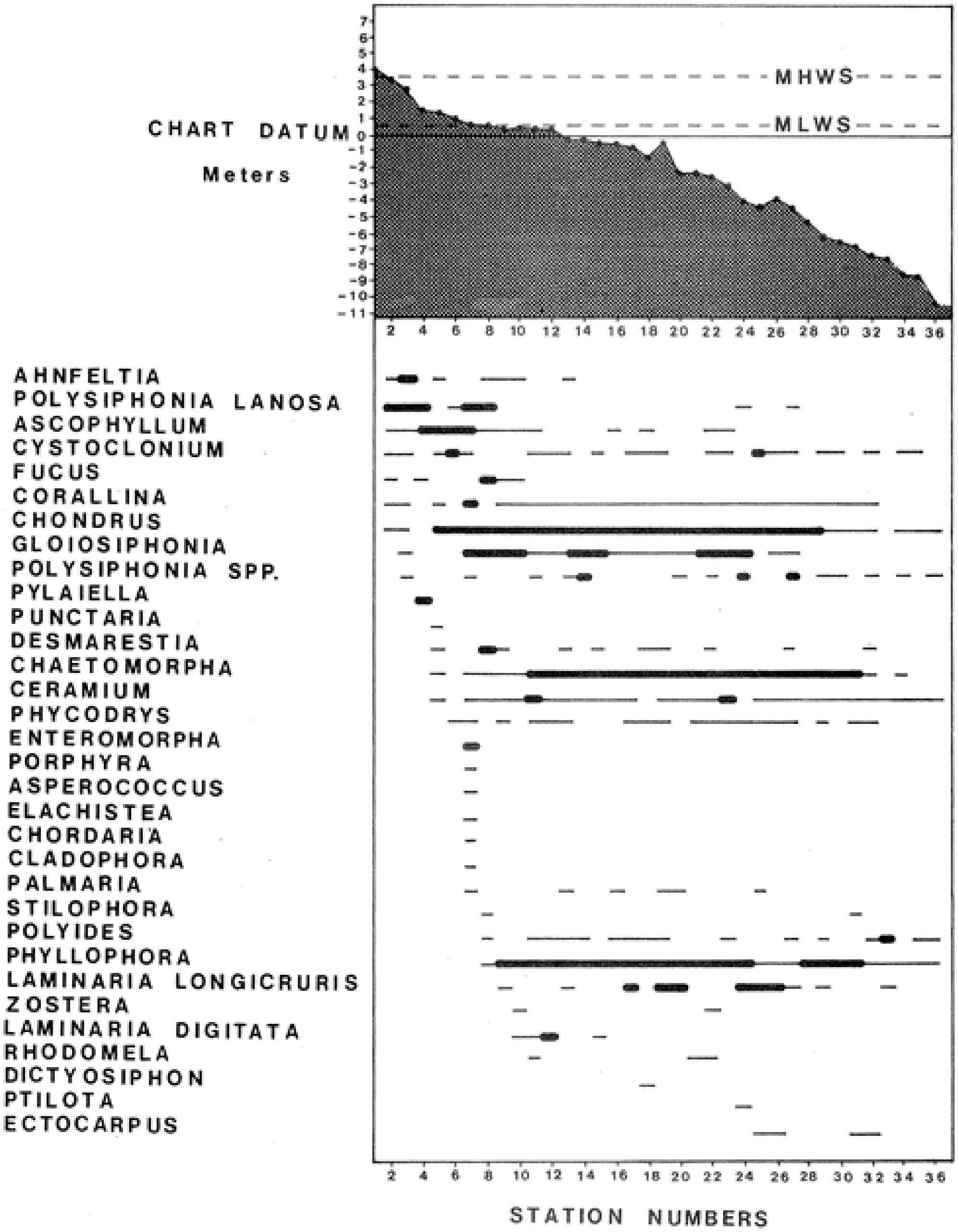


Figure 41. Relative abundance of dominant algal genera on an intertidal to subtidal transect in southern Nova Scotia (adapted from Lewis 1976).

The two major factors affecting the abundance of intertidal species are tidal range and ice coverage. Tidal range varies between southwestern Nova Scotia and eastern Nova Scotia: at Clark's Harbour in the western edge of the region, the tidal range is 3.0 m whereas in Bay St. Lawrence, Cape Breton, at the eastern end, the tidal range is 1.5 m (Section 7.2). This means the intertidal zone is wider given the same slope of the shore in southwestern Nova Scotia. Ice is the other major factor along the coast (Section 7.6): while the ice remains fast to the shore, it has little impact but on break up, ice moving with the wind and current can scour the intertidal of all upright portions of macrophytes. This creates advantageous conditions for *Fucus* spp and many ephemerals that are able to quickly colonize open substrate (McCook and Chapman 1997, Ugarte et al. 2010).

The ultimate stability of the intertidal community is confirmed by a description of the rocky intertidal zone of Nova Scotian shores by Stephenson and Stephenson (1954) that still reflects the situation in 2007. Most of the algal species in the intertidal zone are the brown algae *Ascophyllum* and *Fucus*. *Ascophyllum nodosum* is the predominant species, occurring in more sheltered areas of the intertidal zone (Scrosati and Heaven 2008, Ugarte et al. 2010). *Fucus vesiculosus* is also found in the rocky intertidal zone, but in lesser quantities. It appears especially in more wave exposed or ice-scoured areas and in the upper and lower portions of the *Ascophyllum* beds (Ugarte et al. 2010). The brown seaweeds, *Polysiphonia lanosa* and *Pilayella littoralis*, are common epiphytes of *Ascophyllum*. Two other fucoids, *Fucus evanescens* and *F. serratus*, are also found in the lower intertidal regions in some areas (Ugarte et al. 2010). The most diverse algal community occurs at the subtidal fringe where red, brown and green species mix in the sharp gradient from emersion to submersion. Depending on substrate type and wave exposure *Chondrus crispus* can dominate this fringe, occurring at depths from zero to one metre below mean low water (Figure 42).

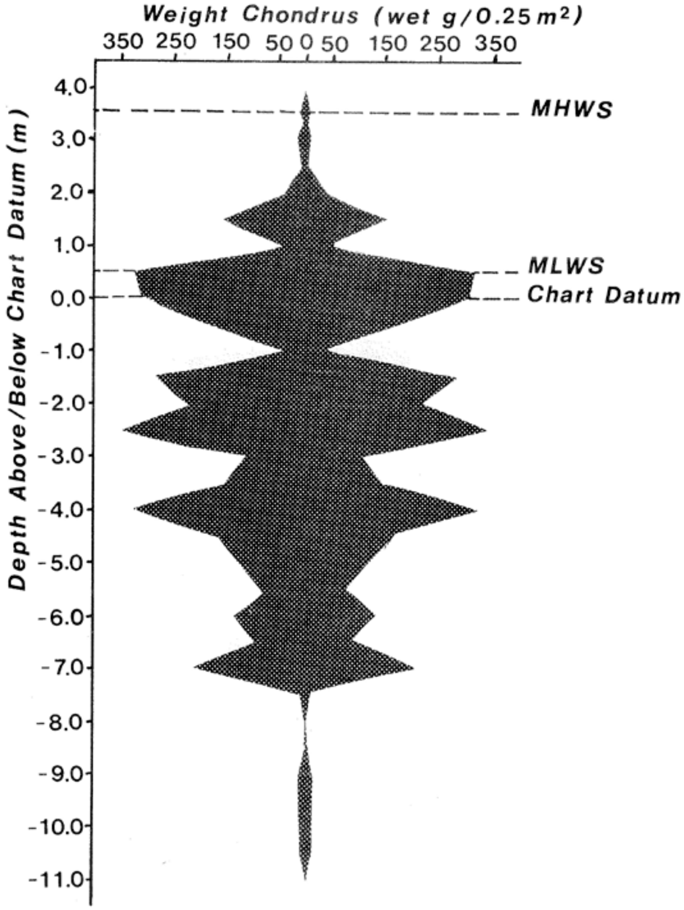


Figure 42. The distribution of <u>*Chondrus crispsus*</u> *biomass with depth (MHWS – Mean High water; MLWS – Mean Low water) (Pringle et al. 1980).*

This part of the zone is rarely a pure stand; epiphytic filamentous reds, associated bladed greens and filamentous greens are also usually present. Kelp species (*Alaria esculenta, Saccharina longicruris* and *Laminaria digitata*) recruit into the fringe subtidal zone in the spring, but these populations are subject to thinning during the summer. Stable beds begin at depths of 1 m to 3 m below mean low water, and species diversity is highly correlated with wave exposure (Sharp and Carter 1986). *Laminaria digitata* dominates in wave-exposed locations while *Saccharina longicruris* is most abundant in wave-sheltered areas.

While kelp beds may be so dense as to prevent an understory (a low level layer of macrophytyes), more frequently the beds are patchy and allow open areas where primarily red algal species, most commonly *Phyllophora* spp. form the understory. Algal biomass diminishes greatly below 13 to 15 m depth, but the low light tolerant red algal species *Ptilota serrata* is found down to 30 m.

Coralline algae include the erect branching species *Coralina officinalis,* which forms an understory, and *Lithothaminon* which forms a calcareous crust that persists to the deepest algal zone 15 m+. These algae are very resistant to grazers and can be the only surviving algae in areas of sea urchin barrens (see below). Encrusting corallines also stabilize substrate providing a base for the holdfast of fleshy macrophytes. The depth limits described above can be highly affected by water clarity since the photosynthetic limits for these species depend on light penetration. If there is a steady source of particulates from either groundwater or river in flow and pollutants, the maximum depth of distribution will decrease.

In areas of high tidal flow, the normal distribution of sheltered algal communities can change to one resembling open exposed waters with dense kelp beds of *L. digitata* in tidal rapids and a dense understory of tufted red algae. Tide pools create another special environment that provides a habitat in the intertidal for species that are normally subtidal. The mix of species found in these pools depends on the degree of flushing or renewal of water related to the tide level of the pool.

Algae are themselves habitat for secondary producers. They provide a food source for grazers such as gastropods and amphipods. The complex structure of shoots, branches and plants provide shelter from predators and buffer dessication, temperature and water movement (Johnson and Scheibling 1987). Some life stages of bivalves use filamentous and tufted algae as their primary settlement sites and then secondarily settle on adjacent inorganic substrate. Fishes move in and out of intertidal canopies with the rising and falling tides. In the canopy they can forage for food and get some protection against piscivorous birds (Rangeley and Davies 2000). Seaweeds in the intertidal zone can influence populations well beyond that habitat into the pelagic and subtidal benthic environment (Figure 43). Subtidal kelp beds have a suite of associated species including epiphytes (Section 9.2.1), attached sessile invertebrates and free living macroinvertebrates and fish.

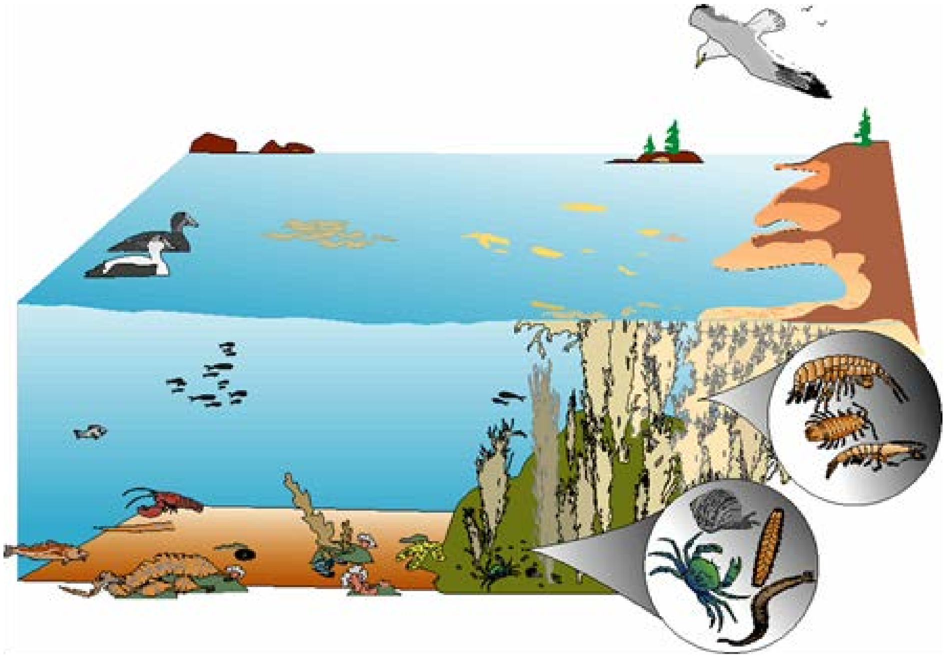


Figure 43. The benthic habitat at high tide in and adjacent to an Ascophyllum nodosum (rockweed) bed.

Ultimately intertidal and subtidal algal beds are the most important primary producers in coastal embayments or estuaries and contribute significantly to the detrital pool. They are also important parts of the nutrient and carbon cycle in the nearshore (Mann 1972; Section 11.2). In areas where seaweed production was measured in a coastwide study, Moore and Miller (1983) estimated that seaweed production was 10 times greater than phytoplankton production per unit area, and equivalent to phytoplankton production from shore to the 90 m contour. In open water systems such as the Bay of Fundy or the Scotian Shelf where depths are beyond photic zones, they represent only a small percent of the total production of phytoplankton (Prouse et al. 1984).

The spread of an invasive species, *Codium fragile* (dead man’s fingers) to Nova Scotia in the 1990s (Bird et al.1993) threatens this cycle. *C. fragile* has successfully spread and colonized inshore areas to the extent that it dominates in areas previously dominated by kelp beds (Harris and Tyrrell 2001, Chapman et al. 2002, Mathieson et al. 2003). Healthy kelp beds are able to resist the establishment of Codium, but another invasive species, the epiphytic bryozoan *Membranipora membranacea*, has facilitated the establishment of *C. fragile* (Scheibling et al. 1999, Chapman et al. 2002). *Membranipora* infests kelps, causing fragmentation and loss of fronds (Dixon et al. 1981), resulting in loss of kelp bed cover, thus allowing space for *C. fragile* to establish. Once established, *C. fragile* outcompetes kelp, prevents its re-colonisation, then persists as the dominant canopy-forming seaweed for prolonged periods (Scheibling and Gagnon 2006; Saunders et al. 2010). The impacts of the replacement of kelp by *C. fragile* are not fully known. However, they could include changes in the structure and functioning of the inshore communities, such as changes in food quality, changes in species composition due to change in habitat (Scheibling and Gagnon 2006), and a negative effect on the sea urchin population due to a reduction in the capacity of individuals feeding on *C. fragile* to grow and reproduce (Lyons and Scheibling 2007). Kelly et al. 2011 tracked changes in community composition at a rocky subtidal site from 1992 to 2008. Composition changed from a dense aggregation of sea urchins grazing on the kelp bed and leaving coralline-algae-dominated barrens through a series of state shifts mediated by mass mortality of sea urchins due to amoebic disease, defoliation of kelp by an invasive bryozoan Membranipora membranacea, invasion of the green alga Codium fragile ssp. fragile, and finally decline of C. fragile and recolonisation by kelps. They distinguished four macroalgal assemblage types (dominated by kelp, coralline algae, C. fragile, or a transitional mixture of species), each associated with a distinct invertebrate assemblage. Sea stars and kelp-grazing gastropods were associated with the kelp-dominated state; sea urchins, chitons and scale worms were most abundant in the barrens state; and small bivalves and amphipods were most abundant in the C. fragile-dominated state.

The positive relationship between water temperature and the degree of Membranipora encrusting, leading to defoliation of kelp beds, and consequent colonization by Codium has implications given that sea surface temperatures are expected to increase (Saunders et al. 2010). Additional factors that can increase the erosion rate of kelp are wave exposure and grazing by snails, which in combination with bryophyte invasions are likely to increase losses from coastal beds to offshore communities. Detritus transport rates from subtidal kelp beds in relation to wave exposure, grazing and invasive species were studied at five sites between St. Margaret’s Bay and Halifax Harbour by Krumhansl and Scheibling (2011a, 2011b). They calculated annual production rates of 0.5-1.71 kg/m^2 that equal or exceed annual phytoplankton production and detrital production from seagrass beds.

Seven algal species have commercial value in Atlantic Canada; *Ascophyllum nodosum*, *Fucus* spp. *Chondrus crispus*, *Palmaria palmata*, *Saccharina longicruris*, *Laminaria digitata. Ascophyllum nodosum* (rockweed) harvests have occurred annually since 1959 and have exceeded 20,000 t per year since 1986. Management on an area basis is controlled by the Nova Scotia and New Brunswick provincial governments (Figure 44). All the rockweed resource is licensed except for the shoreline east of Halifax and the Gulf of St. Lawrence. Overall exploitation rates range from 15 to 25% of the harvestable standing crop annually with a total harvest of 36,547 tons in 2008 (Table 11).

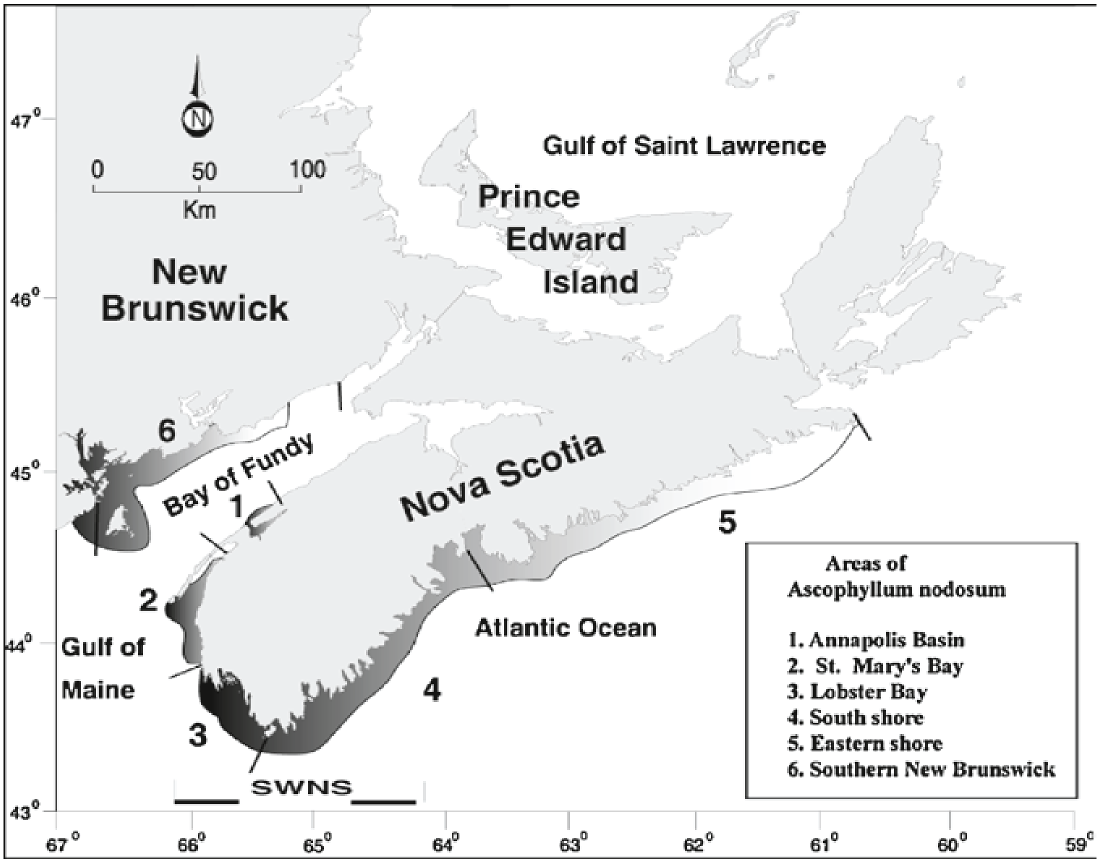


Figure 44. Ascophyllum nodosum distribution in Nova Scotia and southern New Brunswick. Darkest areas along the coastlines indicate zones having higher concentrations of biomass (SWNS: Southwestern Nova Scotia) (Ugarte et al. 2010).

Table 11. Total rockweed biomass and landings in the rockweed areas of Nova Scotia and New Brunswick in 2008 (Ugarte et al. 2010).

Rockweed Area	Area covered (hectares)	Standing stock (wet tons)	Accessible area (hectares)	Landings 2008	Yield (tons/ha)
1	35	998	35	500	14.3
2	93	9,031	47	844	18
3	1,073	91,758	977	20,061	20.5
4	677	42,125	229	3,839	16.8
5	1,250	50,000	0	0	0
6	1,832	158,811	830	11,303	13.6
Total	4,960	352,723	2,118	36,547	

9.2.2.1 Salt Marshes

These occur in sheltered areas along the shore where mud and silt can accumulate, largely in the intertidal zone (Section 4.1) providing another type of sheltered habitat for many species, including fish such as sticklebacks and mummichogs and invertebrates such as snails, shrimp, and crabs. Furthermore, they can be important nutrient exporters; detritus is exported on ebbing tides, contributing to the food resources of the nearshore community (Mann 2000).

Salt marshes occur on stable or emerging coastlines when sediment collects in sheltered intertidal areas in estuaries, behind spits, bars, or islands (Davis and Browne 1996a). A characteristic of a mature salt marsh is the presence of drainage channels and creeks. The areas of salt marsh closest to the estuary are the most mature, for as sea levels have risen over the centuries, salt water has penetrated further inland, creating marsh area (Dame et al. 1992). Salt marshes have two zones, the high marsh which is located above mean high water level and the low marsh which is located below mean high tide level (Figure 45). The high marsh is inundated only during the highest tides or storm surges, whereas the low marsh is frequently inundated by marine waters. Salt marsh flora consists of salt tolerant flowering plants, algae and microscopic fungi (Davis and Browne 1996a). In Atlantic Canada, the high marsh is dominated by salt marsh hay (*Spartina patens*) and the low marsh is dominated by the cord grass (*Spartina alterniflora*) (Figure 45, Raffaelli and Hawkins 1997). Salt marshes occur around the Atlantic coast of Nova Scotia (Figure 46). The most extensive areas of salt marsh are found between Halifax and Ship Harbour along the Eastern Shore, and between Lockeport and Port Mouton on the South Shore (Table 12). Human activities such as shoreline development are the main threats to salt marshes.

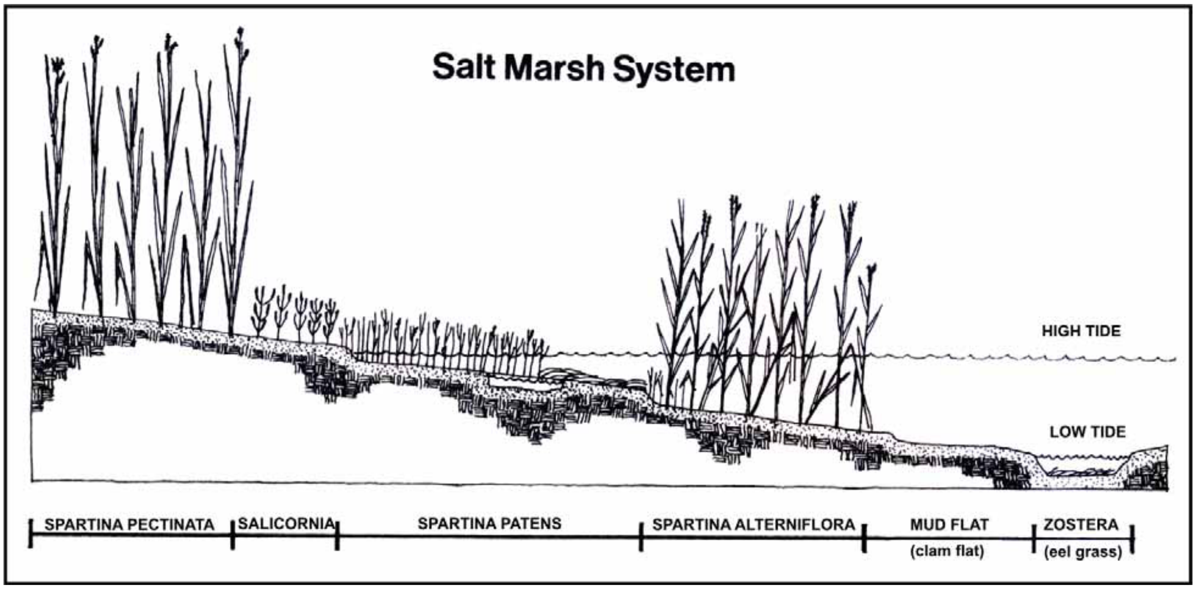


Figure 45. Schematic of a typical salt marsh system (CBCL Limited 2009).

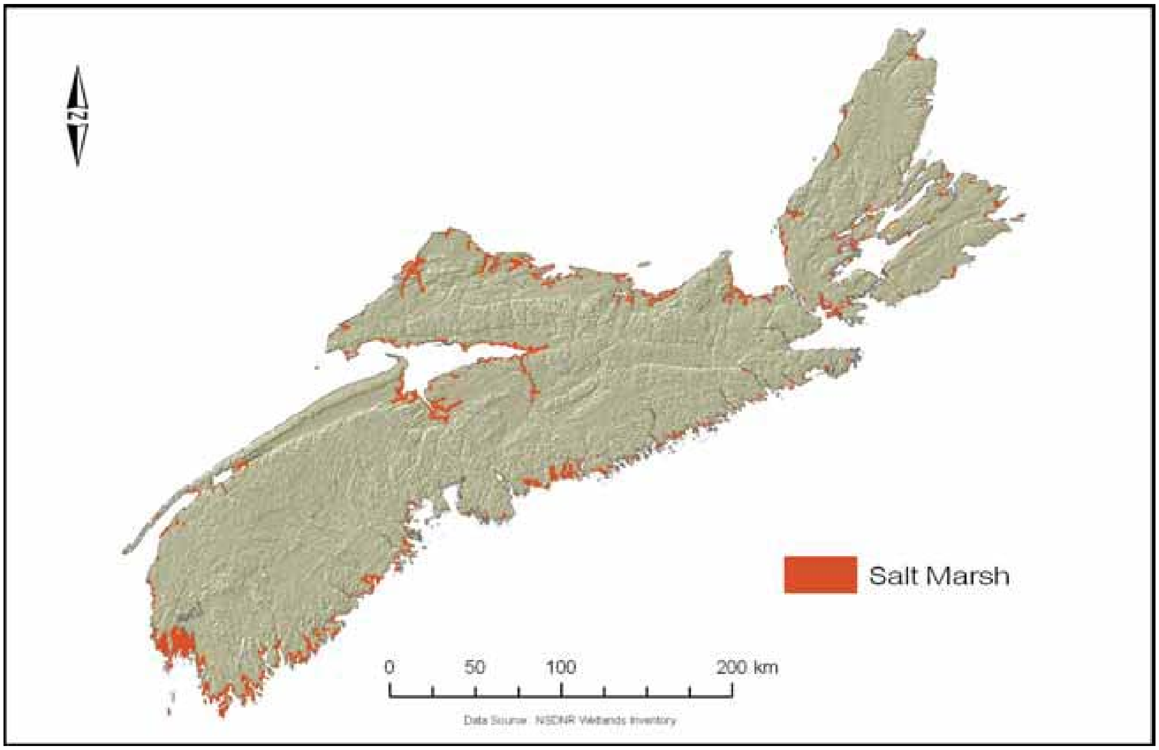


Figure 46. Distribution of salt marshes in Nova Scotia (CBCL Limited 2009).

Table 12. Distribution of salt marshes in Nova Scotia by county (area in hectares) (Davis and Browne 1996a).

County	High Saltmarsh	Low Saltmarsh
Annapolis	122	103
Antigonish	61	228
Cape Breton	96	198
Colchester	723	463
Cumberland	1387	1098
Digby	268	380
Guysborough	77	78
Halifax	173	704
Hants	892	692
Inverness	118	248
Kings	617	832
Lunenburg	111	148
Pictou	41	275
Queens	144	118
Richmond	85	176
Shelburne	487	713
Victoria	91	168
Yarmouth	1650	1508

9.2.2.2 Eelgrass

Eelgrass or seagrasses are typically associated with tidal marshes and require fine sediments in which to anchor their roots (Davis and Browne 1996a). The most commonly occurring species in the inshore region is *Zostera marinus,* which can be frequently found growing in the lower intertidal and subtidal areas of shallow bays and inlets (Keddy and Patriquin 1978; Patriquin 1981). The beds provide important nursery habitat for fish and invertebrates by providing protection from predators, substrate for attachment of invertebrates and epiphytic algae (Section 9.2.1) and an abundant supply of food (Thayer et al. 1984). In most areas, about 10% of eelgrass production is consumed as fresh material (Mann 2000). Dabbling ducks and geese feed extensively on intertidal eelgrass beds during the winter. Most of the production decays and forms detritus, providing a rich food base for a host of detritivores such as shrimps, amphipods, crabs, and fish. Other species, such as filter feeding bivalves and polychaetes, feed on suspended detritus in the water column, while deposit feeders such as polychaete worms feed on detritus buried in the sediment (Mann 2000).

Eelgrass beds are subject to both biological and human threats. A wasting disease caused by the fungus *Labyrinthula* sp. in the 1930s caused massive die offs along the eastern coast of North America. Recovery from this loss has been slow (Schaefer et al. 2004). Green crab (*Carcinus maenus*) is an invasive species that disrupts eelgrass beds by burrowing in the sediments and tearing plants from their sheaths (Davis et al. 1998, Garbary and Miller 2006).

Human threats include coastal development and recreation, high nutrient loadings, aquaculture and harvesting. Throughout the 20th century eelgrass was used commercially in the region. During the 1990s, eelgrass beds studied in four inlets (Cole Harbour, Chezzetcook, Petpeswick and Musquodoboit Harbour) on the Eastern Shore of Nova Scotia were dense and extensive, but anecdotal evidence indicated a rapid and massive decline of populations between 1999 and 2002. In a study designed to quantify this loss, Chapman and Smith (2006) estimated an average decline of intertidal *Zostera marina* beds of 79.5% ± 20.8% (SD), with Petpeswick having the greatest loss (96%) and Cole Harbour the smallest (49%). There were no consistent patterns in eelgrass *Zostera* disappearance, i.e. neither sediment type, exposure, location within the inlet or population features explained the decline of some beds and persistence of others. They also did not find symptoms of the wasting disease. In other parts of Nova Scotia, Sharp and Semple (2004) estimated an eelgrass decline of 30% and 44% between 1978 and 2000 for two areas in Lobster Bay, Yarmouth County and Garbary et al. (2004) documented a 95% decline in eelgrass in Antigonish Harbour between 2000 and 2001.

9.2.3. Infaunal Invertebrates

Contributed by J. Sperl, E. Kenchington, D. Roddick and A. Bundy

Infauna is the collective term for animals that live in the sediment, and includes species such as annelids (segmented worms), molluscs, arthropods, foraminifera (amoeboid protists), sipunculids (peanut worms) (Davis and Browne 1996a, Schaefer et al. 2004, McCullough et al. 2005, Stewart et al. 2001, 2002). Most members of this group are deposit feeders and important recyclers of energy in the ecosystem, transferring energy to higher trophic levels.

The distribution and abundance of benthic species in intertidal communities can be affected by many biotic factors such as predation, competition and recruitment and abiotic factors such as nutrient availability, habitat structure, light, salinity and physical stress (Menge and Sutherland 1987, Underwood and Fairweather 1989, Menge and Branch 2001). Although there are no systematic detailed studies of the infauna of the inshore Scotian Shelf, they occur in soft bottom habitats such as sandy beaches, salt marshes, and mudflats (Davis and Browne 1996a).

Invertebrates have an important role in the ecosystem, as energy recyclers, as keystone species, bioindicators, bioturbators and some are harvested for local and commercial purposes.

Here, we review the research on amphipods, polychaetes and commercially harvested blood and sand worms, quahogs and soft-shelled clams.

9.2.3.1 Amphipods

Amphipods are an important order of infauna and have been documented as keystone species for fragile mudflat ecosystems, such as in Minas Basin (Percy 1999). The amphipods that dwell in the mudflats of the Minas Basin (not in our study area), Cape Breton and along the sandy beaches which appear along the entire Atlantic coast are an important food source for migrant and local shore birds (Percy 1999, Schaefer et al. 2004, Davis and Browne 1996a) and many juvenile fish in the inshore habitat (Bowman et al. 1987). The keystone species in the Minas Basin area is *Corophium volutator (*Percy 1999*).* Corophium is a critical component of the diet of the migrant and endangered piping plovers, comprising 95% of their diet, enabling piping plovers to double their weight at multiple sites in the Bay of Fundy, Minas Basin and possible other sites along the Inshore Scotian Shelf (Percy 1999, Schaefer et al. 2004). This species has been documented within the Inshore Scotian Shelf; however, it has not been extensively studied as a keystone species (Schaefer et al. 2004).

Amphipods have a complex role with the sediments: they can destabilize sediments by consuming diatoms and other microalgae that binds sedimentary particles together (Section 9.2.1) and they can stabilize the sediments with their burrows (Percy 1999). They feed on the microalage that colonize sediment particles, thus they are abundant on fine sediments which have a larger area for organic films. However, if the sediment is too fine, the burrows will collapse (Percy 1999). On mudflats, amphipods stave off encroaching vegetation, bury marsh grass seeds, uproot successfully germinating grasses and destabilize the sediment by eating the microalgae (Percy 1999), thus contributing to the maintenance of the mudflat. Amphipods are very sensitive to biotoxins and are an ideal organism to monitor sediment and ecosystem health (Tay et al. 1992, Percy 1999, Pocklington and Wells 1992).

There are no estimates of the abundance of amphipods in mud substrates on the Atlantic Coast of Nova Scotia but in Minas Basin, an average productive flat contained between 10,000 – 20,000 amphipods per m^2, though not all year round (Percy 1999). In contrast, the most abundant amphipods in a rocky, subtidal ecosystem in Mahone Bay were *Gammarus* and *Caprella* with maximum average densities of 2055 and 76 individuals per m^2, respectively (Kelly et al. 2011).

9.2.3.2 Polychaetes

Polychaetes can be sedentary, burrowing, or free swimming and are the dominant organism in areas of fine sediment (Pocklington and Wells 1992). This numerical dominance within the infaunal community also makes them ideal prey for a vast number of commercially valuable invertebrates as well as juvenile fish (Drummond-Davis et al. 1982; Bowman et al. 1987). A study of biomass, productivity and predation of polychaetes found that 80% of the mortality experienced by *Pectinaria hyperborea* was due to predation (Peer 1970). Polychaetes are excellent bioindicators, and can be utilized to monitor pollutants and environmental health (Pocklington and Wells 1992). Pollution, oil drilling, dredging and aquaculture can all have detrimental effects on polychaete diversity. For example, the organic enrichment produced by a fish farm created a sedimentary gradient impact detectable up to 45 m away, whereas the biological gradient of benthic diversity could be seen up to 150 m away (Pocklington and Wells 1992). Polychaetes (specifically *Neanthes* sp.) have been used to examine some of the biological effects of the sediments in the Halifax Harbour (Tay et al. 1992). Other polychaetes found to be dominating at select aquaculture sites within the Inshore Scotian Shelf include *Nephtys neotella*, under mussel lines and *Nereis diversicolor* under fish pens (Pocklington et al. 1994).

A wide diversity of polychaetes was reported for St. Margaret's Bay by Volckaert (1983, 1987), who found that their distribution is patchy on a scale of 10 cm, 10-50 cm and greater than 50 cm. Volckaert (1983, 1987) also found that the densities of polychaetes in St. Margaret's Bay could range from 14-129 individuals per 100 cm^2 for *Euchone incolor;* higher densities occurred at greater depths and correlated with organic carbon flux.

Sandworms (*Nereis virens*) and bloodworms (*Glycera dibranchiata*) are harvested for fish bait in Cape Breton and on local mudflats along the Atlantic coast (Table 13; Schaefer et al. 2004, McCullough et al. 2005, Miller and Smith 2012). Bloodworms are most abundant on estuarine soft muds rich in organic matter, whereas sandworms are on cleaner soil associated with clam flats (McCullough et al. 2005). A commercial fishery is concentrated in the areas of Minas Basin, St. Mary's Bay and western Nova Scotia (Pubnico area). From 2002 to 2008, landings ranged from 3.6 to 8 million tonnes with an average annual value of about 850,000 dollars (Miller and Smith 2013).

Bloodworms spawn in May. Miller and Smith (2012) reported that size at maturity is greater for worms from western Nova Scotia than for Minas Basin and that the density of the worms is variable both spatially and temporally (Figure 47).

Table 13. Sand and bloodworm harvest and distribution from local ecological knowledge studies (modified from Schaefer et al. 2004 and McCullough et al. 2005).

Harvest Area	Zone
False Bay Moiren Bay Northwest Arm Sydney Harbour North Bay Ingonish Ingonish Harbour Aspy Bay Indian Bay/ Dominion Beach St. Anns Bay	1 - Cape Breton
West Jeddore Jeddore Harbour Fisherman's Cove Eastern Passage Halifax Harbour	Eastern Shore
Boutilier's Cove Black Duck Cove * Hubbard's Cove** Cleveland Provincial Park ** Holland Cove** Sambro Head ** Indian Harbour ** Pennant Cove ** Ketch Harbour **	South Shore

* denotes only bloodworms, and ** denotes only sandworms).

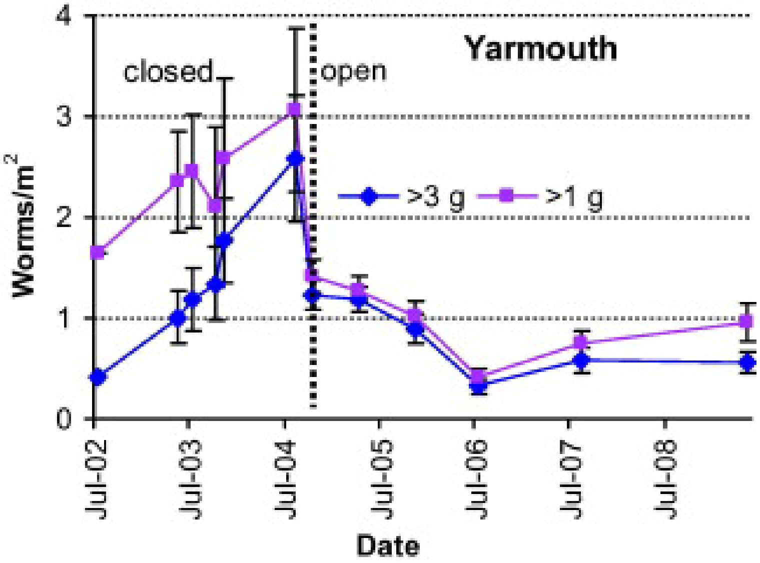


Figure 47. Mean densities of bloodworms (±1 SE) for 12 sampling dates in Yarmouth Harbour. The harbour was closed to harvesting before September 2004 and open for parts of each of 2005–2008 (from Miller and Smith 2012).

9.2.3.3 Ocean Quahogs (Arctic islandica)

Quahogs are ubiquitous infaunal bivalve molluscs found on continental shelves throughout much of the North Atlantic (Dahlgren et al. 2000). They occur in sediment types ranging from hard packed sediment to fine mud, but display a preference for fine silt sediment (Chandler 1983). Quahogs grow very slowly with lifespans of more than 100 years but inshore areas in Nova Scotia do not have the large, older quahogs seen offshore. Rowell and Chaisson (1983) found only 1.3% of the quahogs in the inshore areas were over 100 years old. Ocean quahogs are prey to many species which include rock crabs, sea stars, and other crustaceans, and fish such as longhorn sculpin, ocean pout, haddock, and cod (Cargnelli et al. 1999). Due to their burrowing habit and thick shells, predation rates are low.

Information about the distribution of quahogs in Nova Scotian inshore waters is based on fishing area as summarized from Rowell (1983, Figure 48) and Chaisson and Rowell (1985, Figure 49). They occur at depths of 4 – 256 m, with higher densities in the inshore waters than offshore, (Figure 48).They are known to occur along the south coast of Nova Scotia, and on the offshore banks (Figure 48), as well as on St. Anns Bank off northern Cape Breton (Figure 49). They occur at depths of 4-256 m, with higher densities in the inshore waters than offshore (Rowell 1983).

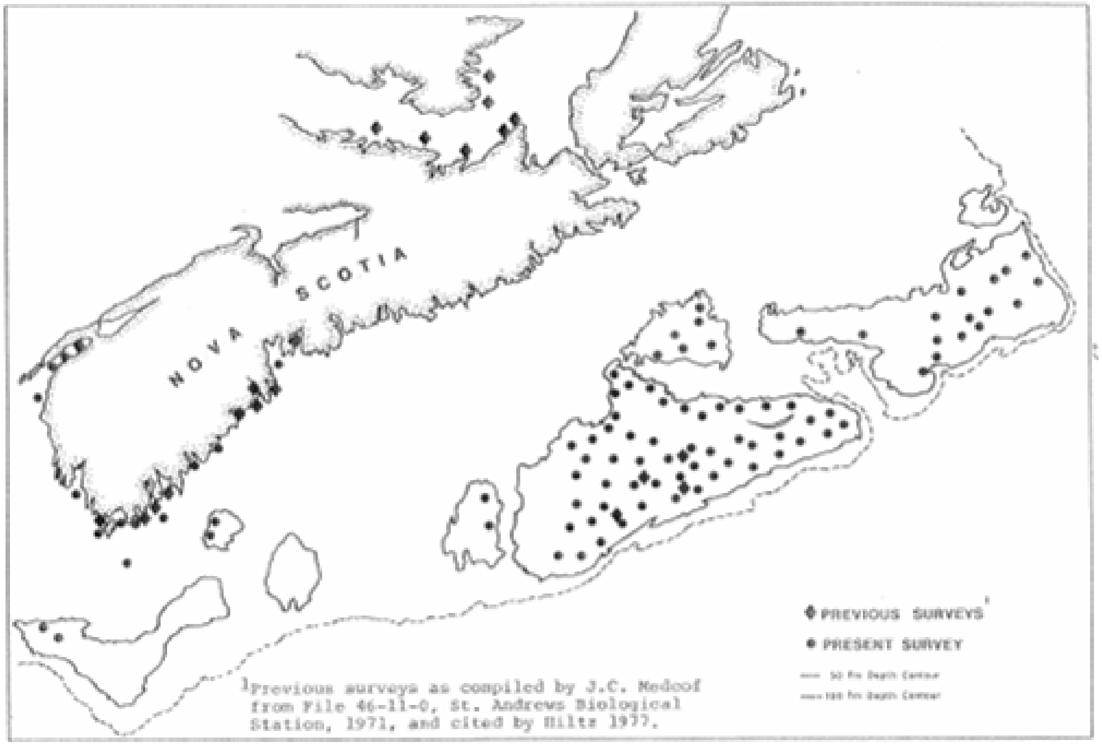


Figure 48. Ocean quahog distribution inshore and offshore (modified from Rowell and Chaisson 1983, which provides detail on quahog densities in individual inlets).

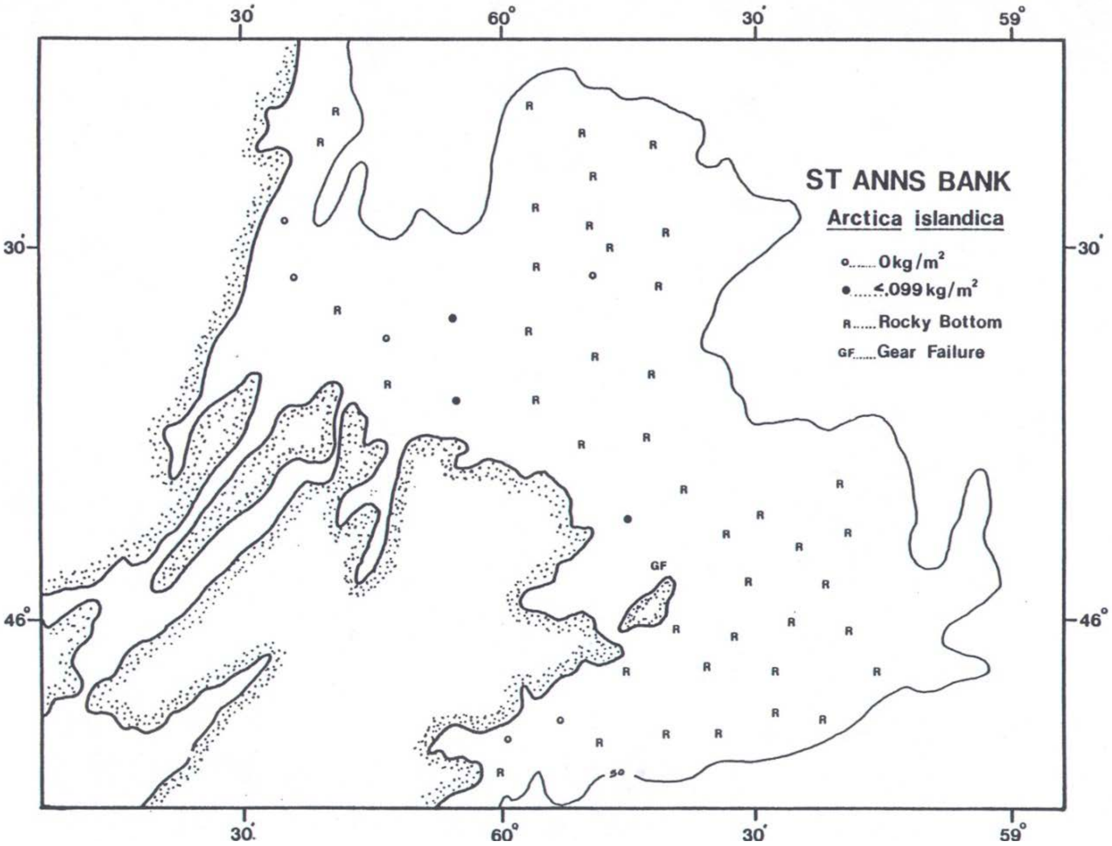


Figure 49. Quahog distribution and abundance on St. Anns Bank, Cape Breton. (Adapted from Chaisson and Rowell 1985).

A large ocean quahog fishery exists in the US but there has been little activity in Canada. A quahog processing plant operated for two years in Port Medway processing 400 and 918 mt in 1970 and 1971, respectively (Chandler 1983).

9.2.3.4 Soft-shell Clams (Mya arenaria)

Soft-shell clams have a broad distribution in North American and European coastal waters, ranging from Cape Hatteras to Labrador on the east coast of North America. They occur in bays and estuaries, usually in muddy, intertidal habitats, but they also occur subtidally and in a range of sediment types, to depths of about 9 m. Clam beds have been identified along the Atlantic coast using scientific surveys and surveys of local ecological knowledge. Locations include St. Margaret’s Bay, Eastern Passage, Cow Bay, Cole Harbour, Petpeswick and Chezzetcook Inlets, Musquodoboit, Clam, Indian and Three Fathom harbours (from sources summarized by McCullough et al. 2005).

Soft-shell clams are buried to depths of up to 10 cm and pump water through their siphon to respire and feed. They are suspension feeders on microscopic plant and animal matter suspended in the water column just above the bottom.

Predators of soft-shell clams include diving ducks, cormorants, crows, groundfish, starfish and green crab (*Carcinus maenas*). They are dioecious, spawn in May through June (based on data for St. Andrews, N.B. from NSDFA 2008) and mature at a shell length of about 25 mm, at an age of about two to three years. Reported time from spawning to harvestable shell lengths (51 mm) varies among clam beds from 6 to 8 years (DFO 1996a). Clam landings on the Atlantic coast rose from 1990-1994 and then dropped in 1995, the last year in which DFO assessed the fishery (DFO 1996b). The decline was attributed to overharvesting of clam beds and closure of beds due to contamination.

Historical gold mining operations have had a lasting adverse impact on some clam beds on the Eastern Shore. Tailings from these operations have migrated downstream over time, causing high levels of arsenic and mercury in several areas including Clam Harbour and Isaac’s Harbour (CBCL 2009). Arsenic contamination of clams has resulted in the closure of the recreational clam fishery in several locations. Environment Canada sampled soft-shell clams, mussels and periwinkles at 10 intertidal sites from Gold River to New Harbour (Guysborough Co). They found that arsenic levels in clam tissue from Seal Harbour were 160 times higher than New Harbour where gold mining had never occurred (Environment Canada 2007).

Declining stocks and the loss of harvesting areas due to environmental closures led to a workshop between NSDFA and the soft-shell clam industry to discuss the potential for enhancement of wild stocks (NSDFA 2008). Enhancement techniques in Massachusetts have focused on capturing wild clam spat as it is settling and on moving clam seed from closed areas that are either over populated or are in areas where they will never grow due to lack of food and good growing condition.

9.2.4. Epifanal Invertebrates

Contributed by J. Sperl, A. Bundy, A. Silva and J. Tremblay

The epifaunal invertebrate community of the Inshore Scotian Shelf spans many phyla, including poriforans, cnidarians, ctenophores, rhyncocoela (nemerteans), bryozoa, brachiopoda, mollusca, sipuncula, annelida, arthropoda, and echinodermata (Martinez and Martinez 1999, Schaefer et al. 2004, McCullough et al. 2005). The functional roles of these invertebrates are diverse. Many are ecosystem engineers, creating habitat structure, modifying water flow or both. Some are keystone species, fundamental to the structure and functioning of the community. Commercially harvested marine invertebrates include lobster (*Homarus americanus*), periwinkle, rock crab (*Cancer irroratus*), green sea urchins (*Strongylocentrotus droebachiensis*), mussels (*Mytilus edulis*), scallops (*Placopecten magellanicus*), Jonah crab (*Cancer borealis*) and snow crab (*Chionoecetes opilio*).

There have been few studies of the epifaunal community along the Atlantic coast of Nova Scotia: reviews of the few studies are provided by McCullough et al. (2005) and Mitchell (2000). Most studies are old. Bousfield and Laubitz (1972) conducted a survey of littoral marine invertebrates at 17 sites in the area (see Table 10-1 in McCullough et al. 2005). There are three main types of community: subarctic, boreal and temperate, with occasional warm temperate-tropical in sheltered bays such as Sheet Harbour.

Studies of epifaunal invertebrates are less comprehensive in the sub-tidal zone (Mitchell 2000). The most detailed survey occurred in St. Margaret's Bay where 17 stations were sampled and community composition, in terms of calorific values, was comprised of 42% annelids, 35% echinoderms, 12% arthropods and 11% molluscs (Brawn et al. 1968). Miller et al. (1971) estimated that sea urchins account for 87% of the biomass (kcal/m^2), followed by mussels (14%), periwinkles (12%), seastars (4%), brittle stars (2%) and lobsters (2%). Other studies include analyses of polchaete production (Peer 1970, Volkaert 1987). However, most of these studies are over 40 years old and community composition may well have changed. McCullough et al. (2005) provide a synthesis of presence/absence data for 11 sites along the Atlantic coast within SHACI units 4-6, based on the Marine Invertebrate Diversity Intiative (MIDI) database and a study by Moore et al. (1982).

More recently, Hatcher et al. (1996), in a study focused on sea scallops, estimated densities of scallops (0.4 individuals per m^2), seastars (*Asteria vulgaris and A. forbes*: 3.71 per m^2), rock crabs (0.03 per m$^{2)}$ and moon snails (*Lunatia heros,* >0.05 per m^2). Barbeau et al. (1996) sampled the same bay a few years later and found similar densities for scallops and rock crabs, but a lower density for sea stars (0.8-1.2 per m^2).

Based on these and other studies, information on a few commercial and non-commercial species of epifauna that occur in the inshore and for which there is information, as well as some species which are subject to new fisheries.

Many benthic invertebrate species undergo a complex life cycle, with planktonic larval stages (Section 9.1.5 meroplankton) that may last days to months. Dispersal by currents during the planktonic stage can be important for slow moving or sessile species. Planktonic larvae consume phytoplankton, zooplankton and other larvae before chemical or tactical cues instigate metamorphosis into another instar, or into the adult form. Some larvae will morph into one or several juvenile forms before they settle to become adults. Specific life histories are discussed where relevant with each species.

9.2.4.1 Commercial Species

Contributed by A. Silva and J. Tremblay

American lobster *(Homarus americanus)*

Background

The American lobster (*Homarus americanus*), is a long lived marine decapod crustacean with a complex life history, distributed from the Strait of Belle Isle in South Labrador (Canada), to Cape Hatteras (US) in the Northwest Atlantic Ocean (Figure 50). Lobsters occur primarily at shallow depths from 4 to 50 m (Herrick 1909) where most fishing takes place, though lobsters can inhabit greater depths of hundreds of metres in the offshore. Lobsters are heavily exploited throughout the entire region. The lobster fishery is one of the main economic activities in coastal communities, valued at over $400 million in the Maritimes, and $90 million in the EOR area in 2005 (DFO Martime Statistical Reports).

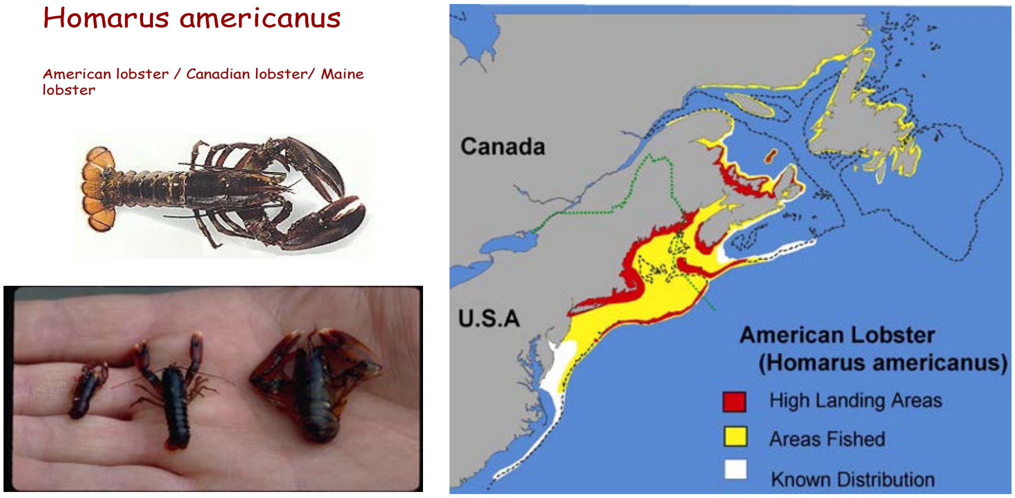


Figure 50. Spatial distribution of American lobster (Homarus americanus). (D. Pezzack; insert photo: P. Lawton).

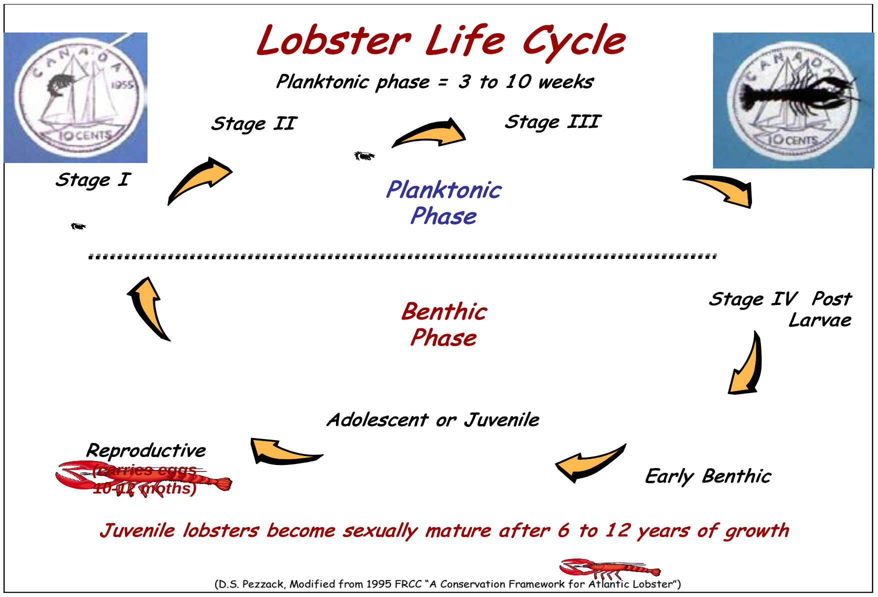
Biology, physiology and ecological relationships of adult lobsters have been studied extensively in the laboratory and to a lesser extent in their natural environment (Factor 1995; Phillips 2006). Adult lobsters have an important ecological role in the nearshore and offshore ecosystems, as top predators of other invertebrates (i.e. urchins, crabs, scallops, polychaetes, fish), and also as a scavenger. Much less is known about early developmental planktonic stages and juvenile lobster settlement.

Life History

Lobsters are long lived, reaching sexual maturity between 5-12 years of age. Growth occurs through a series of moults since, like other crustaceans, lobsters have a rigid carapace or shell. The frequency of moulting is related to sex, physiological status, age, and environmental conditions. Males reach larger sizes than females because females moult less frequently when reproduction begins. After each moult, the new carapace it is at least 10 to 15% longer. The new soft carapace begins to harden within a few hours and it is during this period that lobsters are most vulnerable to predation if not in a protected shelter.

Female lobsters reaching sexual maturity generally moult and mate while in a soft shell and carry spermatophores for at least a year before fertilization and extrusion of a brood of eggs occurs. A newly extruded clutch of eggs could contain from 3,000 to 115,000 (Herrick 1909); older females carry many more eggs than younger ones. Fertilized eggs are carried on the female abdomen attached to her pleopods for 9-12 months before larvae are released the following late spring or early summer (Aiken and Waddy 1980). Females moult shortly after releasing their brood of larvae, although sperm storage enables older, larger females to fertilize up to three batches of eggs without moulting.

Hatched eggs moult quickly into Stage I larvae (Figure 51). Larval development continues by moulting three more times (Stage IV is a post-larva) during the planktonic stage. This post-larval stage varies in duration depending on conditions: within a few hours to a few days, they descend in the water column and reach the benthos to find a suitable substrate on which to settle. A complex cryptic behaviour is associated with early post-larval stages. Generally, as lobsters develop and moult, they undergo ecological niche shifts (Steneck 2006). Moulting into a stage V is dependent on shelter availability and if no adequate substrate is found, juvenile lobsters will spend a longer period of time seeking shelter potentially increasing risk of predation.



(D.S. Pezzack, Modified from 1995 FRCC "A Conservation Framework for Atlantic Lobster")

Figure 51. Life cycle of American lobster (<u>Homarus americanus)</u> (provided D. Pezzack, DFO Maritimes 1995).

Habitat Requirements

Lobsters are found in a wide variety of habitats including mud, cobble, bedrock, peat reefs and eelgrass and in some areas on open sand, often in bowl-like depressions (Lawton and Lavalli 1995). The most common habitat is sand substrate with overlying rocks and boulders (Cooper and Uzmann 1980). In general lobsters are found on a broader range of habitats as they increase in size. Newly settled and juvenile lobsters require shelter, usually in the form of cobble. As lobsters grow and become less vulnerable to predation their daily range increases.

Coastal waters near shore are also important habitat for early developmental stages of planktonic larvae. A few studies have examined the distribution of lobster larvae within the Cape North-Cape Sable region (Dibacco and Pringle 1992, Miller 1997). A unique ongoing monitoring study of lobster larvae has been in place since 2002 in Lobster Fishing Area (LFA) 31A (Miller and Boudreau 2004) and continues to date. Interestingly, large ovigerous females appear to be more abundant on the Eastern Shore (Miller 1997) but this has not resulted in greater landings.

Stage IV lobsters settling to the bottom seek habitats that provide shelter such as cobble. An ongoing study of spatial patterns in lobster settlement in coastal Nova Scotia (Cape Breton to Southwest NS) uses cobble filled wire cages to sample young-of-the-year lobsters (DFO/FSRS joint study, M.J. Tremblay, pers. comm.). This study confirms that lobster settlement occurs in nearshore areas during late summer and early fall. In addition lobster settlement densities from Halifax County and east appear to be lower or at least much patchier compared to southwest Nova Scotia.

Lobsters live mostly solitary lives, although adult lobsters do aggregate during the reproductive period in shallower areas. Once mature, lobsters alternate their use of habitat moving to deeper, warmer waters during the fall-winter and returning to more temperate waters near the coast during the spring. Off Cape Breton, tagging studies show that most lobsters are usually found within a few kilometers of where they were tagged after 8-12 months, but this type of study does not capture seasonal movement (Tremblay et. al. 1998). Female lobsters seem to take advantage of the warmer waters in late spring and summer to mature eggs and release larvae. Similarily, in the Gulf of St. Lawrence lobsters may move 10-15 km from their release sites

(Moriyasu et al. 2001), but in the Gulf of Maine some lobsters undertake much more extensive migrations (Pezzack and Duggan 1986).

The Lobster Fishery

The history of lobster fishing in Canada dates back to the mid 1800s. Recorded landings increased dramatically in the late 1970s and 1980s throughout much of the lobsters range, and in some areas, record landings were reached in recent years (FRCC 2007). Reasons for the increase are not well understood. Although a large-scale phenomenon is suggested, ocean temperature does not explain the widespread increases (Drinkwater et al.1996). However, effort and fishing efficiency have also increased, and the abundance of predators such as large groundfish has decreased (Shackell and Frank 2007, Bundy 2005, Choi et al. 2004, Boudreau and Worm 2010). These factors need to be investigated further.

Lobsters are spatially managed within eight LFAs in the Maritimes (Figure 52). Most fishing takes place within 12 miles off the coast, and often within 2 miles of the coast (R. Miller, pers. comm.). Two main fishing seasons are distinguished: a spring fishery (May to July) in LFAs east of Halifax (LFA 27-32), and a fall-winter-spring fishery (November to May) in LFA 33, southwest of Halifax (Table 14).

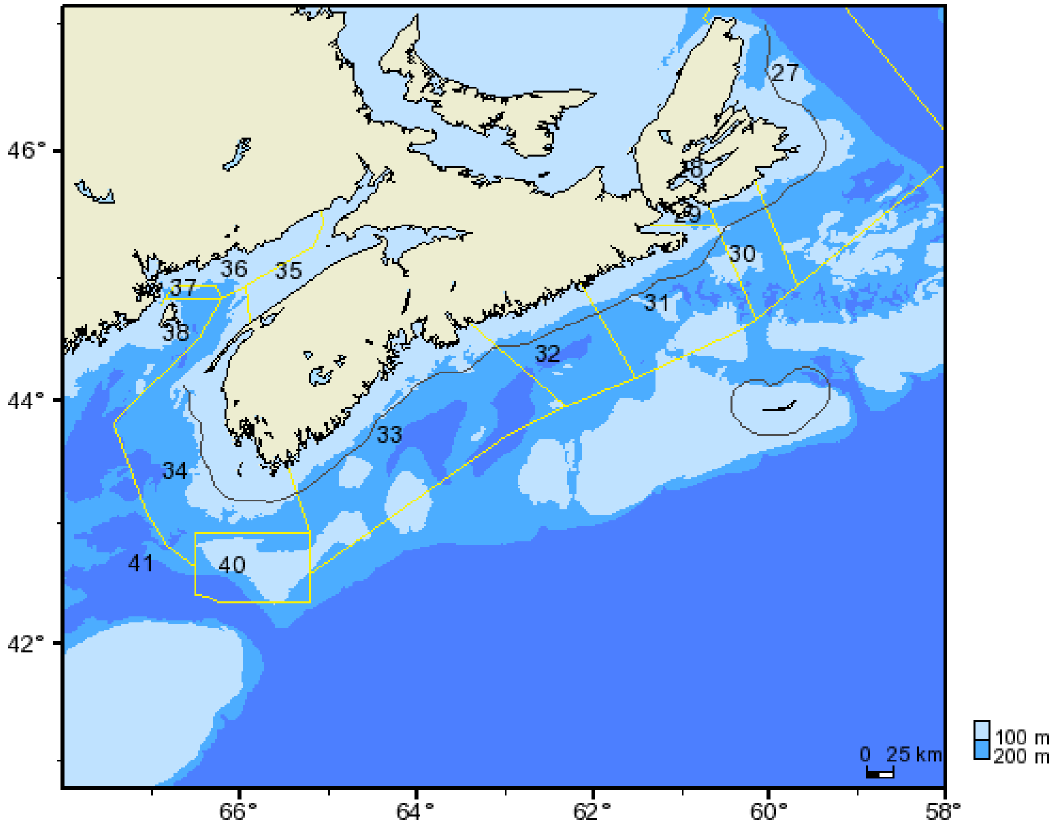


Figure 52. Map of the Maritimes showing Lobster Fishing Areas (LFAs). LFAs 27 and 30-33 are within the study area.

Research

Most information about lobster populations along the Atlantic coast is derived from monitoring the catch composition (size, sex and females with eggs) of the fishery through at-sea and port samples, and from daily catch and effort logs kept by fishermen. However, this is not consistent throughout all areas. Current research projects include the distribution and abundance of lobster settlers (young-of-the-year), the biodiversity associated with lobster settlers, evaluation of lobster size at maturity and fishery independent estimates of abundance from underwater imaging (e.g. Tremblay et al. 2009a). Since 1999, an FSRS project has monitored juveniles using standarized traps throughout the entire area during the fishing season (Tremblay et al. (2009b). Since 2004 the Lobster Science Centre, FSRS and DFO have conducted sampling of blood protein to evaluate lobster moult timing and the prevalence of soft lobsters during the fishing season.

Table 14. Management measures in effect in 2011 in Scotia-Fundy Lobster Fishing Areas (LFAs) (DFO 2011a).

LFA	Season	Trap Limit[1]	Legal Size (mm)	Other Measures
27	May 15 - July 15	275	81	-
28	April 30 - June 30	250	84	Max entrance hoop 153 mm; Release V-notch
29	April 30 - June 30	250	84	Max entrance hoop 153mm; V-notching[2]
30	May 20 - July 20	250	82.5	Max. CL-135mm (female); V-notching
31A	April 29 - June 30	250	82.5	Closed window (female), 114-124 mm
31B	April 19 - June 20	250	82.5	V-notching
32	April 19 - June 20	250	82.5	V-notching
33	Last Mon. Nov - May 31	250	82.5	Release V-notch
34	Last Mon. Nov - May 31	375/400	82.5	Release V-notch
35	Oct 15 - Dec 31; Apr 1-July 31	300	82.5	Release V-notch
36	2nd Tues Nov - Jan 14; March 31-June 30	300	82.5	Release V-notch
38	2nd Tues Nov - Jun 30	375	82.5	Release V-notch
38B	June 30 - Nov 6	375	82.5	Release V-notch

(1) Trap limit is for “A” licence holder. Part-time or “B” licences are allowed 30% and Partnerships 150% the limit of a single full-time licence.
(2) V-notching means there is an active program to V-notch berried lobsters. There is a possession restriction of V-notched lobsters except in LFA 27 and LFA 31A.

Crabs

Crabs occur in depths from the intertidal zone to several hundred meters, and have niches in every substrate available (Schram 1986). At least 16 species of crab occur in the inshore area of the Scotian Shelf (Tremblay 2006): the Brachyura; Rock Crab (*Cancer irroratus*), Jonah Crab (*Cancer borealis*), Snow Crab (*Chionoecetes opilio*), Toad Crab (*Hyas araneus* and *H. coarctatus*), Portly Spider Crab (*Libinia emarginata*), Green Crab (*Carcinus maenus*), Blue Crab (*Callinectes sapidus*), Mud Crab (*Dyspanopeus sayi*); Anomura; Hermit crabs (5 species of *Pagurus*), Stone Crab (*Lithodes maja*) and Squat lobster (*Munida iris*). We have little to no information for 8 of these species. There are gradients in species distribution with depth and temperature. Snow crabs are generally distributed to the north of the Port Mouton area. Green crab, an invasive warmer water species, occurs inshore, together with rock crab. Snow crab and stone crab are deeper water species (Tremblay 2006, Bundy 2007b).

Like lobster, crabs belong to the order Decapoda. The claws or chelae are used for cutting and tearing and can be asymmetrical. Fertilization occurs by the deposition of a sperm packet inside the female for delayed fertilization, or takes place when the female has moulted and is soft-shelled and able to be penetrated. Eggs are extruded and brooded on the pleopods and, depending on the species, undergo either an abbreviated juvenile larval stage to adult or a series of larval stages to reach adulthood. Crabs exhibit a huge diversity of form and habitat ranging from detrital and filter feeding such as the hermit crab, to voracious carnivores such as rock crabs and green crabs (Schram 1986; Berrill and Berrill 1981). Commercial crab species include rock crab, Jonah Crab and snow crab.

Rock Crab *(Cancer irroratus)*

Rock crabs occur along the east coast of North America and were found at all sites sampled with baited traps in the Inshore Ecosystem Project Fishery-Independent Survey in depths up to 50 m (Bundy 2007b). They are associated with a range of bottom types such as rock, sand and mud, though most are found on softer bottoms. Rock crabs are opportunistic benthic predators and scavengers (Ristvey and Rebach 1999) and important in the ecosystem as omnivores and as prey. Ellis et al. (2007) suggest that rock crabs are prevented from developing large populations in the low to mid-intertidal region by sea gull predation, an exclusion which enhances midtidal populations of green crab, whelks and mussels. Rock crabs are also major prey of lobster at all life stages (Hanson 2009).

Males can grow to 140 mm carapace width (CW), whereas females are smaller, with a maximum CW less than 100 mm. In eastern Nova Scotian, age of 50% maturity for males is 62 mm CW and 49 mm CW for females (Tremblay and Reeves 2000). Average maturity in SW Nova Scotia occurs between 50 mm and 57 mm for females and between 65 mm and 75 mm CW for males (DFO 1998a). Eggs are extruded in late October, with the development of 6 larval stages the following summer (DFO 1998a). Commercial size is reached at around age 5-6 years, and longevity is around 8 years (DFO 2000).

Rock crab are commonly caught as by-catch in the lobster fishery in the Maritimes. Since 1993, there has been an exploratory fishery for rock crab in eastern Nova Scotia and Cape Breton, and in LFAs 34 and 35 in the Bay of Fundy (SW Nova Scotia) since 1996 (Figure 53). A dockside monitoring program is in place and only males with a carapace width of 102 mm or greater can be retained. The average inshore catch from 2003-2006, was 430 tons, most of which was caught in Cape Breton and the Eastern Shore. Since then, commercial landings have declined to less than 300 mt in 2010.

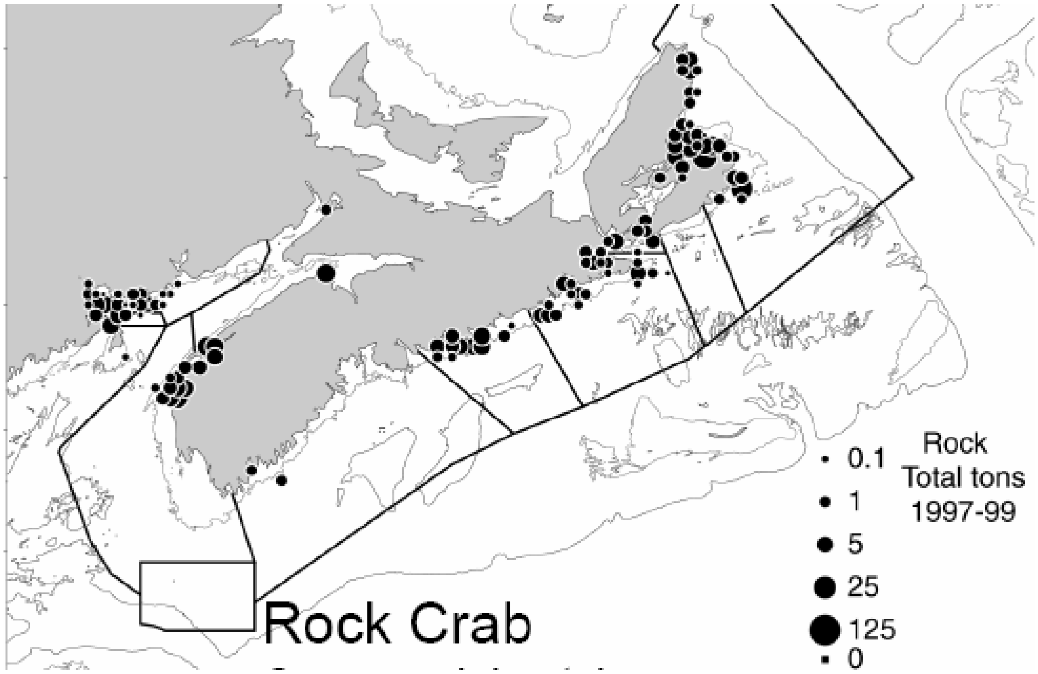


Figure 53. Commercial catch of rock crabs (metric tons) (Tremblay and Reeves 2000).

Jonah Crab (*Cancer borealis*)

Jonah crabs are distributed from the western Scotian Shelf to South Carolina and the Bermudas. They occur at depths from a few metres to 800 m and prefer substrates of rock, sand, clay and mud. Size at maturity is 90-100 mm CW for males and 85 mm CW for females. They are similar in appearance to rock crab, but are generally larger with heavier claws, and the carapace has a rougher texture and a more jagged appearance. There is little information about Jonah crab in Nova Scotian waters. There has been an intermittent directed fishery for them since the 1980s in LFAs 33 and 34, and they are retained as bycatch in LFA 34 (Figure 54), although most of the fishery occurs offshore. A dockside monitoring program is in place, and only males with a carapace width of 130 mm or greater can be landed. Total catch has decreased from around 1000 metric tons in 2003 to 160 tons in 2010.

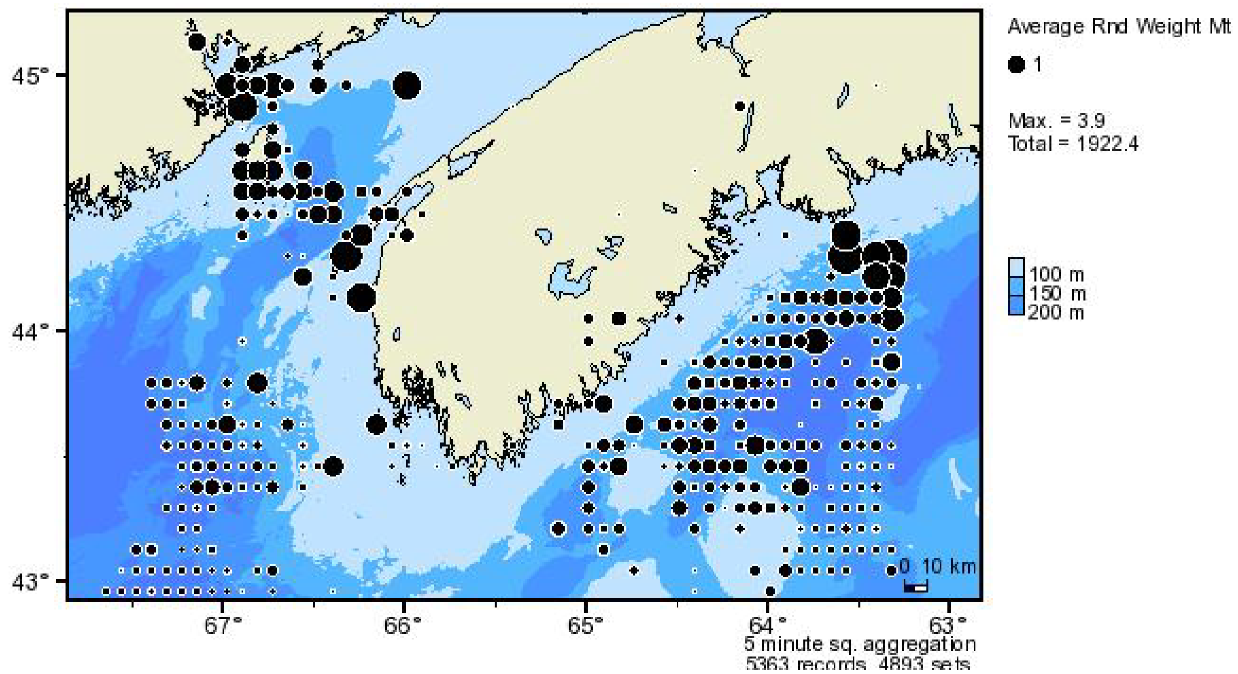


Figure 54. Averaged landings (metric tons) of Jonah crabs from 2002–2011(MARFIS 2011).

Snow Crab *(Chionoecetes opilio)*

Snow crab are distributed from the Gulf of Maine to northern Labrador. On the Scotian Shelf they occur largely on the eastern Scotian Shelf, in depths from 60 to 280 m and temperatures from -1 to 6 °C (DFO 2011b). Large crabs prefer soft mud bottoms, whereas smaller crabs occur in habitats that provide shelter, such as boulder and cobble substrates.

Snow crab feed on a range of prey including shrimp, capelin, lumpfish, starfish, sea urchins, worms, detritus, large zooplankton, other crabs, ocean quahog, molluscs, sea snails, and sea anemones. They are also prey to other predators such as halibut, skates (especially thorny skate), cod, seals, American plaice, squids, and other crabs, and are particulary vulnerable when small (3-30 mm CW) or soft-shelled. In inshore areas, there are also likely to be competitive interactions with toad crab and Jonah crab.

Females produce eggs in the spring, which may be brooded for up to 2 years. The eggs hatch in late spring to early summer, when the young become pelagic (zoea stages 1 and 2 and the intermediate megalopea stage) and feed on plankton. In the late fall, early winter, they settle into the benthic phase (after 3 to 5 months as pelagic larvae) as post-larval stages. Snow crab reach legal size by the twelfth instar, representing an age of approximately 9 years since settlement to the bottom. Females mature at 55 mm CW. Snow crab can live up to 18 years old.

The fishery for snow crab began in the late 1970s, and now exploits the entire spatial extent of the species on the Scotian Shelf inshore and offshore (Figure 55), but is managed as the N-ENS (northern part of the eastern Scotian Shelf), S-ENS (southern part of the eastern Scotian Shelf, Crab Fishing Areas 23 and 24) and Crab Fishing Area (CFA) 4X (DFO 2009). The distribution of landings has shifted from being mostly from inshore areas in the past (2000-2002) to mostly from the offshore areas in more recent years (Figure 50). In most exploited areas, a general decline in the abundance of snow crab was observed from the late-1990s, when their abundance peaked, to 2005 in S-ENS and 2007 in N-ENS. Since then, exploitable biomass has increased. The index of recruitment has decreased from highs in 2007 in S-ENS and 2008 in N-ENS; it is at low levels in N-ENS and intermediate levels in S-ENS. Recruitment in 4X has been decreasing since 2010 and is low and variable (DFO 2013a). Female snow crab abundance and associated egg production in all areas continue to decline after reaching highs in 2007/2008. Egg production is now below the long-term mean and is expected to remain so for at least 2 - 4 years due to a lack of maturing female crab (DFO 2013a).

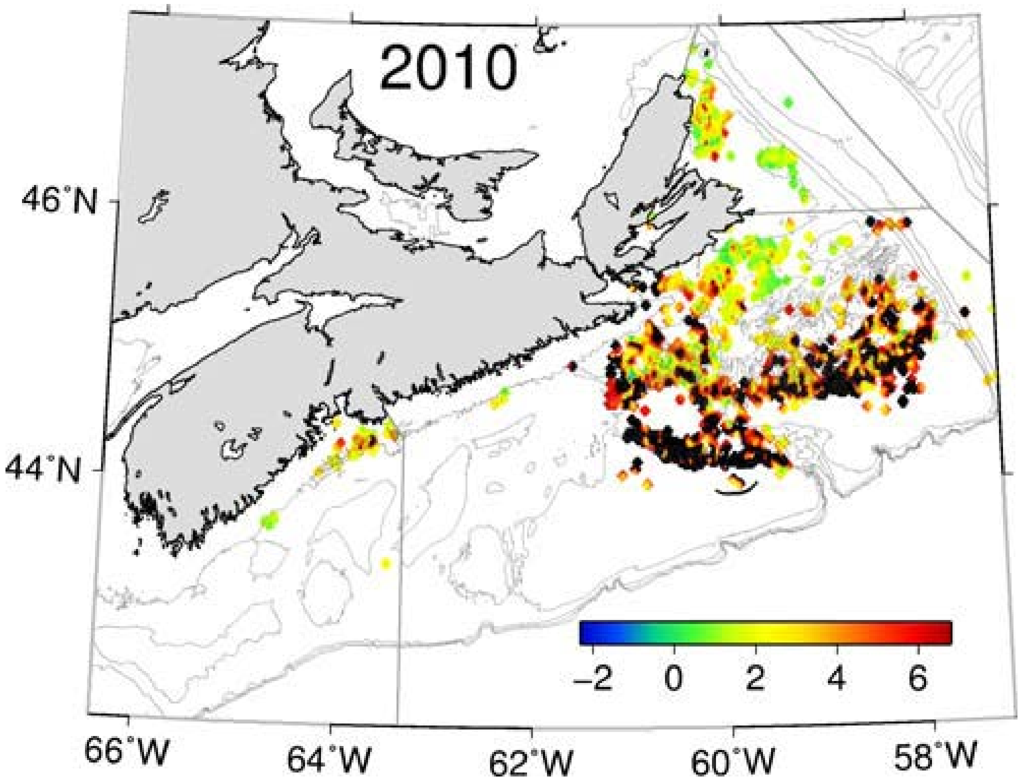


Figure 55. Commercial landings (log10; metric tons) in the 2010 fishing seasons. Areas in black are off the scale (DFO 2011b).

Green Sea Urchins (*Strongylocentrotus droebachiensis*)

Green sea urchins are the dominant herbivore in the inshore Scotian Shelf. Urchins range from the intertidal up to 140 meters deep (Miller and Mann 1973). They are sexually mature at 23 mm, spawning synchronously along the coast in March and April (Miller and Nolan 2000, Meidel and Scheibling 1998) and have a 2 month planktonic larval period prior to settlement. Urchins occur in size-based aggregations, for example, juveniles 3 – 6 mm in diameter disperse and take refuge under small cobbles, whereas small adults 25 – 30 mm in diameter gather together, and hide under ledges or between crevices (Scheibling and Hamm 1991).

The preferred food of urchins are the macroalgae making up the kelp beds, and include *L. digitata, S. logicruris* and, to a lesser extent, *C. fragile*, *Agarum cribosum* and *Desmarestia aculeata* (Scheibling and Anthony 2001). They also consume epiphytic bryozoans and hydrozoans living on the macroalgae, small mussels attached to holdfasts, barnacles, or coralline algae, diatoms, cyanophyta, and filamentous red and brown algae when macrophytes are not available (Scheibling and Anthony 2001; Miller and Nolan 2000; Chapman 1981). Urchins can be found in densities of 98 – 70 large adults per 0.25 m^2 on a dense front feeding on the perimeter of a kelp bed (Scheibling et al.1999).

Along the Atlantic coast of Nova Scotia, large-scale fluctuations in population size of *S. droebachiensis* cause dramatic changes in the state of the shallow sub-tidal ecosystem (Mann 1977, Bernstein and Mann 1981). They play a major role in the dynamics of the kelp community, mediating a stable cyclical transition between two alternate states: one where rich algal beds are dominated by kelp and one described as barren, where kelp has been removed through predation by sea urchins, and only the resistant coralline algae remain. Dense urchin fronts can graze a mature macrophyte bed at a rate of 1 – 4 meters per month, drastically altering the seascape from diverse kelp beds to urchin barrens (Meidel and Scheibling 1998). When a grazing urchin front encounters a kelp bed, they uncover mussels that would normally remain hidden within the holdfasts and crevices of the undisturbed kelp (Scheibling and Lauzon–Guay 2007). The broken and half eaten mussels exposed to the seawater act as cues attracting local scavengers such as sea stars, whelks, crabs, and demersal fish to prey on the newly accessible food source of mussels (Scheibling and Lauzon–Guay 2007).

Barrens are clear of almost everything except for the crustose coralline algae and urchins, feeding off the algae, diatoms, and broken pieces of macrophyte floating back over the barrens from the front (Scheibling et al. 1999). It can take 2 – 3 years for the kelp bed to re-establish in a grazed area (Scheibling and Anthony 2001). This cycle begins with large macrophytes dominating the benthos to depths of approximately 20 meters. Then, urchins migrate to the edge of the kelp bed from deeper waters where a feeding aggregation develops on the edge and planktonic settlers within the kelp graze down patches (Miller and Nolan 2000). Greater wave action in shallow water makes the kelp inaccessible to urchins. Eventually, the urchins die off from starvation or through mass mortality events such as that propagated by the waterborne marine amoeboid *Paramoeba invaclens* (Miller and Nolan 2000; Scheibling and Hennigar 1997) and the kelp grow back (Miller and Nolan 2000). During the urchin die off, kelp forests are able to re-establish (Scheibling et al. 1999). However, the spread of the invasive *Codium fragile* (Section 9.2.2) is replacing kelp beds in some areas. This may have detrimental effects on sea urchins, such as a reduction in growth and ability to reproduce by individuals feeding on *C. fragile* as a result of its poorer quality as food (Lyons and Scheibling 2007). Urchins that feed on rich kelp beds are likely to make the greatest contribution, per unit area, to the overall larval pool of sea urchins (Meidel and Scheibling 1998).

Urchins are also prey to a variety of species, such as cunner, ocean pout, winter flounder, wolffish, sculpins, American plaice, sea birds, sea stars, lobster, and even benthic micro predators when newly settled (<1 mm test diameter) (Scheibling and Hamm 1991, Miller and Nolan 2000, Miller and Mann 1973). Planktonic larvae are preyed upon by planktivorous fish, zooplankton and benthic suspension feeders (Scheibling and Hamm 1991).

Management of the urchin fishery off Nova Scotia began in 1989 (Miller and Nolan 2000). The gonads of both male and female are harvested and shipped to Maine and Japan. The minimum urchin size is 50 mm diameter, and undersized urchins must be culled and discarded at sea. Harvesting takes place using divers, and recreational fishing is prohibited. The highest average landings from 2005-2009 are 1240 mt from the southwestern Nova Scotia and the Bay of Fundy, 61 mt in the inshore fishery off Cape Breton and 22 t off the Eastern shore (Figure 56).

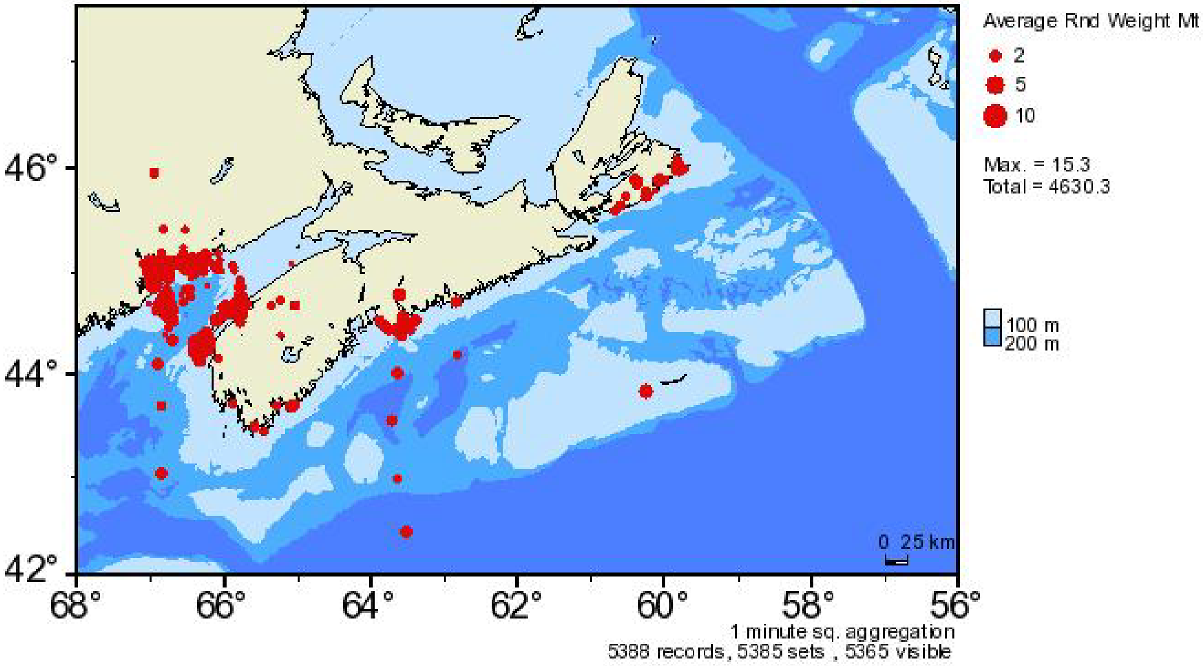


Figure 56. Total commercial landings of green sea urchins from 2005-2009 (MARFIS 2011).

Recurrent outbreaks through the 1980s and 1990s of a disease caused by the amoeba *Paramoeba invaclens* resulting in mass mortalities of sea urchins (Scheibling and Hennigar 1997, Miller and Nolan 2000) have been linked to warm water temperatures associated with relatively high tropical storm and hurricane activity. Scheibling and Lauzon-Guay (2010) examined relationships among sea urchin mass mortality events, hurricane activity, and water temperature (which mediates disease outbreaks) on the Atlantic coast of Nova Scotia over the past 30 years. They found that storms have been tracking closer to the coast and surface temperature has increased during the hurricane season, and that these trends are likely to continue with climate warming, resulting in a regional shift to a kelp bed ecosystem and the loss of the urchin fishery.

Sea Scallop (*Placopecten magellanicus*)

There is little information available on the inshore range and harvest of the sea scallop, although discrete areas have been studied and historically fished (Brocken and Kenchington 1999). Sea scallops range throughout the inshore waters from the low water line up to 150 m depth, occurring most commonly at 35 – 120 m depth (Brocken and Kenchington 1999, McCullough et al. 2005). Their temperature range extends from 0 – 18°C (Brocken and Kenchington 1999, Couturier et al. 1995), and in northern climates they are found in more shallow water. In a survey of Lunenburg County scallop beds, Brocken and Kenchington (1999) found that scallops were most abundant on substrates composed of combinations of mud and gravel, plants or boulders; gravel and plants, boulders or mud; or kelp and boulders, as opposed to mud or sand only.

Like other bivalves, scallops are filter feeders and relatively sedantary with a typical life cycle beginning with external fertilization, followed by formation of a planktonic trochophore larva, a swimming shelled veliger larva, and finally a swimming pediveliger which sinks to the substrate after 6 weeks (Cragg and Crisp 1991). Following metamorphosis, the juvenile scallop attaches to the substrate with byssal threads, but at 16 mm length or greater, it can detach from the subtrate and swim to a new location (Couturier et al. 1995). Scallops can swim until 100 mm length, at which size they become too heavy to swim great distances. Adult scallops can move

10-20 m at 67 cm per second, however they rarely exceed distances of 10 m at a time (Brocken and Kenchington 1999). Maximum reported migrations are up to hundreds of meters, though there is no indication of migration routes or patterns (Kenchington et al.1991).

Larval and adult scallops are prey for a number of animals. They are preyed upon as larva by zooplankton and planktivorous fish, and in the adult form by cod, sea stars, American plaice, and wolffish (Brocken and Kenchington 1999). Damaged or injured scallops can also fall prey to moon snails, rock crabs, groundfish, winter flounder and lobster. Scallops also provide an unusual refuge to juvenile red hake and sea snail fish, which seek shelter within the mantle cavity (Brocken and Kenchington 1999).

Inshore scallop fishing has been recorded since 1886 in Lunenburg (Brocken and Kenchington 1999). In the 1950s, the fishery consisted of 30 boats dragging off Second Peninsula, Lunenburg County, and in the 1970s, SCUBA divers began to harvest the scallops in the area. Exploitation continues commercially and recreationally via dragging, dredging, dipping, diving and tong usage. In 1990, the Scallop Fishery Area (SFA 29) was established as well as the Inshore Scallop Advisory Committee which worked in conjunction with DFO. This area extends from South Yarmouth (latitude 43° 40 N) to Cape North, Cape Breton, encompassing up to 12 miles offshore. The south-western shore is managed in 5 subsections (A to E), only one of which (D) is in the Inshore Scotian Shelf EOR study area (Figure 57). Thus, the scallop fishery is not assessed for most of the inshore area considered in this report. There is a bycatch of lobster in the inshore scallop fishery, greatest in subsection B, though the effects on juvenile lobster habitat and recruitment are unknown.

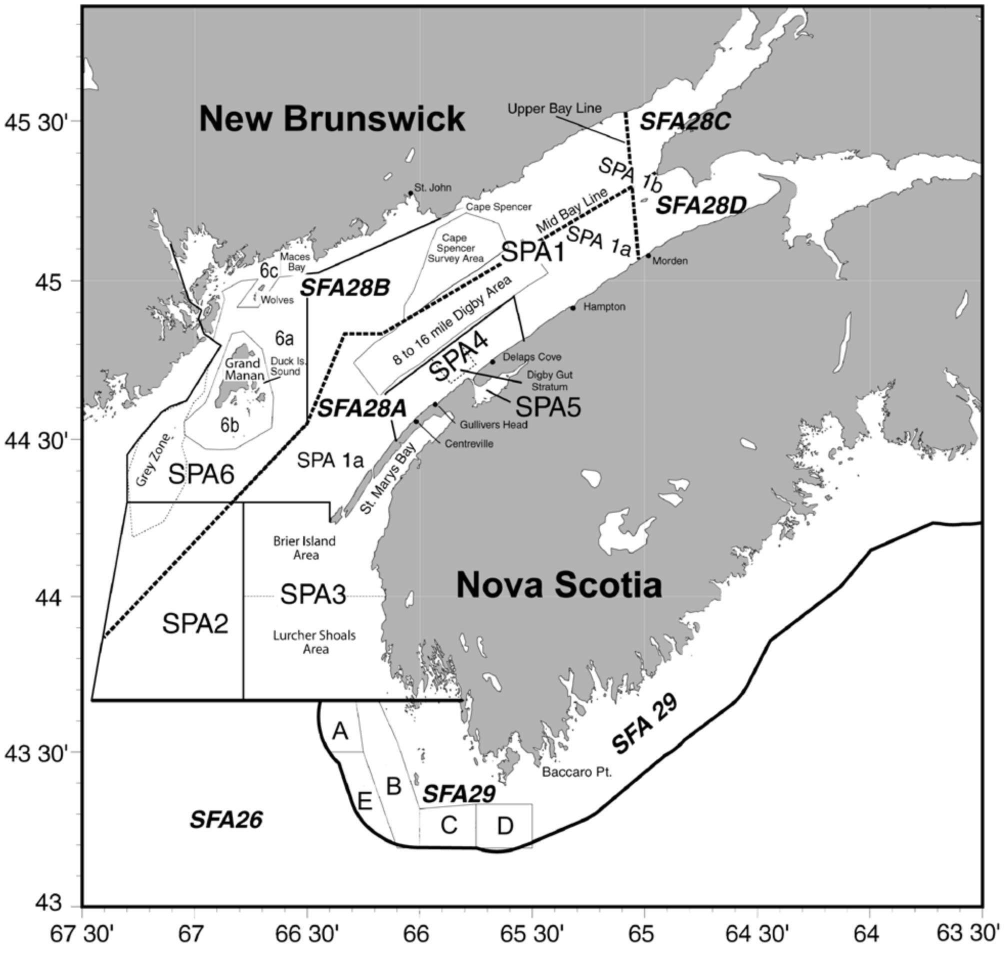


Figure 57. Inshore scallop fishing grounds (DFO 2009a).

9.2.4.2 Exploratory and Emerging Fisheries

In response to declines in abundance of traditional species and changing global demand and markets, exploratory fisheries for non-traditional species have developed, commonly for lower trophic level species (Anderson et al. 2008). The inshore area of the Atlantic coast of Nova Scotia supports several such endeavours.

Toad Crabs (*Hyas araneus* and *H. coarctatus*)

There are two species of toad crabs within the inshore waters, *Hyas araneus* and *H. coarctatus* (Tremblay et al. 2001). Their life history is poorly described, though they are found along the entire inshore Scotian Shelf (Bundy 2007) but occur mostly on the eastern Scotian Shelf (Figure 58). They were subject to an experimental fishery off Sydney Bight in the 1990s, caught mainly at depths of 35 – 80 m. Yields were sufficient for commercial exploitation at 16 – 40 crabs per trap, and averaged 6 t in 4Vn from 2002-2006. However, there is not a large market demand and the fishery has not become lucrative.

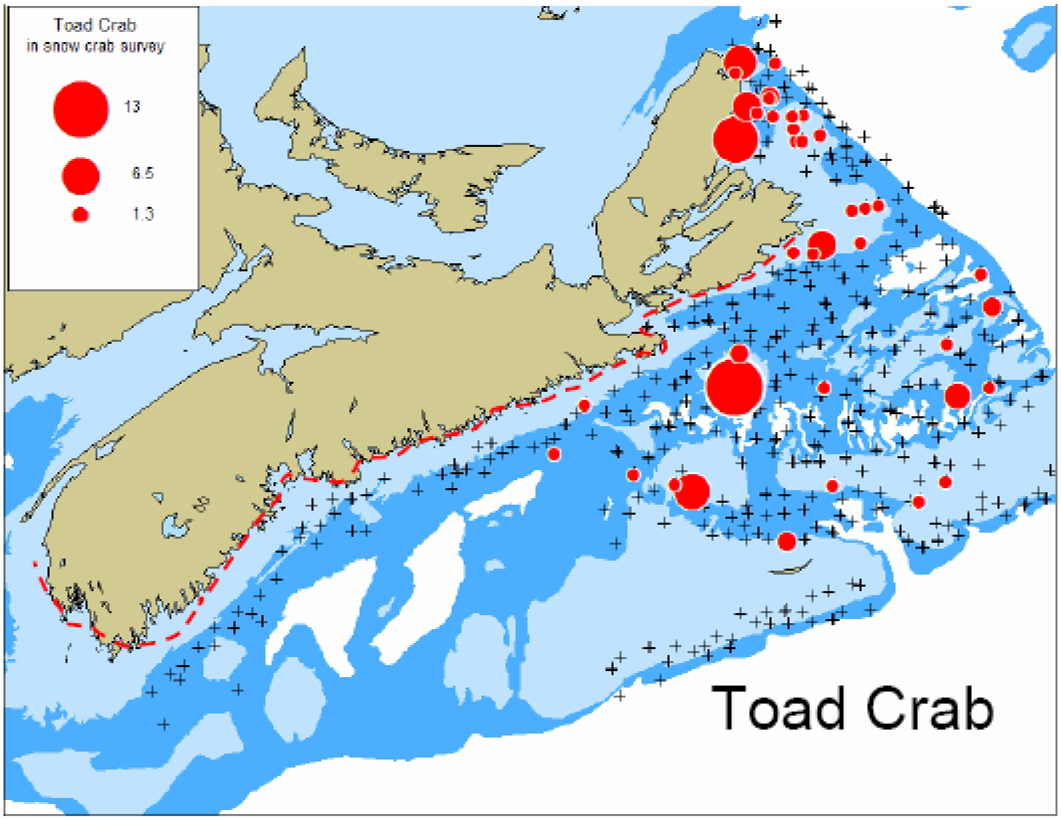


Figure 58. Toad crabs caught in the 2005 Snow Crab Survey. Red dashed line indicates distribution in the inshore, not sampled by the Snow Crab Survey (Tremblay 2006).

Green Crab *(Carcinus maenas)*

The green crab is an invasive species that originated in France and was likely introduced to North America by ballast water (Behrens Yamada 2001). They reached Nova Scotia in the late 1950s, and a recent survey of green crab determined that they are firmly established (Tremblay et al. 2006, Figure 59). Green crabs are tolerant to air exposure, starvation (up to 3 months) and a wide range of salinity and temperature. They are most abundant in shallow sheltered areas, including those with eelgrass, though they are generally fished on sand and mud. They prey on a number of organisms depending on the season and habitat, but prefer bivalve molluscs including commercially valuable mussels *Mytilus edulis* and *Mya arenria* (Miron et al. 2005).

They may also negatively impact native species such as lobster through competition for food, and predation of juveniles (Rossong et al. 2006). Mussels, barnacles and urchins cannot establish in areas dominated by green crabs as the crabs readily prey upon newly settled invertebrates (Behrens Yamada 2001). There has been an experimental fishery for green crab, but it is currently at a very low level (J. Tremblay, pers. comm.).

Green crab are implicated in the destruction of eelgrass beds (Sections 9.2.2.2) and also as a vector for the invasive tunicate *Styela clava* which outcompetes native tunicates and fouls marine habitats and manmade structures such as aquaculture gear (Locke et al. 2007).

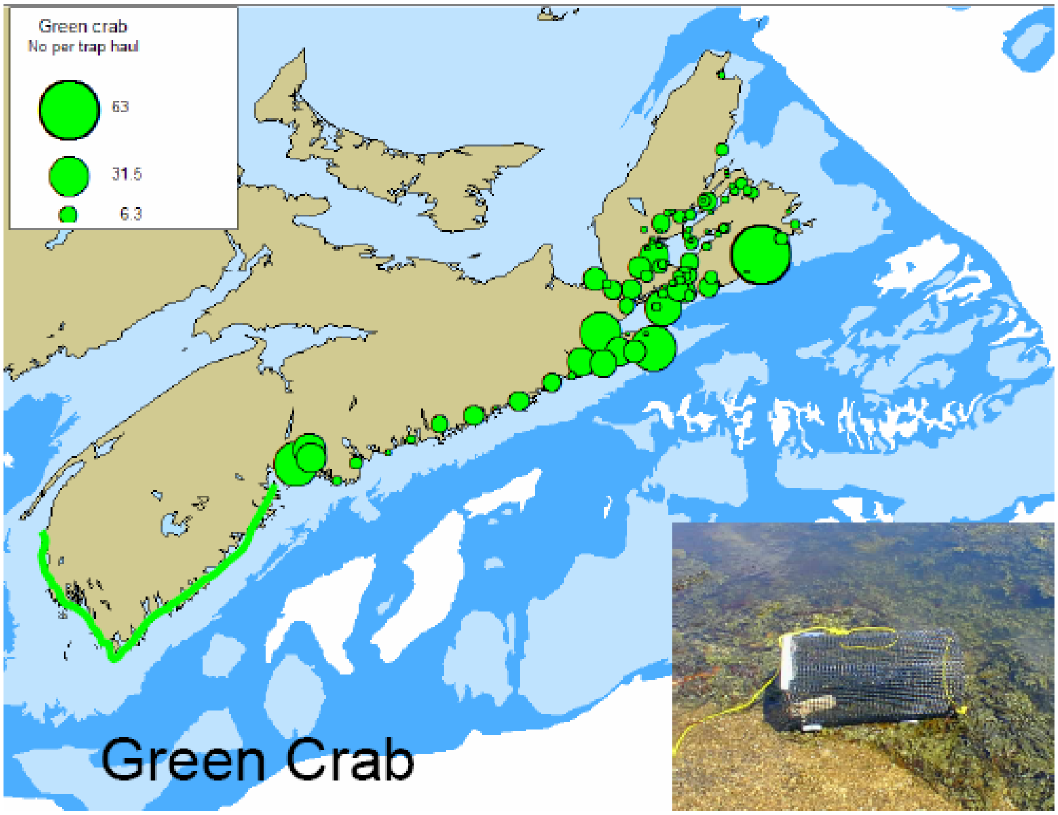


Figure 59. Distribution of green crab around the Atlantic coast of Nova Scotia. Data from green crab trap survey (from Tremblay et al. 2006).

Blue Mussel *(Mytilus edulis)*

Blue mussels are ubiquitous along the Atlantic coast of Nova Scotia, occurring in rocky habitats in cracks and crevices of the intertidal zone and in subtidal areas, in preferred depths of 3 – 5 m (Scrosati and Heaven 2008, Kenchington et al. 2002). They can also exist in deeper beds up to 60 m where sea star predators are low in abundance and will colonize any sort of structure (McCullough et al. 2005, Seed and Suchanek 1992). Mussels are sedentary as adults, attached by byssal threads to hard or solid surfaces, with a similar life cycle to other bivalves such as scallops (Section 9.2.4.1). They spawn mainly between mid-May and mid-June. The larva is planktonic and capable of swimming and positioning itself within the water column to avoid being washed away by tides, and to position itself for settlement.

A variety of fishes feed on the larvae, and the adults are an important food source for local sea stars, crabs, urchins and sometimes whelks (Scheibling and Lauzon–Guay 2007; Kenchington and Glass 1998). A filter feeder, *M. edulis* is microphagous, consuming diatoms, dinoflagellates and bacteria, as well as planktonic larvae of bivalves, crustaceans, gastropods and polychaetes (Davenport et al. 2000; Lehane and Davenport 2002, 2004; LeBlanc et al. 2007).

Due to widespread aquaculture of mussels, commercial exploitation of wild adults is almost non-existent, though many of the aquaculture facilities seed their mussel farms with wild larvae collected from spat collectors of polypropylene rope or mesh tubing (McCullough et al. 2005, Mallet and Myrand 1995, Hickman 1992). A second species of mussel, *M. trossulus*, also occurs along the Atlantic coast, co-existing with *M. edulis*. They prefer depths of ≤ 1 m and are tolerant of a wide range of salt concentrations, whereas *M. edulis* prefers saltier water. (Kenchington et al. 2002). Some limited hybridization occurs between the two species (Comesaña et al.1996). *M. trossulus* is not commercially exploited or cultivated (Mallet and Myrand 1995).

Whelks (*Buccinum* spp.) and Dogwhelks (*Nucellus* spp.)

Whelks are gastropod molluscs found within the coastal waters of Nova Scotia and in depths up to 180 m (Kenchington and Glass 1998).The only species that is fished commercially is waved whelk (*Buccinum undatum*). Other species of whelk also occur in the inshore Scotian Shelf; however, they accumulate toxins which can be fatal if ingested by humans. Waved whelks are highly specialized within each locality, and appear to have a thicker shell in areas where lobster predation is a concern. These local specializations could be due to the limited dispersal, as whelks do not have a planktonic stage. Between May and August, waved whelks migrate inshore to mate and deposit egg masses on boulders and kelp stipes. They prey on filter feeding bivalves and scavenge dead fish, often occurring in lobster traps. Waved whelks are preyed upon by sea stars, lobsters, dogfish and cod. There is an exploratory fishery for them in inshore areas of NAFO Divisions 4VsW and 4X although landings are very low.

Dogwhelks (*Nucellus lapillus*) are the most abundant predator of intertidal mussels (*Mytilus trossulus* and *M*. *edulis*) on rocky shores along the Atlantic coast (Hunt and Scheibling 1998). Based on the relatively high feeding rate of recent recruits and broad size range of mussels they consume, Hunt and Scheibling concluded that small whelks are potentially important in limiting mussel recruitment. Dogwhelks may be keystone species in intertidal communities around Halifax Harbour by predating on species such as mussels and barnacles which reduce the amount of available substrate for settlement and growth of macrophytes. Coray and Bard (2007) found several changes in community structure associated with the presence of dogwhelks including decreased barnacle coverage, increased numbers of intertidal species and numbers of algal species. Sites with dogwhelks had significantly lower numbers of green crabs, indicating that dogwhelks may help control populations of this invasive predator.

Imposex is a condition causing sterility in whelks through the superimposition of male characteristics on females. A major culprit is tributyltin, a compound used in marine anti-fouling paints until 2003, and also found in wastewater and sewage. A comparison of whelks from Halifax Harbour with those from uncontaminated locations outside the harbour showed that the occurrence of imposex characteristics increased from 19% of all whelks at the mouth of Halifax Harbour to 100% at midharbour, compared to 0% outside the harbour (Coray and Bard 2007). Increased frequency of imposex between 1995 and 2006 near a container pier and the absence of dogwhelks from the harbour head led the authors to conclude that TBT is partially responsible for the the absence of dogwhelks in some areas, and that current TBT controls (banned from use since 2003) have not effectively minimized endocrine disruption or population decline of susceptible marine gastropods. Imposex in dogwhelks has been noted in Sydney Harbour and other locations in Halifax County (CBCL Limited 2009).

9.2.4.3 Non-commercial species

Hermit Crab *(Pagurus spp.)*

Hermits crabs differ from the other crabs discussed above by not having a carapace. They are adapted to occupy the empty shells of other animals, usually gastropods, and continually switch to larger shells as they grow, thus maintaining a shelter that adequately protects them from predators (Hazlett 1981). They have a widespread distribution and are found in virtually all marine environments. There are several species along the Atlantic coast, such as *Pagurus longicarpus*, but little specific information is known about their distribution or ecology. Hermit crabs are omnivorous detritivores, and detritus is their main source of nutrients (Hazlett 1981). They are an important prey species for rock crab (Angel 2000).

Periwinkle *(Littorina littorea)*

Periwinkles are common gastropods occurring along the inshore Scotian shelf, ranging from the low water mark to depths of up to 40 m (DFO 1998b). They tend to aggregate at the low water mark intertidally but can be found on a variety of substrates ranging from rock to sand and also within *Ascophyllum nodosum* beds (DFO 1998b; McCullough et al. 2005). *Littorina littorea* graze on microalgae and newly settled invertebrates, and can influence the benthic species community (DFO 1998b). There is no license required for harvesting periwinkles unless using a mechanical device. Landings are not regularly reported, but the majority of the harvesting takes place outside of the Inshore Scotian Shelf in the southern New Brunswick and Digby areas.

Intersex is a condition affecting periwinkles characterized by a phenotypic disturbance of sex determination between gonad and genital tract. A study of tributyltin effects on gastropod populations in Halifax Harbour found that intersex incidence ranged from 0% outside the harbour to 100% at sites near the head of the harbour (Coray and Bard 2007). Periwinkles appear to tolerate higher TBT exposure than dogwhelks and were found where dogwhelks have been extirpated because of TBT contamination.

Sea Cucumbers *(Cucumaria frondosa)*

There is very limited information on life history and stock structure of sea cucumber in the Maritimes Region (Rowe et al. 2009), and there has been no focused research on the inshore Scotian Shelf. The common species that does occur within these waters, *Cucumaria frondosa,* can exist from the intertidal zone, up to 370 m deep, but is most common at depths shallower than 30 m (Jordan 1973). The distribution of sea cucumbers in inshore Scotian Shelf waters is largely unknown, although there is an exploratory fishery for them in Passamaquoddy Bay, southwest New Brunswick (Rowe et al. 2009). Their offshore distributions are known primarily from bycatch during scallop, groundfish and clam fisheries and the DFO RV Survey (DFO 1996a).

Sea cucumbers release gametes into the water column and larvae have a brief planktonic phase of 48 days before settlement (Hamel and Mercier 1996). Gravel or rock is favoured as a settling substrate, and adults are found mainly on hard clean surfaces, under ledges and in crevices (Hamel and Mercier 1996; Jordan 1973). Sea cucumbers are slow moving filter feeders, but can crawl using their tube feet and/or muscular wall (Jordan 1973). Jordan (1973) also noted that the larger individuals of the populations in Maine migrated to deeper waters in the winter season.

Sea cucumbers play an important role in bioturbation, transferring organic matter and inorganic matter into the water column by disturbing the sediments and depositing digested particles on to the substrate (DFO 1996b). The animal passively intercepts particulate matter and planktonic organisms with its tentacles, which it inserts into its mouth to remove the particles trapped in the mucous layer (Singh et al. 1999). The proportion of larval planktonic organisms in sea cucumber diets, and possible impacts of this consumption on planktivorous fish or invertebrates is not known. The proportion of the sea cucumber diet that is made up of larval planktonic organisms, or the impacts this consumption has on fish and invertebrate species (Singh et al. 1999), is also not known. Sea cucumbers may exert competitive pressure on other filter feeders, such as the commercially important sea scallop. Sea cucumber predators are not well documented. They can be consumed by large green sea urchins (*S. droebachiensis*), sea stars *Solaster endeca,* and *Asterias vulgaris*; however, C. *frondosa* is poisonous to groundfish (DFO 1996b, Jordan 1973).

Sea Stars

Sea stars are an ecologically important but non-commercial species of echinoderm that inhabit the inshore waters of the Scotian Shelf. Species include seastar (*Asterias vulgaris*), mudstar (*Ctenodiscus crispatus*), bloodstar (*Henricia sanguinolenta*) and brittle star (*Ophiopholus aculeata*) (McCullough et al. 2005). They are predators on a variety of invertebrates in the intertidal and subtidal zone including barnacles, mussels, sea urchins and clams. Seastars feed by extruding their stomach onto a prey item, secreting digestive enzymes and then sucking up the resulting liquid (Brusca et al. 2002). Observations on seastars during foraging indicate that the release of these chemicals may attract other foragers such as smaller seastars, bloodstars, whelks and crab species (Morissette and Himmelman 2000, Scheibling and Lauzon–Guay 2007).

Asterias settle on rocky shores following a pelagic larval phase. They tend to be found in kelp beds and population density is correlated with subtidal mussel beds (Barbeau et al. 1996). These beds are short-lived due to intense predation. Sea stars also feed on small to medium sized scallops. While sneaking up on their prey, predatory sea stars emit saponins which scallops and other prey species detect and use to monitor the distance between them and the predator (Barbeau and Scheibling 1994a). This allows the scallop time to protect itself from the hungry predator by assuming the ready-to-swim position. Studies of the effect of temperature upon predation rates concluded that the effectiveness of sea scallops' escape response decreases with increasing temperature, resulting in a higher success rate for the sea star. (Barbeau and Scheibling 1994b).

Sand Dollars *(Echinarchius parma)*

Sand dollars can be found from the subtidal zone to the offshore banks on sandy sediments of fine to medium grade sand. Certain grades of sand may be preferential because they trap an optimal level of organic material whereas finer subtrates may become too foul (Stanley and James 1971). They can occur at densities of 100/m^2 or more and are a major factor in altering species composition and reducing abundance of other macrofaunal invertebrates in soft-bottomed communities (Stanley and James 1971). Reported length at maturities are > 28 mm in the Gulf of St. Lawrence (Cabanac and Himmelman 1998) and 43 mm in the Gulf of Maine (Brown 1983). Cabanac and Himmelman (1998) found that juveniles (<28 mm in length) were extremely abundant at 16 and 20 m depth (460-660/m^2) and decreased in number with decreasing depth, whereas the density of adults was relatively stable at different depths. Juveniles were more frequently buried (95%) than adults (30%). They suggested that larger sand dollars move to shallower water to take advantage of food resources such as benthic diatoms, which are more abundant there. Large individuals are probably better adapted than juveniles to exploiting shallower water because they are less likely to be transported by water turbulence. Sand dollars are eaten by birds, fish (haddock, flounders), crabs, seastars and sea urchins (Cabanac and Himmelman 1998).

Bryozoans

Bryozoans are colonial organisms that can take on a variety of forms (McKinney and Jackson 1991). One common indigenous form found in the inshore Scotian shelf is an encrusting bryozoan called *Electra pilosa*, which grows predominantly on understory algae (Berman et al. 1992). In the 1990s an invasive species of European encrusting bryozoan, *Membranipora membranacea*, made its way into Canadian waters becoming very prominent on kelp blades (Saier and Chapman 2004). *M. membranacea* thrives in areas of high water movement (Hermansen et al. 2001). In years of high coverage, the large colonies of *M. memembranacea* can effectively cover the kelp blade, causing the blade to become brittle and susceptible to breakage in the stormy winter months (Lambert et al. 1992, Scheibling et al. 1999, Saunders and Metaxas 2008, Scheibling and Gagnon 2009, Krumhansl and Scheibling 2011b). This defoliation of the kelp beds opens a colonizable habitat for *Codium fragile,* an invasive green algae (Scheibling and Anthony 2001, Kelly et al. 2011, Section 9.2.2).

9.2.5. Groundfish

Contributed by J. Sperl, J. Simon and A. Bundy

Groundfish live on or near the bottom of the ocean and include roundfish, flatfish, skates and sharks. Extensive information on the biology and distribution of groundfish exists for the Scotian Shelf and is well documented in Breeze et al. (2002), Bundy (2004), Zwanenburg et al. (2006) and Horsman and Shackell (2009). However, little of this research has been focused on the inshore portion of this area, and consequently there is much less information. The scientific research that does exist is spatially and temporally limited. There have been three dedicated, one-off fish surveys of the inshore. An exploratory trawl survey was conducted in the inshore areas of southern Nova Scotia at depths between 8 and 40 m in the mid-1980s (Simon and Campana 1987). Although this survey only included the southern shore from Yarmouth to Lockeport (the other portion of the survey took place between Minas Basin and Cape St. Mary), it is indicative of groundfish species that typically occur inshore of 12 nautical miles. Simon and Campana (1987) reported the occurrence of 34 fish species in their survey including some pelagic species such as herring (*Clupea harengus) (*Section 9.3.3.2), smelt (*Osmerus mordax*) (Section 9.3.4) and alewives (*Alosa* species) (Section 9.3.4), 25 of which occurred in the inshore area considered in this report (Table 15).

Table 15. List of groundfish species that occur in the inshore area of Atlantic Nova Scotia (< 100 m, within 25 km) from several surveys.

Groundfish	Species	Commercial fishery	O'Conner 2008	DFO/FSRS Inshore Project	Simon and Campana (1987)	4Vn Sentinel Survey	4VsW Sentinel Survey	ITQ Survey	# surveys
American Plaice	*Hippoglossoides platessoides*	Y		Y		Y	Y	Y	4
Atlantic Cod	*Gadus morhua*	Y	Y	Y	Y	Y	Y	Y	6
Atlantic Tomcod	*Microgadus tomcod*		Y	Y					4
Banded Gunnel	*Pholis fasciata*			Y					1
Cunner	*Tautogolabrus adspersus*		Y	Y	Y				3
Cusk	*Brosme brosme*					Y	Y	Y	3
Greenland Cod	*Gadus ogac*					Y	Y		2
Grubby	*Myoxocephalus aenaeus*		Y	Y					2
Haddock	*Melanogrammus aeglefinus*	Y			Y	Y	Y	Y	3
Hake (white/red)	*Urophycis spp*	Y	Y	Y	Y	Y	Y	Y	6
Halibut (Atlantic)	*Hippoglossus hippoglossus*	Y				Y	Y	Y	3
Little Skate	*Leucoraja erinacea*		Y	Y	Y		Y	Y	5
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	Y	Y	Y	Y	Y	Y	Y	6
Lumpfish	*Cyclopterus lumpus*	Y	Y	Y				Y	3
Monkfish	*Lophius americanus*				Y	Y	Y	Y	4
Ocean Pout	*Zoarces americanus*				Y	Y	Y	Y	4
Pollock	*Pollachius virens*	Y	Y	Y	Y	Y	Y	Y	6
Redfish	*Sebastes sp.*	Y		Y		Y	Y	Y	4
Rock Gunnel	*Pholis gunnellus*		Y	Y				Y	3
Sea Raven	*Hemitripterus americanus*		Y	Y	Y		Y	Y	5
Shorthorn Sculpin	*Myoxocephalus scorpius*			Y			Y	Y	4
Silver Hake	*Merluccius bilinearis*	Y				Y	Y	Y	3
Smooth Skate	*Malacoraja senta*					Y	Y	Y	3
Spiny Dogfish	*Squalus acanthias*	Y		Y	Y	Y	Y	Y	5
Thorny Skate	*Amblyraja radiate*				Y	Y	Y	Y	4
Twohorn Sculpin	*Icelus bicornis*					Y		Y	2
Windowpane	*Scophthalmus aquosus*		Y	Y	Y			Y	4
Winter Flounder	*Pseudopleuronectes americanus*	Y	Y	Y	Y	Y	Y	Y	6
Winter Skate	*Leucoraja ocellata*			Y	Y	Y			3
Wolffish	*Anarhichas spp*		Y	Y	Y	Y	Y	Y	4
Wrymouth	*Cryptacanthodes maculatus*			Y	Y				2
Yellowtail Flounder	*Limanda ferruginea*	Y	Y	Y	Y	Y			4

The most frequently encountered species encountered across these six surveys were cod (*Gadus morhua*), skates (winter skate, *Raja ocellata* and smooth skate, *Malacoraja senta*), winter flounder (*Pseudopleuronectes americanus*), pollock (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), sea raven (*Hemitripterus americanus*) and yellowtail flounder (*Limanda ferruginea*). As reported by Simon and Campana (1987), all of these species are regularly reported in the DFO Research Vessel Surveys of the Scotian Shelf (Simon and Comeau 1994). Of the groundfish species, the length-frequency data indicated that young-of-the-year and age 1 pollock and white hake were more prevalent in the catch than older fish, consistent with the theory that these species use the inshore as nursery areas (Clay et al. 1989, Bundy and Simon 2005). Three joint DFO-industry surveys include inshore stations as part of a broader survey area: the 4VsW and 4Vn Sentinel Surveys are long-line surveys and the ITQ survey is a trawl survey. The 4VsW Sentinel survey began in 1995 and occurs during autumn, the 4Vn began in 1994 and occurs during September (Figure 60) and the ITQ survey has been conducted every July since 1986 in southwestern Nova Scotia (Figure 61).

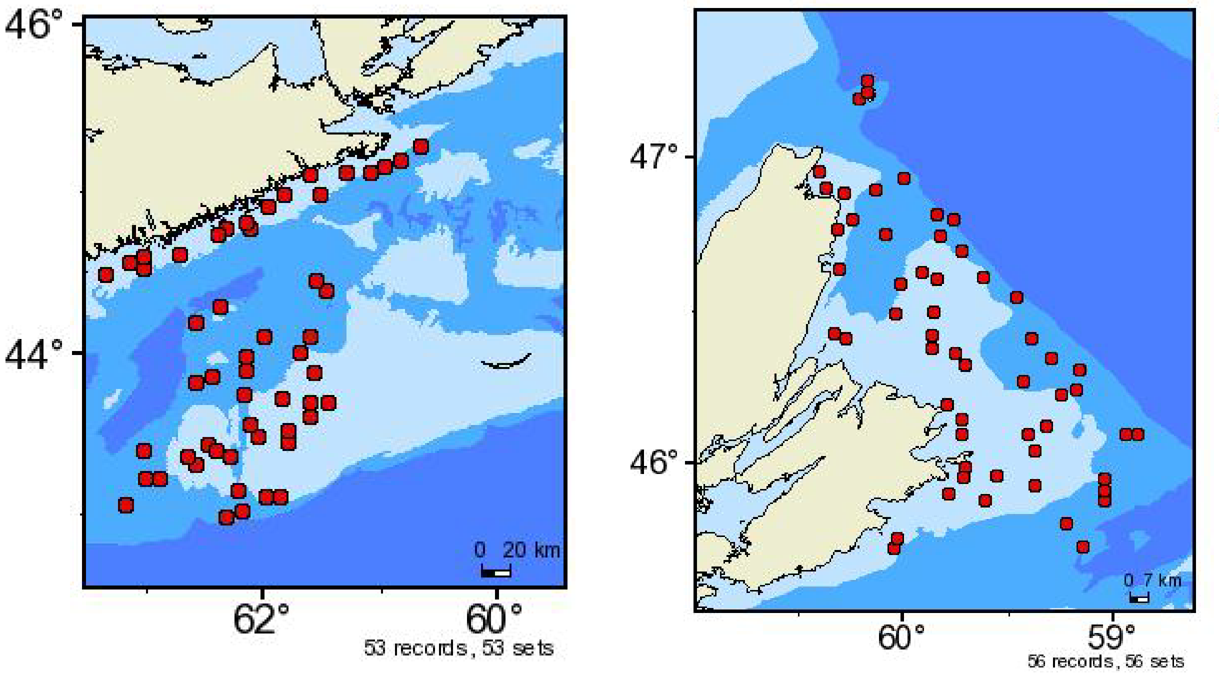


Figure 60. Station locations of the 4VsW (left) and 4Vn (right) sentinel surveys in 2011.

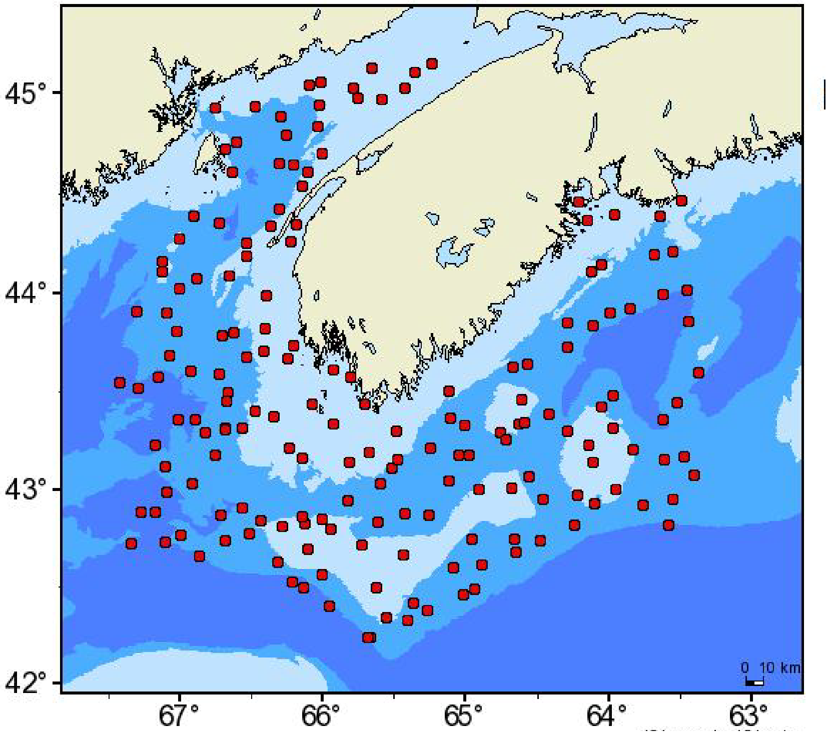


Figure 61. Fixed station locations of the ITQ survey in 2011.

The 4Vn sentinel survey consists of two main components, a stratified survey where stomachs are collected by crew (SS) or observers (JSS) and a commercial index surveys. Species that were only observed in the sentinel and ITQ surveys include more northern species such as Greenland cod (*Gadus ogac*), Atlantic halibut (*Hippoglossus hippoglossus*), northern wolffish (*Anarhichas denticulatus*) and Greenland halibut (*Reinhardtius hippoglossoides*), and other species such as cusk (*Brosme brosme*) eelpouts (*Lycodes sp*.) and the more offshore longfin hake (*Phycis chesteri).*

More recently, the DFO/FSRS Inshore Ecosystem Project (Bundy 2007b) sampled 910 sites along the Atlantic coast of Nova Scotia, from Port La Tour in the south, to Mira bay in Cape Breton using beach seines, lobster traps and gillnets, at depths ranging from 1 m to 100 m in 2006 (Figure 62, Table 15). The beach seine survey of fish in the immediate inshore revealed a diversity of species, including several species that are restricted to shallow inshore waters, such as sticklebacks (Gasterosteidae family), mummichog (*Fundulus heteroclitus*) and northern pipefish (*Syngnathus fuscus*). However, the most abundant fish species caught by beach seine were Atlantic herring, Atlantic silversides (*Menidia menidia*) and Sand lance (*Ammodytes* spp.). The most abundant fish caught by gillnets (in deeper water up to 100 m) were redfish (*Sebastes* spp.), Cunner (*Tautogolabrus adspersus*) and Atlantic herring (*Clupea harengus*). The lobster traps caught mostly crustaceans, but commonly included fish such as cunner, winter flounder, Shorthorn sculpin (*Myoxocephalus scorpius*) and Longhorn sculpin (*M. octodecemspinosus*). In a comparable beach seine study of juvenile fish in twenty bays from St. Mary's Bay in the Bay of Fundy to Chedabucto Bay (Canso County) in the summers of 2005 and 2006 (O'Conner 2008), the most abundant species were Sand lance, Atlantic herring, unspecified red or white hakes (*Urophycis* spp) and sticklebacks. Overall, the majority of juvenile fish species were distributed over the entire study area.

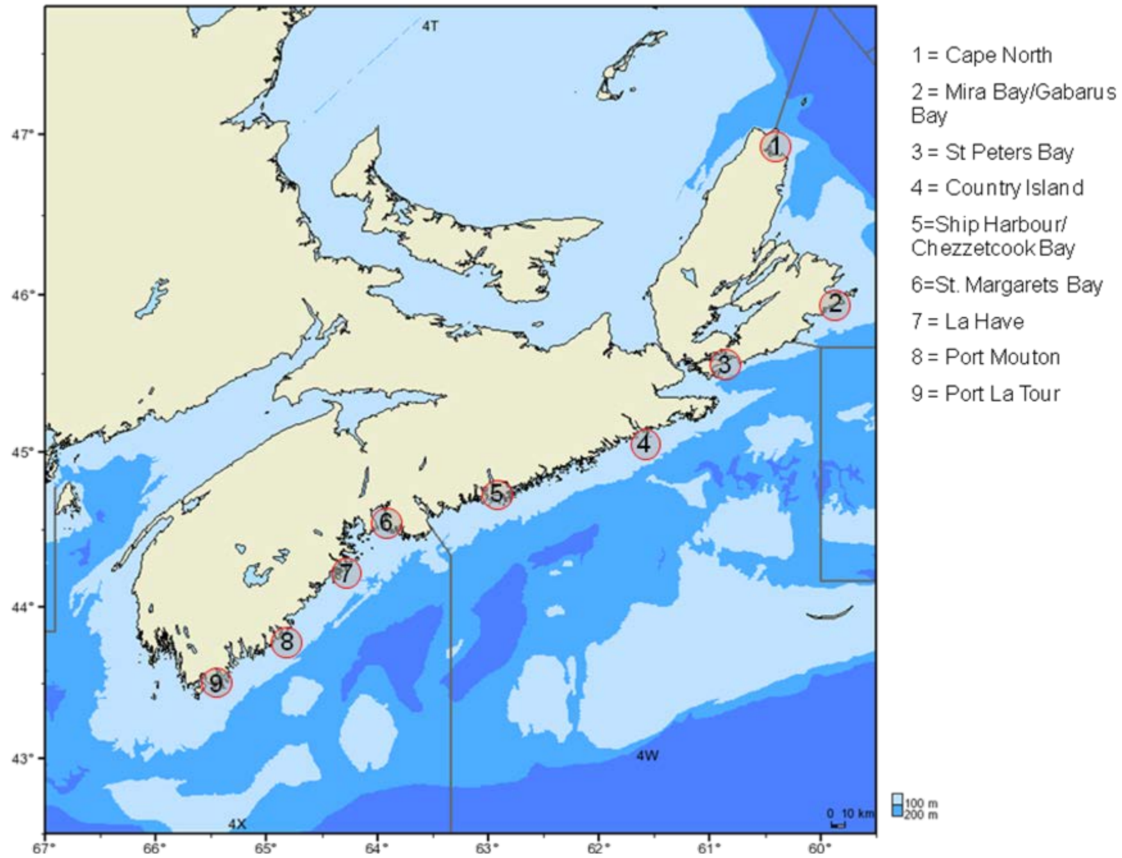


Figure 62. Map of Nova Scotia showing the 9 sites sampled by the DFO/FSRS Inshore Ecosystem Project (Bundy 2007b).

These various surveys indicate that at least 58 species of groundfish occur in inshore areas of the Scotian Shelf (Table 15). However, few are restricted to the inshore: in some cases, their distribution includes the inshore (e.g. cod, cunner, monkfish, redfish), others utilize the inshore for only part of their life histories (spawning, nursery grounds) and in some cases, there are (or were) separate inshore populations, e.g, cod (Clark 2006). For example, a few species, such as Atlantic tomcod and Winter flounder migrate inshore to spawn in the shallow regions and in estuaries. The young of the year remain inshore to feed and grow, then migrate offshore when they have reached a species specific size. Other species spawn offshore and their young migrate inshore to grow, such as pollock and Atlantic cod. They may stay there for several years before they also move offshore to spawn. How each species uses the inshore depends on their life history and the geomorphology of the area. For example in NAFO Division 4Vn there is a very wide shallow area adjacent to the shore while in NAFO Division 4Vs this area can be quite narrow with rocky shores. On the Eastern Shore there are quite extensive estuarine ecosystems with sandy beaches separated by rocky headlands. These differences will affect which species occupy the inshore and their local distribution. A number of the groundfish species found inshore Nova Scotia have been assessed by COSEWIC. Atlantic cod (Southern and Laurentian South populations), deepwater redfish (Gulf of St. Lawrence - Laurentian Channel population) and cusk have been assessed as Endangered. American plaice (Maritimes population), Acadian redfish (Atlantic population), winter skate (Eastern Scotian Shelf population), northern wolffish, spotted wolffish, and white hake have been assessed as Threatened. Atlantic wolffish, smooth skate (Laurentian – Scotian population), thorny skate and winter skate (Georges Bank-Western

Scotian Shelf population) have been assessed as Special Concern. Of these, only the wolffish species are currently listed on Schedule 1 of SARA.

Most of the exploited fish species (Table 15) are taken by fisheries occurring offshore, although there is some activity in the inshore (see Figures 63-66), and most have been well described by Breeze et al. 2002, Horsman and Shackell (2009) or Scott and Scott (1988). Thus we give a very brief overview of the main species that use the inshore below, with a focus on what is known about them in the inshore.

9.2.5.1 Major Commercial Species

Atlantic Cod *(Gadus morhua)*

Cod have an Atlantic-wide distribution and much has been published about them (e.g. Dutil et al. 2003, Hutchings 2005) and their lengthy history of exploitation (e.g. Kurlansky 1997). They are omnivorous and cannibalism is common at all life stages; they are preyed on by larger cod, squid, pollock, halibut, grey and harbour seals (Scott and Scott 1988, Araujo and Bundy 2011) and are broadcast spawners.

Historically, a number of discrete cod stocks were identified along the Atlantic inshore coast of Nova Scotia. These were largely stationary, mixing only slightly with neighbours along the shore or offshore. Their movements tended to be related to submarine physiography and deep channels tended to act as barriers (McKenzie 1956). These inshore spawning stocks no longer exist. The cod landed inshore were much larger than cod taken today anywhere on the Scotian Shelf. The average size of cod tagged off Halifax in 1934 was 59 cm; 1935, 75 cm; and 1936, 66 cm. Maximum sizes were over 110 cm (McKenzie 1948). Cod are still caught in inshore areas of 4Vn and 4X, and in 4VsW, which has been under a moratorium since 1993, there is a small by-catch (Figure 63). COSEWIC assessed the Laurentian South (4T, 4VsW, 4Vn cod management areas) and Southern (4X5Y and 5Zjm cod management areas) populations of Atlantic cod as endangered in 2010 (COSEWIC 2010a).

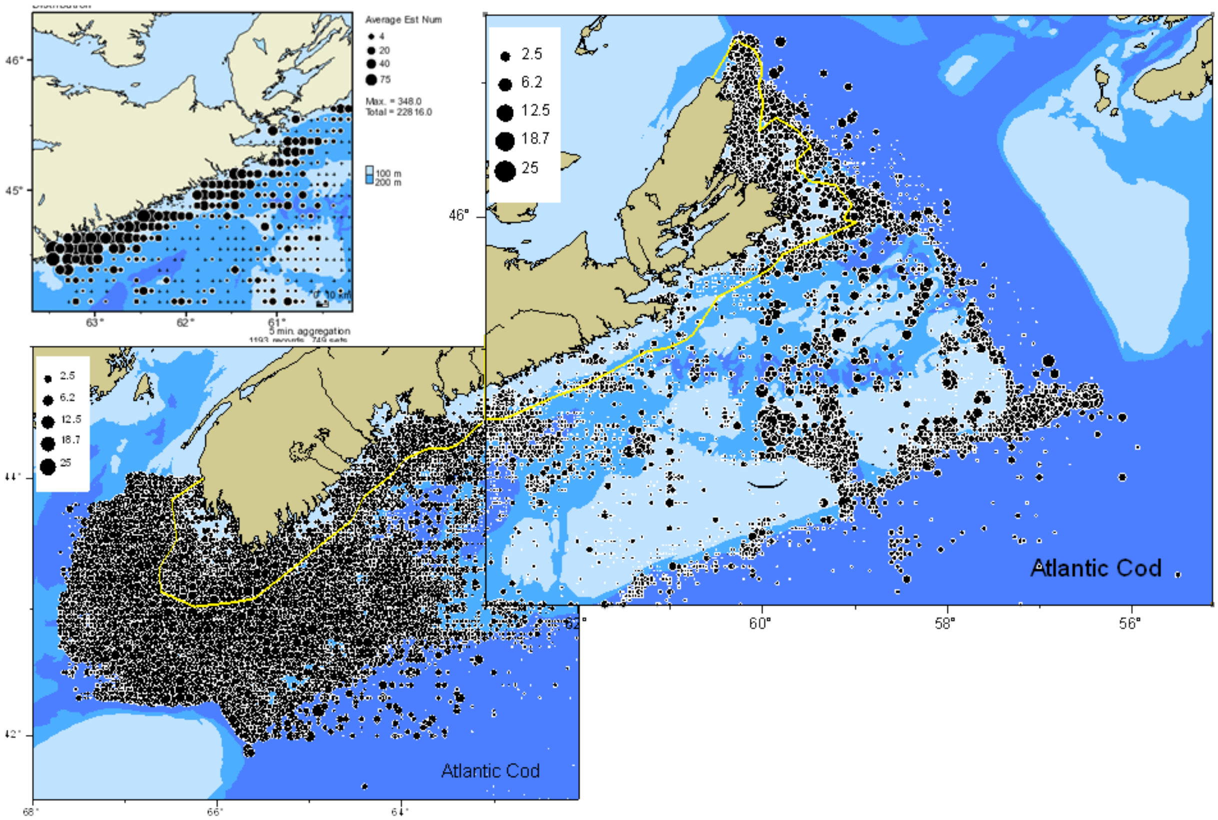


Figure 63. Distribution of commercial landings of Atlantic Cod from 1999-2005. The yellow line indicates the 25 km limit of the inshore Scotian shelf ecosystem. Upper left figure shows catches from 4VsW survey from 1995-2009.Grey dot indicates zero catch).

Spawning occurred in both the spring and autumn, beginning west of Halifax in April, in the Halifax area in April and May, Canso in early June, and Eastern Cape Breton during June and July (McKenzie 1956). Autumn spawning occurred during October and November noticeably in St. Margaret's Bay, Halifax Harbour (Figure 3 in McKenzie 1940) and Chedabucto Bay and to a lesser extent in certain Cape Breton regions, Country Harbour, Jeddore Harbour and Green Bay (McKenzie 1940). Cod eggs were found well up in bays and not outside them. Tows in smaller bays and as far offshore as Sambro Bank yielded practically no eggs (McKenzie 1933).

Given the widespread distribution of cod in all the recent surveys (Table 15) along the Atlantic coast it is possible that there are still small spawning components in the inshore. Using information from an ecological knowledge study, Benham and Trippel (unpublished data) identified several historical cod coastal spawning areas along the Atlantic coast of Nova Scotia, although many observations were not corroborated by other respondents. Notable areas included Chedabucto Bay (spawning in May) and off Capelin Cove in Cape Breton (see also McCullough et al. 2005). Gagné and O'Boyle (1984) examined the distribution of cod larvae and found that their distribution was similar to that of cod eggs in coastal areas. While no larvae were found along the coast of Nova Scotia in early fall or January, larvae were abundant off Halifax and the South Shore in November and December. They concluded that rather than drifting from spawning to nursery grounds, cod larvae are generally retained within large areas where both spawning and nursery areas occur. Nursery areas may also be supplied by larvae from offshore spawning components: Suthers and Frank (1989) found the number of young cod to be 3 times as abundant inshore when compared to the offshore. Note that all of these studies are dated prior to the stock collapse of 4VsW cod and the fishery closure in 1993. The ITQ survey, which is more recent, indicates that age 0 and 1 cod were most abundant inshore (compared to offshore) with the highest catches off Cape Sable (Clark 2006).

Tupper and Boutilier (1995a) showed that survival and juvenile densities of post-settlement cod (< 60 mm) in St. Margaret's Bay in 1991 were higher in more structurally complex habitats and the growth rates were influenced by habitat type, which could affect overwinter survival. Habitat associations may change as juveniles grow and may depend on the substrate available. Newly settled cod in St. Margaret's Bay inhabiting a rocky reef established territories which they defended against intruders, whereas cod that settled on sandy substrates schooled for protection (Tupper and Boutilier 1995b). In studies of young cod in an inshore bay in Newfoundland, age 1 juvenile cod, were associated with gravel substrate with low relief, and used camouflage as a means of predator avoidance, whereas as older juveniles (2-4) were associated with three dimensional structures which offered refuge from predators (Gregory and Anderson (1997).

Benham and Trippel (unpublished data, see above) reported juvenile or nursery areas mainly off Cape Breton in Sydney Bight, between St. Paul and Scaterie islands, and off Cape Gabarus. Based on commercial catch records, cod are distributed throughout the inshore areas, with concentrations in Sydney Bight and in the south (Figure 63). Though there are minimal catches along the Eastern Shore due to the groundfish fisheries moratorium, the 4VsW Sentinel survey indicates that there are cod in this area (Figure 63).

Haddock *(Melanogrammus aeglefinus)*

Haddock are distributed over rocky or hard bottoms and can be found from the inshore to the continental shelf. Like cod, there were important fisheries for haddock in the inshore dating back at least to the 1900s. From 1929 to 1938, 196,734 t of haddock were caught off the Nova Scotia coast; 53% of which was taken offshore and 47% inshore (Needler 1930). As far as Nova Scotia fishermen were concerned, the best haddock producing areas were inshore (McKenzie 1946). The inshore fishery was predominantly longline but considerable quantities of haddock were taken in traps operated along the shore. Runs came almost to the beach (could be seen from a boat in 3-7 m of water). These runs of freshly spent fish supported large fisheries for a month or so from mid-May to mid-July. Ingonish in Cape Breton had possibly the largest runs followed by the Arichat and Petit de Grat regions of Cape Breton. Catches in Jordan Harbour ranked with those from St. Mary Bay and St. Margaret's Bay. These were virtually all trap fisheries (McKenzie 1946). Tagging results summarized by Needler (1930) suggested that haddock in these locations belonged to distinct populations. Similar to cod, haddock to the east tended to migrate between inshore and offshore; whereas those at the southern end of the province tended to move east and west along the shore and not offshore.

Inshore haddock populations were fished out by by the 1950s, and only two reproductively discrete populations are discernible now: one occupying the Gulf of St. Lawrence/eastern Scotian Shelf and the other the Bay of Fundy and Browns Bank (Fowler 2011). These occupy the offshore banks in the winter and only appear inshore in any numbers during the summer.

Benham and Trippel (unpublished data) identified several historical inshore haddock spawning areas, although many observations were not corroborated by other respondents. Where timing information was provided, spawning was said to occur in the late fall/winter (also see Figure 11-6, McCullough et al. 2005). Young haddock were observed by Scott (1982) to aggregate in the shallows around Sable Island segregated by size. Their distribution near the island may be indicative of their behaviour in inshore waters of the Scotian Shelf. For example Scott (1982) found that haddock were distributed by age at depth; aged 0 were found in 27 – 36 m of water and 1 year old fish were found at 36 – 45 m depth.

Benham and Trippel also identified juvenile haddock areas within the inshore. Though juvenile haddock are still found off Jeddore Harbour and in a large area between East Head and Taylor

Head, the areas were previously much more extensive, and contained many more fish. Based on commercial catch records, haddock are distributed throughout the inshore areas, with concentrations in Sydney Bight and in the south (Figure 64). There are minimal catches along the Eastern Shore due to the groundfish fisheries moratorium and the 4VsW Sentinel survey indicates that there are few haddock in this area, though they are caught offshore.

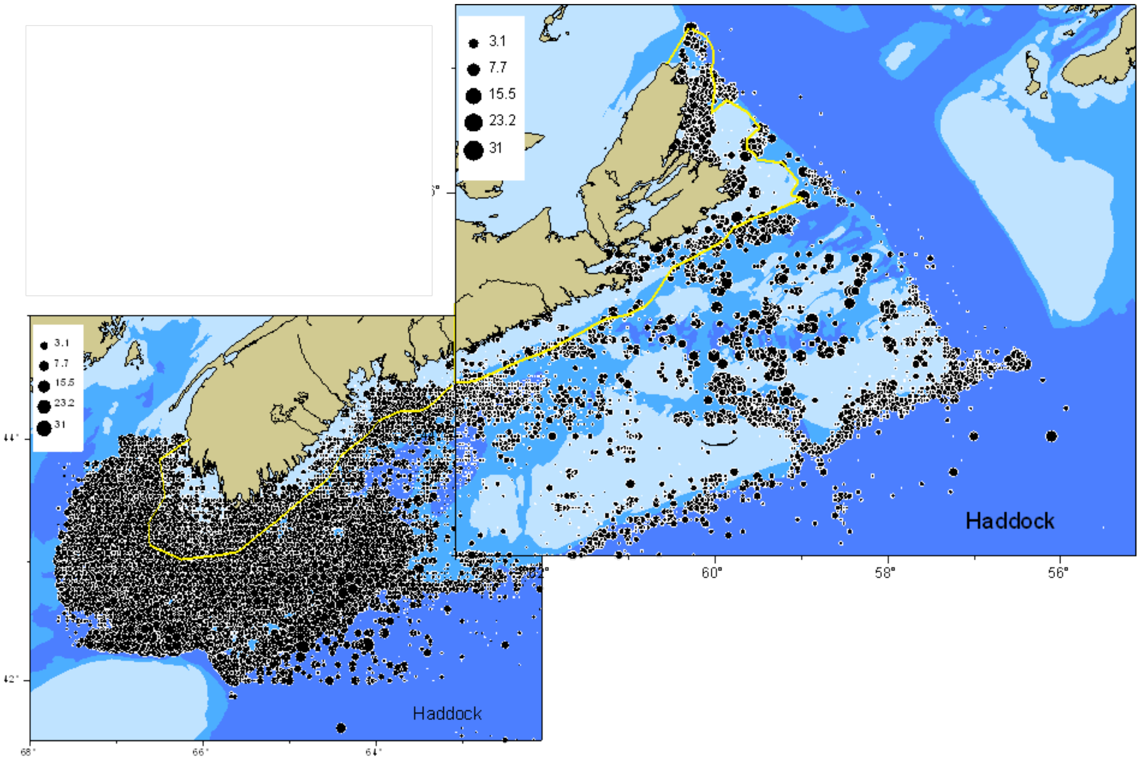


Figure 64. Distribution of haddock from commercial landings data between 1999-2005. Yellow line indicates the 25 km limit of the inshore Scotian shelf ecosystem.

Haddock primarily consume echinoderms and other invertebrates such as crustaceans, molluscs, and annelids, although they will eat small fish such as sand lance, capelin, silver hake, eel elvers, argentine, herring, and herring eggs. As juveniles, they are preyed upon by other groundfish such as cod, pollock and hake.

Pollock *(Pollachius virens)*

Pollock are distributed from North Carolina to the Davis Strait in the Northwest Atlantic, at depths ranging from 35 to 380 m with bottom temperatures varying from 5 to 8°C (DFO 2005a). Although spawning takes place on the Scotian Shelf (between November and March), inshore waters are a recognised nursery area for pollock: after hatching, the larvae migrate to the inshore where they stay until age 2, or around 40 cm (Clay et al. 1989). It is not known whether this migration is active or passive, but growth occurs during this process (Clay et al. 1989): the larvae are 3-4 mm when they hatch then, like cod and haddock, they settle to the bottom when they reach around 5 cm in length (Scott and Scott 1988; Clay et al. 1989).

Results from Benham and Trippel's (unpublished data) local ecological knowledge study suggest that there may have been pollock spawning areas inshore in the past. Several were identified and are mapped in McCullough et al. 2005. Based on commercial catch records, pollock are distributed throughout the inshore areas, with concentrations in Sydney Bight and in the south where the bulk of the stock is located (Figure 65). Due to the groundfish fisheries moratorium, there are minimal catches along the Eastern Shore.

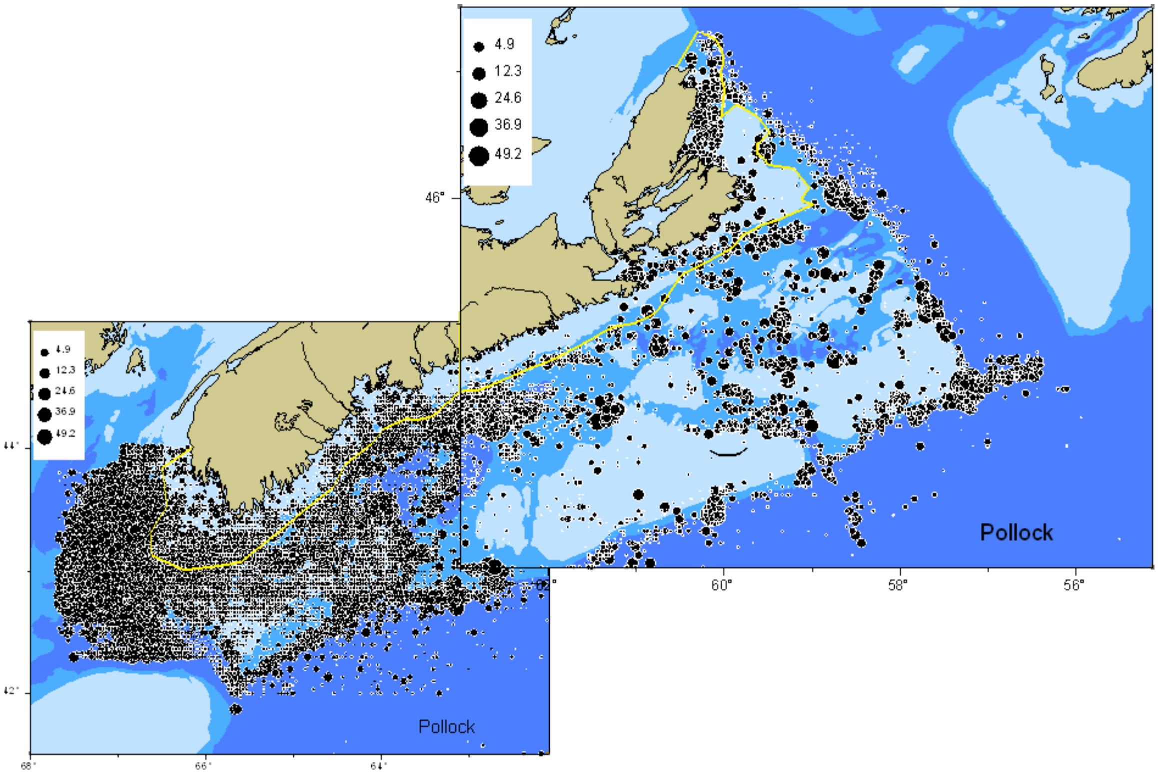


Figure 65. Distribution of pollock catches from 1988-2005. Yellow line indicates the 25 km limit of the inshore Scotian shelf ecosystem.

Juveniles are voracious feeders and have been observed chasing juvenile herring to the point of beaching themselves. As they grow, their diet switches from copepods and crustaceans to larger crustaceans and fish such as herring, sand lance, silver hake and redfish (Scott and Scott 1988). In the past, juveniles were observed to aggregate in thousands around effluent from fish plants and feed off fish discards from the plants (Clay et al. 1989). Adult pollock have few predators other than harbour seals (Scott and Scott 1988) and themselves (Langton and Bowman 1980).

White Hake *(Urophycis tenuis)*

White Hake are distributed from the mid-Atlantic Bight to the southern Grand Banks. They favour temperatures between 6° and 10°C, and their depth range varies with life history stage, with age 2 and older fish occurring predominantly at depths between 50 to 200 m (Bundy and Simon 2005). White hake occur across the Scotian Shelf (Figure 66) and spawn offshore (see Bundy and Simon 2005), but small white hake may actively migrate to the inshore (Fahay and Able 1989). There is some evidence of nursery areas for juvenile white hake in the inshore areas of the Scotian Shelf. Simon and Campana (1987) observed 0 or 1 age group white hake in the inshore areas of 4X during an inshore trawl survey of southwest Nova Scotia. The DFO/FSRS Inshore Ecosystem Study observed white hake less than 7 cm in inshore areas off Cape Breton and the southern shore of Nova Scotia (A. Bundy, unpublished data). Young white hake were captured in the 4Vn Sentinel survey in and around St. Anns Bay (T. Lambert, unpublished data, cited in Schaefer et al. 2004): 0-group white hake were observed in St. Anns's Bay and outside of Sydney Harbour, age-1 and 2 were caught in St. Anns's Bay and around Bird Islands. Markle et al.(1982), on the basis of SSIP data on the distribution of pelagic juveniles around the coast of Cape Breton from May to July (and the lack of pelagic juveniles inshore on the southern half of Nova Scotia), have suggested that these fish may originate in the southern Gulf of St. Lawrence.

Studies from other areas of the NW Atlantic indicate that juveniles settle in inshore areas (Black and Miller 1991; Horne and Campana 1989). Adults and large juveniles are reported to be associated with fine substrates such as mud and clay (Scott 1982), but juveniles are reported to settle on a variety of substrate types in addition to mud and clay, such as gravel, sand and eelgrass (e.g. Fried 1973, Targett and McCleave 1974, Markle et al. 1982, Macdonald et al. 1984, Fahay and Able 1989, Methven et al. 2001, Wroblewski et al. 2006) from the northeastern United States and New England to Newfoundland and Labdrador. Juveniles prey upon amphipods, nematodes, isopods, euphausiids, polychaetes, copepods and mysids; predators include cod, white hake, and harbour and grey seals (Scott and Scott 1988).

There is little evidence of inshore spawning grounds for white hake along the Atlantic coast of Nova Scotia: results from Benham and Trippel's local ecological knowledge study (unpublished data) indicate that only a couple of historical areas off the Eastern Shore north of Halifax were identified by one respondent (see McCullough et al. 2005).

White hake are caught as a bycatch fishery (DFO 2005b), predominantly outside the 12 mile line (Figure 66). White hake were assessed as threatened by COSEWIC in 2013.

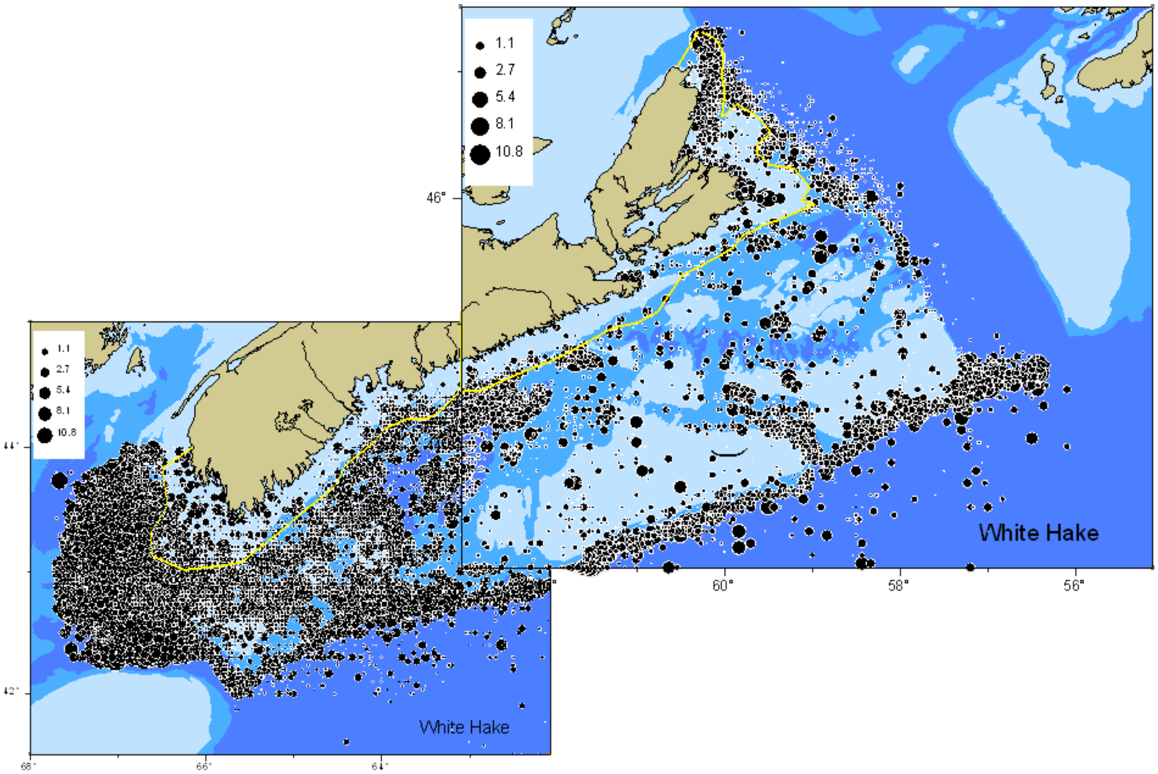


Figure 66. White hake. catches from 1988-2005. Yellow line indicates the 25 km limit of the inshore Scotian shelf ecosystem.

Flounders

Flounders commercially harvested off the Scotian Shelf include American Plaice (*Hippoglossoides platessoides*), Yellowtail Flounder (*Limanda ferruginea*), Witch Flounder (*Glyptocephalus cynoglossus*) and Winter Flounder (*Pseudopleuronectes americanus*). Of these, winter flounder has a specific association with the inshore.

Winter Flounder are a small-mouthed, right-eyed flounder, largely an inshore species, distributed from Georgia to Labrador, but concentrated in the middle of this range (Scott and Scott 1988). They occur all along the Atlantic coast of Nova Scotia (Table 15), and are generally found between 1.8 and 36.6 m deep over muddy to hard bottom. They also are distributed over the offshore banks on the Scotian Shelf. This species has been the subject of considerable research in the northeast US (e.g. Phelan 1992, Able and Fahay, 1998, Pereira et al. 1999, Stoner at al. 2001, Chant et al. 2000, Phelan et al. 2001).

Along the northeast US coast, winter flounder spawn in estuaries at temperatures between 0 and 3 °C. Studies suggest that there are several substocks of winter flounder that intermix during the summer, but return to natal estuaries to spawn (Phelan 1992 and other references cited in Chant et al. 2000). Spawning occurs in winter in the US and in spring in Newfoundland (Van Guelpen and Davis 1979). The Atlantic coast of Nova Scotia is between the two temperature regimes indicating that winter flounder may spawn between winter and spring. The eggs are demersal, and in the US, the larvae settle after 4-6 weeks at the larval stage (depending on water temperature). The newly settled juveniles are very vulnerable to predation due to their small size and weak burying ability: one notable predator is Sand Shrimp (*Crangon septemspinosa*), to which the flounders are vulnerable until they reach 17 mm SL (Witting and Able 1995).

The juveniles remain in or near shallow natal waters for much of their first 2 years. Although winter flounders have been described as generalists with respect to habitat preferences, Phelan et al. (2001) suggest that this changes with size. Their results indicate that winter flounders < 40 mm SL select fine grained sediments whereas fish ≥ 40 mm SL select coarser grained sediments. Stoner et al. (2001) also demonstrated size-related changes in habitat association: winter flounder initially recruit to muddy sediments, but were often associated with drift algae by the time they reach 55 mm total length. A study by Pappal et al. (2009) indicated that age-0 winter flounder strongly prefer cobble to sand, particularly cobble of an intermediate complexity.

Winter flounder make small inshore-offshore migrations in the summer and winter. McCracken (1963) originally postulated that winter flounder leave inshore waters in the summer when water temperatures are high and return in the fall and early winter to spawn. However, this is not consistently observed in all locations, and more recent work suggests that food availability is also a factor (Kennedy and Steele 1971) in these migrations. McCracken also suggested that in more northerly regions, winter flounder move into deeper water in the winter when it gets too cold. However, winter flounder have been reported in St. Margaret’s Bay in early spring at a water temperature of -1.2 °C (Duman and DeVries 1974, cited in Van Guelpen and Davis 1979) and in winter in ice-covered shallows (Levings 1973, cited in Van Guelpen and Davis 1979). Seasonal movements of winter flounder are now understood to be a response to temperature, food or both in the summer and turbulence and pack ice in the winter (Van Guelpen and Davis 1979). The evidence indicates that there is no avoidance of cold temperatures in winter (Van Guelpen and Davis 1979).

Sexual maturity is usually reached at age 3– 4 years, at 20 cm for males and 25 cm for females. Winter flounder forage primarily in the daytime as they rely on their sight to find food (Pereira et al. 1999). Prey includes polychaetes, bivalves, gastropods, planktonic crustaceans, and bottom invertebrates. They are preyed upon by monkfish, dogfish, sea ravens; harbour, grey (Bowen and Harrison 1996) and harp seals; and osprey, blue heron, and cormorants.

There is some evidence for a role of the inshore for American plaice: MacKinnon (1972, 1973) conducted a detailed study of the metabolism and oxygen demands of American plaice in St. Margaret's Bay as part of a larger study into the processes controlling the productivity of marine organisms (BIO 1968). MacKinnon concluded that American plaice store energy during the summer that is then used in metabolism and gonad maturation during the winter, further suggesting that this may be an adaptation to an irregular availability of food. Bakken (1987) later suggested that the St. Margaret's Bay plaice constituted a local stock, based on analysis of vertebrae numbers, tagging and observations of size shifts. However, the current status of American plaice in St. Margaret’s Bay is unknown.

9.2.5.2 Non-Commercial and Other Key Species

Sculpin Species *(Myoxocephalus* spp.*)*

Two species of sculpin are broadly distributed in the Northwest Atlantic from southern New England to the Arctic Ocean. Shorthorn Sculpin (*Myoxocephalus scorpius*) live inshore at depths to 37 m over smooth muddy, sandy, pebbled and weedy bottoms (Klein-MacPhee 2002a). Some were captured in beach seine surveys at depths of ≤1 m (Table 15). Spawning takes place from November to December, with the egg masses deposited in crevices or on sandy bottom. Incubation takes four to twelve weeks with larvae appearing in February and through the spring. Newly hatched larvae are 7-8 mm and feed on small planktonic organisms (Scott and Scott 1988). Shorthorn Sculpin are omnivorous, feeding on crabs, shrimp, sea urchins, marine worms, amphipods and gastropods, bivalves, herring and small cod (Scott and Scott 1988).

Longhorn Sculpin (*Myoxocephalus octodecemspinosus*) are distributed from Virginia to Newfoundland. They occur in coastal waters from the shoreline onto the banks (Klein-MacPhee 2002a), migrating to deeper water in the winter and shallower depths in spring (Scott and Scott 1988). Their preferred depth range on the Scotian shelf is 53-90 m (Scott and Scott 1988). Spawning occurs in inshore areas in the Gulf of Maine and western coast of Nova Scotia during the winter, peaking in late December to mid-January, based on observations from the southern New England coast (Klein-MacPhee 2002a). Larval sculpins were found in plankton collections on the western Scotian Shelf in March through May (Comeau et al. 2009). Eggs are deposited in clusters on sponges and in crevices, and hatching occurs one to two months after spawning. Longhorn Sculpin feed on crabs, shrimp, mollusks, squid, tunicates, and a variety of small fishes such as herring, mackerel, smelt, sand lance and silversides.

Sea Raven *(Hemitripterus americanus)*

Sea Ravens occur from North Carolina to Labrador in depths of 2 to 91 m. They prefer rocky or hard bottom and are seldom found in estuaries or tidal flats (Scott and Scott 1988). Sea ravens were collected in shallow water on sand, pebble and cobble bottom from Yarmouth to the Eastern Shore by O'Connor (2008). They spawn from late autumn to early winter, based on observations of southern New England populations, depositing large eggs (4 mm diameter) in small clusters of 140-500 eggs on sponges (Scott and Scott 1998). Eyed eggs have been taken in the Bay of Fundy in December (Van Guelpen, pers. comm. in Scott and Scott 1988).

Fish (comprising 74% by weight) and crustaceans (24%) are the most important components of sea raven diets at all sizes (Bowman et al. 2000). Prey includes benthic and near-benthic invertebrates (bivalves and gastropods), crustaceans, sea urchins, worms, and a broad variety of fishes (skates, silver hake, herring, sculpins, haddock, rock gunnel, sand lance and ocean pout (Scott and Scott 1988, Klein-MacPhee 2002b). Sea ravens are occasionally eaten byLlittle Skate, Spiny Dogfish, Monkfish, cod, Longhorn Sculpin and halibut (Rountree 1999 in Klein-MacPhee 2002b).

Cunner (*Tautogolabrus adspersus*)

Cunners occur in shallow waters, around eelgrass, seaweed beds, docks, pilings and rocky outcrops (Scott and Scott 1988). Young cunner occupy extremely shallow water habitats with dense vegetation (algae or eelgrass) and tidepools and can be a numerically dominant component of the fish community (Collette 1986, O'Connor 2008, Jordaan 2011). They mature at lengths of 8-11 cm and reach a maximum length of about 43 cm (Scott and Scott 1988). Spawning occurs in the late summer on the Scotian Shelf. The eggs are about 0.8 mm in diameter and buoyant (Scott and Scott 1988).

Cunner do not undertake extensive seasonal migrations. They can withstand a wide range of temperatures, for example, inhabiting inshore areas in Newfoundland where the temperature is below -1.5°C (Green, pers. comm. in Munroe 2002a). During the winter season, cunners become inactive and enter a torpid state buried in sand, hidden under loose rocks and boulders, or wedged into crevasses. Cunner will enter this state when water temperatures decrease to 1.9 ^{o}C and reanimate when the temperature rises to 5 ^{o}C again (Bradbury et al. 1997).

Cunners are omnivorous on small mollusks and crustaceans, as well as sea urchins, barnacles, marine worms, tunicates, fish eggs and eelgrass (Scott and Scott 1988). Predators are cod, sea raven, white hake, sculpins and piscivorous birds such as double-breasted cormorants (Scott and Scott 1988, Munroe 2002a).

Forage Species

Many of the smaller fish species occurring in the inshore region, such as sand lance, gunnels and ocean pouts, are important as forage species (Table 16). With the exception of sand lance, distributional and life history information for these species is sparse and, for the most part, only available from studies conducted twenty or more years ago.

Sand Lance *(Ammodytes spp)*

Sand lance are key non-commercial species distributed inshore and on offshore banks (Scott and Scott 1988). They are an important source of prey for many species including commercial groundfish (cod, haddock, silver and white hake, yellowtail flounder), non-commercial species (longhorn sculpin), sea birds and marine mammals (Auster and Stewart 1986). Their abundance has increased since the collapse of the groundfish fishery, a likely result of predator release (Bundy 2005). There is little recent information for this species, despite its importance. The northern sandlance, (*A. dubius)*, is concentrated more offshore, between 73 – 90 m, whereas the American sandlance (*A. americanus)* is found at depths between 6 – 20 m (Scott and Scott 1988). Both species are found over bottoms with substrates that allow burrowing and are seldom found over rocky bottoms or shores (Scott and Scott 1988). O'Connor (2008) reported that sand lance were one of the most abundant fish species occurring in beach seines of the inshore and showed a preference for open homogeneous sites.

Sand lance spawn from December to March with the peak in January on sandy bottom habitats where eggs can adhere to sand grains (Nizinski 2002). Eggs have been collected from nearshore habitats but not above the low-water mark. Larvae consume phytoplankton, fish eggs, and copepod nauplii while copepods, mysids, euphausiids and chaetognaths are the primary food for older larvae, juveniles, and adults (Auster and Stewart 1986).

Table 16. Non-commercial benthic fish species occurring in the inshore area of Atlantic Nova Scotia (< 100 m, within 25 km, habitat from O'Connor 2008; Horne and Campana 1987; Scott and Scott 1988; Collette and Klein-MacPhee 2002).

Benthic Species	Distribution	Depth	Habitat	Diet	Spawning
Atlantic Tomcod	North Carolina to Labrador	Inshore, shallow	Estuarine, mud, pebble, cobble	Crustaceans, worms, mollusks, squid, fish	Early to mid winter spawn over gravel and sand
Banded Gunnel	Bay of Fundy to Arctic Ocean	Intertidal to 28 m	Rocky substrate	Crustaceans, amphipods, worms	-
Fourhorn Sculpin	Labrador to Arctic Ocean	Shallow to 20 m	Shallow, tolerates estuarine waters	Crustaceans, mollusks, fish (Baltic Sea records)	Late fall through March
Grubby	New Jersey to Nfld	Shallow to 15 m on Scotian Shelf; 50 m in Gulf of Maine	Estuarine and coastal, all kinds of substrates inc. eelgrass	Omnivorous: shrimp, crab, copepods, mollusks, tunicates, sea urchins, small fish	Winter-spring
Little Skate	North Carolina to Nfld	Intertidal to 111 m	Sand and gravel bottoms, seasonal migration inshore in winter, may move offshore in summer	Crustaceans: decapods, amphipods, polychaetes, isopods, mollusks, fish	Year-round, two periods of maximum egg deposition June-July; Oct-Jan
Lumpfish	Chesapeake Bay to Hudson Bay	First year in top m, older to depths of >300 m	Rocky bottom,	Euphausiids, amphipods, copepods, jellyfish, small pelagic fish	Migration into shallow waters to spawn in spring
Monkfish	Northern Florida to Nfld	Subtidal to 668 m	Fine gravel, clay, inshore migration in spring	Variety of fish and invertebrates	June to Sept
Ocean Pout	New Jersey to Labrador	Intertidal to 183 m, inshore migration in spring, deeper water in fall	Rocky bottom	Variety of invertebrates, herring and smelt	August through October, benthic eggs deposited in crevices
Rock Gunnel	Scotian shelf and Bay of Fundy	Intertidal to depths of 183 m	Tide pools, rock bottom	Polychaetes, crustaceans, amphipods	Spawning offshore in winter
Wolffishes	Gulf of Maine to Greenland	73-126 m on Scotian Shelf, mature individuals at 5-15 m	Rocky and clay bottom offshore rocky or boulder bottom inshore	Hardshelled invertebrates: echinoderms, mollusks, crustaceans, some redfish; larvae eat benthic invertebrate and fish larvae	May have some seasonal migration in May-June , spawning Sept-Oct benthic eggs, restricted larval distribution
Thorny Skate	South Carolina to Hudson Bay	18-996 m, preferred 36-108 m and 2-5°C	Hard and soft bottoms	Polychates, amphipods, decapods and fishes (sandlance, haddock, sculpins)	Year round egg production
Windowpane	Florida to Gulf of St. Lawrence	Shallow to 73 m	Sand and mud bottom	Mysids, Crangon shrimp, amphipods, small fish	Late spring-early summer
Winter Skate	North Carolina to Nfld	Shallow to 111 m most caught at 37-90 m depths	Sand and gravel bottoms	Benthic invertebrates and fish, ontogenetic shift to from amphipods, cumacecans to decapods, polychaetes and fish, especially sand lance	Year round; highest abundance of females with developed egg cases in summer-fall
Wrymouth	New Jersey to Labrador	Intertidal to 110 m	Soft muddy bottom	Amphipods, Crangon	Winter spawner

9.2.5.3 Estuarine/Salt Marsh Fish

Estuaries, salt marshes and eelgrass areas provide special habitat for some fish species (Section 9.2.2). Several species of stickleback (Gasterosteidae), silversides (*Menidia menidia*), the Northern Pipefish (*Syngnathus fuscus*) and Mummichog (*Fundulus heteroclitus*) are closely associated with estuaries, salt marshes and eelgrass (Table 17).

Table 17. Occurrence of estuarine fish species in inshore and DFO-Industry surveys.

Species	Scientific name	O'Connor 2008	DFO/ FSRS	Simon and Campana	4Vn Sentinel survey	4VsW Sentinel survey	ITQ survey	Number of studies
Northern Pipefish	*Syngnathus fuscus*	Y	Y	-	-	-	-	2
Mummichog	*Fundulus heteroclitus*	Y	Y	-	-	-	-	2
Blackspotted Stickleback	*Gasterosteus wheatlandi*	Y	Y	-	-	-	-	2
Fourspine Stickleback	*Apeltes quadracus*	Y	Y	-	-	-	-	2
Ninespine Stickleback	*Pungitius pungitius*	Y	Y	-	-	-	-	2
Threespine Stickleback	*Gasterosteus aculeatus*	Y	Y	-	-	-	-	2
Silversides	*Menidia menidia*	Y	Y	-	-	-	-	2

Northern Pipefish (*Syngnathus fuscus*)

Pipefish live in seaweed and eelgrass beds on mud, sand and gravel substrates in warm water coastal areas, salt marshes and estuaries (Scott and Scott 1988; Klein-MacPhee 2002c). Records listed in Scott and Scott (1988) are mainly from the Gulf of St. Lawrence and Bay of Fundy but O'Connor (2008) collected them in beach seines over mud bottom at sites between Mahone Bay and Chedabucto Bay. Pipefish have a maximum size of 30.5 cm but rarely grow larger than 20.3 cm, and mature at one to two years (Scott and Scott 1988). The occurrence of males carrying larvae in August in Cobequid Bay indicates that pipefish probably spawn in June and July in Nova Scotia (Scott and Scott 1988). Their diet consists of copepods, amphipods, fish eggs and larvae (Scott and Scott (1988). Pipefish are considered marine transients rather than permanent residents of salt marsh, because they are not developmentally tied to estuaries for nursery areas (Nordlie 2003).

Mummichog (*Fundulus heteroclitus*)

Mummichog occur in salt marshes, eelgrass beds, open shores and areas with altered or impacted habitats (Scott and Scott 1988, Able 2002). Maximum size is 10 to 13 cm and their lifespan is about four years (Scott and Scott 1988). They are physiologically adapted to environments with extreme salinities and temperatures and are a dominant component of many shallow water estuarine systems especially salt marshes (Smith and Able 1994) and mudflat tidepools (Jordaan 2011). Information on reproduction in populations from the Gulf of Maine and further south (Petersen et al. 2010; Able 2002) indicate that they probably spawn when one year old. Spawning occurs in shallow water from April to August depending on water temperature (Scott and Scott 1988). A population observed at sites in the Gulf of Maine spawned daily from June through August with no preference for spring tides (Petersen et al. 2010). Spawning occurred in the intertidal zone during the falling tide over mudflats of *Spartina* and bare gravel. Penczak (1985) concluded that Nova Scotia populations had a shorter spawning period, lower fecundity and smaller eggs than populations living further south.

High annual production and mortality implies they are important in trophic dynamics of salt marshes, yet their role in these ecosystems is hard to quantify (Able 2002). They feed on small crustaceans, polychaetes, insect larvae and vegetative material, as well as eggs and small fishes (Penczak 1985; Scott and Scott 1988; Able 2002). They are likely to be eaten by a variety of birds, fish, shrimp and crabs (Scott and Scott 1988; Able 2002).

Sticklebacks

Four species of sticklebacks are sympatric in estuaries with marine to brackish water (Table 16). The salinity preferences and tolerances of individual species range from almost completely marine for blackspotted stickleback to indifference for the ninespine, which has both freshwater and saltwater populations. Sticklebacks were common in beach seine samples along the Atlantic coast of Nova Scotia and were mainly associated with mud habitats (O'Connor 2008). Maximum size is 52 mm for fourspine and 76 mm for the other three species (Scott and Scott 1988). Lifespans are 1 year for Blackspotted, 1-2 years for Fourspine, and 3-3.5 for Threespine and Ninespine (Scott and Scott 1988). Blackspotted, threespine and ninespine sticklebacks migrate to shallow brackish or freshwater in summer months to breed in intertidal areas associated with aquatic vegetation. Males build nests out of twigs and aquatic plants and guard the nests during incubation. The main prey for sticklebacks includes gammarids, isopods, chironomids, copepods, euphausiids, small fish, own species (eggs, larvae, adults), and algae. Predators include sea birds, small mammals and fish (Scott and Scott 1988).

Silversides *(Menidia menidia)*

Silversides is a nearshore schooling species of fish found commonly near the shores of brackish waters, marshes, intertidal creeks, sedge grasses and estuaries from Florida to the Gulf of St. Lawrence (Sargent et al. 2008). Adults move into estuaries and salt marshes in April and May (Jessop 1983) and spawn between May and July before returning to sea between July and October (Jessop 1983). Young-of-the-year begin migrating out of the estuary in September (Jessop 1983) by which time they can grow to 130 mm (total length) (Able and Fahay 1998), depending on location and time of hatching (references in Sargent et al. 2008). This offshore migration may be in response to potential stressful and/or lethal water temperatures in shallow estuarine waters during winter (Conover and Murawski 1982). Bottom surveys in the Gulf of Maine showed that most offshore captures were within 50 km of the shoreline at depths of 10-50 m in temperatures of 2-6 °C. A study of geochemical signatures in the otoliths of silversides collected at 11 locations between New Jersey and Maine found that fish had a high probability of originating from the same location in which they were captured but there was evidence of mixing throughout the sample area, and some fish migrated over 700 km (Clarke et al. 2010). Some populations may be more tolerant of extreme temperatures as some individuals remain in estuaries throughout the winter (Chernoff 2002) and have even been taken through the ice in Malpeque Bay, Prince Edward Island (Scott and Scott 1988). The lifespan ranges from one year for Gulf of Maine fish (Conover and Murawski 1982) to two years in the Canadian Atlantic (Jessop 1983).

Habitat and depth preferences of silversides were reviewed recently by Sargent et al. (2008). They are found frequently in large numbers over sand, gravel, mud, or peat substrates at depths < 50 m. Young-of-the-year are most abundant at depths of 1 – 3 m over sandy substrates and where complex habitat includes eelgrass. Smaller individuals are found in larger proportions over vegetated habitats. Silversides use estuaries as spawning sites and feeding sites for juveniles and adults during warmer months. Vegetated areas within these environments act as nurseries for young-of-the-year.

Silversides are omnivorous, feeding on copepods, mysids, shrimp, small squid, marine worms, as well as their own eggs (Scott and Scott 1988). They are forage fishes for many species moving into shallow water, such as striped bass and bluefish as well as seabirds, and marine mammals.

9.3. Pelagic Communities

The inshore pelagic habitat extends from surface waters to near bottom. The pelagic zone is inhabited by species that inhabit the inshore year round, species that migrate between inshore habitats and shelf or open ocean pelagic waters, as well as species that are seasonal visitors.

9.3.1. Invertebrates

Contributed by J. Sperl and G. Harding

There are a wide range of planktonic invertebrates, some of which have already been discussed as zooplankton (Section 9.1.5). In this section, the focus is on larger, more motile animals including jellyfish, ctenophores, chaetognaths, krill, mysids, shrimp, and squid.

Jellyfish *(Cnidaria)*

Sixty-four species of jellyfish have been reported in Atlantic Canadian waters (Shih 1997) of which 25 species have been recorded off Nova Scotia: 18 species of hydromedusans, 3 syphonophores (Class Hydroza) and 4 scyphomedusans (Class Scyphoza) (Platt and Irwin 1968, Shih et al. 1971, Shih 1977, Matsakis and Conover 1991). Since jellyfish have not been extensively studied in the region there may be more species present. The most conspicuous jellyfish occurring inshore are the scyphozoans moon jellyfish (*Aurelia aurita* and *Aurelia limbata)* and lion's mane (*Cyanea capillata)*. The smaller hydromedusae can be an order-of-magnitude more abundant than the scyphomedusans and therefore ecologically more important. For example, the hydromedusan *Rathkea octopunctata* in Bedford Basin was calculated to consume at least 50% of the carbon consumed by all medusan species, including *Aurelia aurita* (Matsakis and Conover 1991)*.* Jellyfish are more common in the coastal region of Nova Scotia at certain times of the year. Matsakis and Connor (1991) reported that *Aurelia aurita* occur in the surface waters of Bedford Basin during spring through early summer whereas *Cyanea capillata* were most abundant in late August in St. Margaret's Bay (Matsakis and Connor 1991).

Jellyfish feed on a variety of pelagic prey including zooplankton, ichthyoplankton, fish and ciliates (Lucas 2001, Dawson and Martin 2001). A study of plankton in Bedford Basin reported that the hydromedusans *Aglanthe*, *Cosmetira*, *Euphysa*, *Rathkea*, and *Sarsia* consumed copepodites and planktonic eggs, whereas *Aurelia aurita* fed on fish larvae (Matsakis and Conover 1991). Jellyfish may indirectly cause algal blooms through feeding on the zooplankton that feed on phytoplankton (Lucas 2001). In the summer when nutrients are abundant, predation by zooplankton may be the only limit on algal abundance. Thus jellyfish can exert top-down control of the system, causing a small trophic cascade.

Jellyfish are important prey, notably for leatherback turtles (Section 9.3.2), which are a species at risk. Sherril-Mix et al. (2007) observed that leatherback turtles departed earlier from their northern feeding grounds when water temperatures and chlorophyll concentrations were higher. They attributed early departure rates to acceleration of the life cycles of gelatinous prey and/or increased feeding efficiency in these areas.

Ctenophores *(Phylum Ctenophora)*

Four species of comb jellies are seasonally abundant in the inshore water of Nova Scotia: *Mertensia ovum*, *Beroe cucumis*, *Pleurobrachia pileus* (Sea Gooseberry) and *Bolinopsis infundibulum* (Anderson 1974; Shih 1971). *Mertensia ovum* is a cold-water species from further north off Newfoundland and occurs occasionally in St. Margaret's Bay during spring. Sea gooseberries are common in Nova Scotia's inshore waters throughout the year with maximum abundances in St. Margaret's Bay reported for January (Platt and Irwin 1968) and spring

(Anderson 1974). *Beroe cucumis*, which feeds mainly on Sea gooseberry, occurs year-round but is most abundant in February (Platt and Irwin 1968). Sameoto (1971b) found Sea gooseberries to be abundant in Bedford Basin between December and March and absent between June and mid November over a 2-year monthly sampling regime. *Bolinopsis* and *Beroe* were most abundant in St. Margaret's Bay during May and July, respectively, but were notably absent from the bay from October to December (Anderson 1974).

Sea gooseberries are passive plankton feeders, feeding on small inshore adult copepods and copepodites as well as *Temora longicornis* and *Centropages typicus* (Anderson 1974). *Bolinopsis* swims slowly to intercept its prey and consumes less active copepods such as *Oithona* (Anderson 1974). *Beroe* feeds entirely on the planktonic feeding ctenophores *Pleurobranchia* and *Bolinopsis* in St. Margaret's Bay (Swanberg 1974; Anderson 1974). *Pleurobranchia* and *Bolinopsis* are known to be seasonally important controls on the abundance of zooplankton in inshore waters (Greene et al. 1986; Anderson 1974).

Chaetognaths *(Phylum Chaetognatha)*

Sagitta elegans is the only chaetognath occurring in the inshore plankton and is mainly abundant in deep coastal bays such as Bedford Basin and St. Margaret's Bay (Sameoto 1971a, 1973; Zo 1973). Ranging in length from 4 to 28 mm, it forms a major component of the predatory zooplankton community (Lewis and Sameoto 1989; Brusca et al. 2002), feeding on copepod species (*Pseudocalanus*, *Oithona*, *Temora, Eurytemora* and *Calanus finmarchicus)* as well as small fish, other chaetognaths, polychaetes, tinntinnids, and rotifers (Sullivan and Meise 1996; Pearre 1973). Chaetognaths are an important predator in the zooplankton community of Georges Bank, perhaps controlling copepod levels; however the role chaetognaths play in the inshore Scotian Shelf ecosystem has been less studied (Clarke et al. 1943; Sullivan and Meise 1996).

Mysids *(Class Crustacea, Order Mysidacea)*

Mysids (commonly known as opossum shrimp) live on the surface of the sediment or swim just above it in the daytime and vertically migrate into the water column at night (Mauchline 1980). Nine species of mysids have been reported in the plankton of marine waters off the Canadian Atlantic east coast (Shih 1971) including *Erythrops erythrophthalma*, *Meterythrops robusta*, *Mysis mixta, Neomysis americana* and *Pseudomma truncatum* (Shih 1971; Paranjape and Conover 1973)*. Neomysis americana* is the most common, occurring in shelf habitats and estuaries to depths of 200 m. It is known to undertake diel migrations from the bottom into the water column, particularly during summer and fall, and it may also undertake seasonal, horizontal migrations from nearshore to offshore during winter (Jumars 2007).

Mysids have an important role in the shallow coastal ecosystems of mid-latitude continental shelves. Although frequently observed in high abundances, they are likely to be underrepresented in marine food web models due to sampling challenges and a lack of research focused on mysid ecology (Jumars 2007). Mysids are omnivorous and predacious, filter feeding on phytoplankton and suspended detritus, zooplankton, small benthic invertebrates (Mauchline 1980) and macrophyte detritus (Zagursky and Feller 1985). Because of their omnivory and benthic and pelagic existence, mysids are likely predators on a wide range of benthic and pelagic species, as well as prey for both demersal and pelagic fishes, connecting benthic to pelagic and nearshore to offshore food webs and lending dynamic stability to benthic community structure (Jumars 2007).

Krill *(Order Euphausiacea)*

Seven species of krill have been reported in Atlantic Canada, the most common of which are *Meganyctiphanes norvegicus, Thysanoessa inermis*, *Thysanoessa raschii* and *Thysanoessa longimani.* Adult *M. norvegicus* require depths greater than 100 m and were rarely detected in inshore studies at the approaches to St. Margaret's Bay (Parajape and Conover 1973). *T. inermis*, *T. raschii* and *T. longimani* have all been reported from inshore Nova Scotia waters (Platt and Irwin 1968, Paranjape & Conover 1973, Harding 1977, Sameoto 1978), although *T. longimani* and *T. inermis* are more likely to be found further off the coast (Sameoto 1977,1978). Paranjape and Conover (1973) reported the presence of adult *T. inermis* and *T. raschii* at low abundance in St. Margaret's Bay and approaches but their eggs and larvae were common in the plankton between March and June. Sameoto (1971b) collected *T. inermis* and *T. raschii* frequently with a high speed sampler (4 knots) in December and January in Bedford Basin.

Krill feed predominantly on copepods such as *Calanus*, *Temora*, *Acartia*, *Pseudocalanus* and others (Bamstedt and Kalson1998). They are an important source of prey of many marine species such as filter feeding fish (herring, mackerel), juvenile groundfish (silver hake, cod, redfish), marine mammals (sei whales) and birds. Krill form surface swarms during warm months of the year that attract vigorous feeding by herring and whales (Johnson et al. 2011).

Squid *(Phylum Mollusca: Class Cephalopoda)*

Two species of squid, Longfin Squid (*Loligo pealeii*), and the Shortfin Squid (*Illex illecebrosus*) occur in Nova Scotian waters. Longfin squid, which is known to spawn in shallow waters of the mid Atlantic Bight, is more neritic than the more migratory and oceanic shortfin squid (Dawe et al. 2007). Both species have a relatively short (1-2 yr) life span and have highly variable interannual abundance (Dawe et al. 2007). In general, longfin squid do not occur north of Browns Bank (Dawe et al. 1990), and the only record in the summer RV survey is from the outer Bay of Fundy in 2005. They were observed in St. Margaret's Bay in several years between 1974 and 1986, including mature and spawning individuals in 1986 (Dawe et al. 1990). A combination of warm water occurring nearshore and eastward displacement of the North Atlantic Oscillation may cause favourable conditions and northward expansion of longfin squid. These conditions occurred in 2000 when mature individuals and spawned egg cases were observed in southwest Newfoundland (Dawe et al. 2007).

Shortfin Squid are a highly migratory, transboundary species, distributed throughout the Northwestern Atlantic, from the Newfoundland Sea to the Florida Straits (Hendrickson and Holmes 2004). Shortfin squid spawn mainly in winter off the continental shelf south of Cape Hatteras (Dawe et al. 2007). From there, eggs and larvae are transported north by the Gulf Stream. Juveniles migrate through the slopewater closer to the shore as they age. Adults and juveniles undergo diel vertical migration, feeding near the surface at night.

As squid grow, their diet expands from euphausiids, mysids and other planktonic crustaceans to fish (redfish, sand lance, mackerel, Atlantic herring, haddock, sculpin, capelin) and both longfin and shortfin squid (Hendrickson and Holmes 2004). Shortfin squid are preyed upon by a variety of fish (including tuna, swordfish, cod, silver hakes, sea raven, dogfish, monkfish), marine mammals (pilot whales, harbour seal, common dolphins) and birds (gannets, shearwaters and fulmars) (Hendrickson and Holmes 2004; Bowen and Harrison 1996). Shortfin squid support commercial fisheries in Newfoundland inshore waters during summer to autumn when local water temperatures exceed 5°C (Dawe et al. 2001). In Nova Scotia, they are used as bait in groundfish longline and swordfish fisheries.

Shrimp

Contributed by P. Koeller

Many species of shrimp have been reported in the nearshore region of Nova Scotia; however, most related information are records of occurrences and ancillary information (e.g. Holthuis 1980, Squires 1990), and in some cases, biological and ecological information from other areas. Squires (1990) reported nearshore occurrences in Nova Scotia for 25 shrimp species in 15 genera. Some of these records must represent individuals expatriated from their preferred deepwater habitats. For example, the 10-2000 m depth range reported for *Pasiphaea multidentata,* or glass shrimp, certainly falls within the nearshore area, however their main concentrations are usually in deeper offshore water at depths of 200-400 m (Holthuis 1980). This group of species is ecologically insignificant in the nearshore and will not be discussed further here.

A few shrimp species can be considered as truly nearshore along the coast of Nova Scotia. At least two species of the genus *Palaemonetes*, including *P. vulgaris* and *P. pugio* occur here. These small- to medium-sized shrimp (~40-50 mm body length), also known as “grass” or “marsh” shrimp, are associated with sea-grass beds (e.g. *Zostera*) and are common in the estuarine and nearshore marine environment from Quebec to Texas. They are not important commercially due to their limited abundance and small size, but are apparently used as bait in some areas, such as Chesapeake Bay. There they are considered relatively important components of the nearshore environment, consuming zooplankton, algae, marine worms and other crustaceans, and provide an important food source for commercial or forage fish species (Davis et al. 2003). Presumably this is also true in Nova Scotia. The sand shrimp *Crangon septemspinosa*, or sevenspine bay shrimp, is an ecologically important species of coastal and estuarine waters of the Northwestern Atlantic (Locke et al. 2005) occurring throughout Nova Scotia (Squires 1990). It provides a significant proportion of the diet of estuarine fish species and may be an important food source for seabirds. It may also be a major predator of small fish (e.g. metamorphosing flatfish) (Keefe & Able 1994). A relatively abundant and large (up to 70 mm body length) animal, it has been the object of an experimental fishery in Chaleur Bay, New Brunswick (Hanson and Lanteigne 1999).

The third and largest group of shrimp is entirely marine and could be termed “midshore”. Like the first group they have depth ranges that straddle the nearshore and offshore, but with maximum (and probably preferred) depths that tend to be shallower than truly “offshore” species. These species are too small (maximum 14-20 mm carapace length) or rare to be commercially important but collectively are probably of ecological importance, both in the nutrient cycle and as forage for fish. They include four species of the genus *Eualus*, three species each of the genera *Lebbeus* and *Spirontocaris*, two species of *Sabinea,* and *Pontophilus norvegicus*. On the eastern Scotian Shelf they are routinely caught in commercial and survey shrimp trawls but only in small numbers as bycatch to the important commercial shrimp *Pandalus borealis*. These catches are not quantitative due to the trawl mesh sizes used (40 mm), however catches in small-meshed nets attached to shrimp survey trawls suggest that their abundance, particularly of *Eualus spp.* is relatively high and tends to increase in the nearshore area off Cape Breton (P. Koeller, unpublished data). *Argis dentata* is also routinely found in small numbers in shrimp trawl catches off eastern Nova Scotia. Although not abundant, it may be relatively important ecologically because of its larger size (27 mm carapace length) and widespread distribution. It is likely that the relative abundance of these species in the nearshore will change with prevailing local environmental conditions (temperature, salinity, water flow) as these can have significant effects on the distribution and abundance of shrimp species (Piazza et al. 2010).

A final group of species, while generally concentrated in deeper offshore or midshore water, may make relatively large migrations, or establish populations nearshore where conditions are suitable. This has been shown for *Pandalus borealis* in the Gulf of Maine and in Chedabucto, Mahone and St. Margaret’s Bays in Nova Scotia (Koeller 2000, Koeller et al. 2007). Here they can concentrate in numbers that make trap fisheries economically viable (Figure 67). They are probably ecologically significant during their presence nearshore, particularly as prey for fish. Other species may fall in this category, in particular *Pandalus montagui*, which tends to prefer shallower, less saline and harder bottom types than *P. borealis*. It is routinely found in nearshore trap samples, but is generally much less abundant than *P. borealis.*

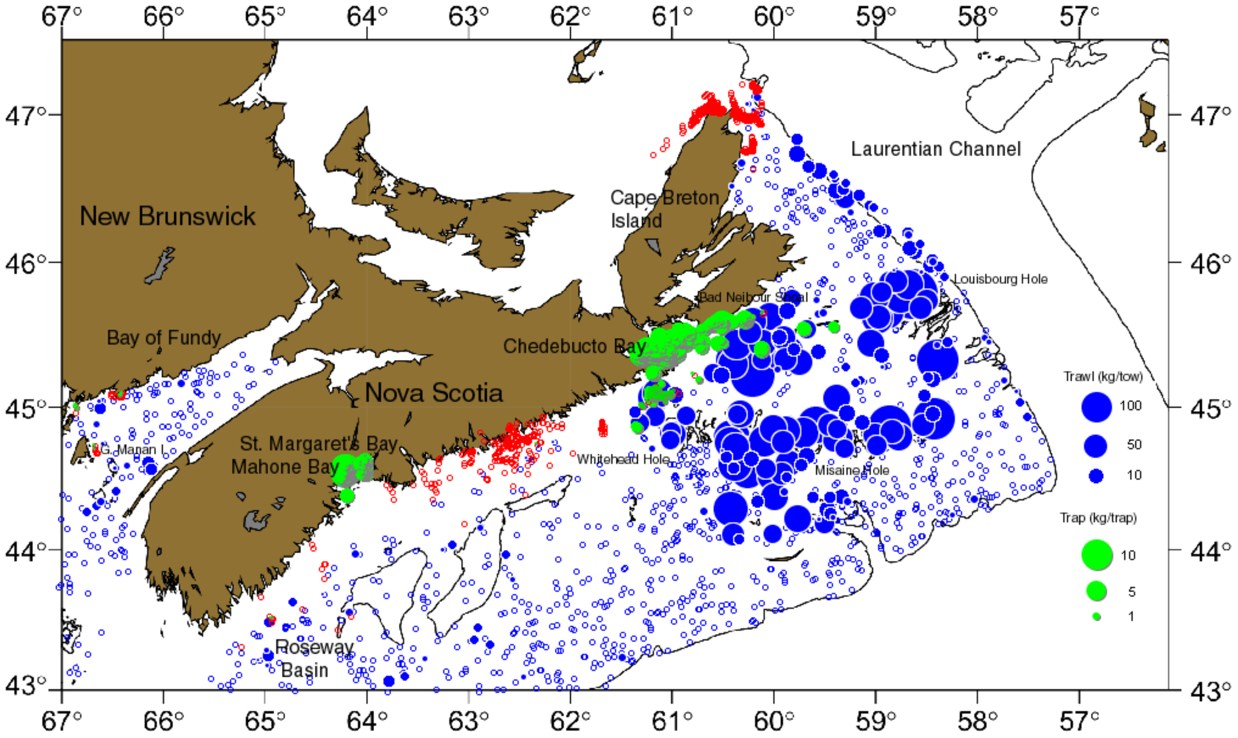


Figure 67. Cumulative catches of Pandalus borealis from experimental and commercial shrimp trap logbooks (1995-2005, solid green circles) and DFO RV surveys (1996-2006), solid blue circles). Locations where no shrimp were caught are showns as open circles (trap-red, trawl–blue) from Koeller et al. (2007).

9.3.2. Marine Turtles

Contributed by J. Sperl and J. McMillan

Few marine reptiles occur in the inshore areas of the Scotian Shelf and the only species that is regularly found is the Leatherback Turtle (*Dermochelys coriacea*). Leatherbacks are distributed globally. They were listed as critically endangered by the IUCN in 1986 (James et al. 2005a) and were listed as endangered under Canada's Species at Risk Act (SARA) in 2003. The status of the leatherback turtle population in the Atlantic Ocean was assessed as endangered by COSEWIC in 1981, and confirmed in 2001 and 2012 (COSEWIC 2012b). Leatherbacks are highly migratory and regularly move north and south from nesting beaches in the tropics to feeding grounds in the north (James et al. 2005a; 2005b). Both sexes eventually return to the southern waters but only the females return to the nesting beaches to lay eggs.

The Scotian Shelf is thought to be home to the largest densities of leatherback turtles in the North Atlantic (James et al. 2006). They are attracted to these productive waters, particularly the areas dominated by gelatinous zooplankton such as jellyfish, comb jellies, salps and other jellied organisms. Their main prey are the jellyfishes *Cyanea* and *Aurelia* (James and Herman 2001). James et al. (2005a) illustrated that leatherbacks, foraging on the Scotian Shelf, will catch prey at depth and consume their prey at the surface. They also found that leatherbacks will spend a significant amount of time basking at the surface, suggesting that ingesting cold prey may cool them down. Further, they documented that leatherbacks are highly mobile. One leatherback tagged in Nova Scotia migrated back to tropical waters, then returned to Nova Scotia within a year.

Leatherbacks are pursued by different predators at different life history stages. Whereas adult leatherbacks do not have many natural predators, large sharks and killer whales may attack them in the water (Muir 2003). Entanglement in fishing gear is a frequent cause of death for adult sea turtles, as is the ingestion of plastics, which resemble their jelly-fish like prey (Muir 2003, James et al. 2005b, Sinclair 2004). The greatest danger to leatherback turtles in Nova Scotian waters is entanglement in fishing gear (Sinclair 2004).

Juvenile Loggerhead Turtles occur seasonally in Canadian waters and are most commonly encountered on the Scotian Shelf and Slope, Georges Bank and the Grand Banks (COSEWIC 2010). Incidental captures in the swordfish pelagic longline fishery were concentrated at temperatures above 22°C, and no animals have been captured at temperatures below 15 C or inshore waters, despite a broad range of fishing locations and temperatures (Brazner and McMillan 2008). Sightings of loggerhead turtles inshore have been few compared to offshore records. The few occurrences may be the result of warm core ring water of Gulf Stream origin coming close to shore (M. James, pers. comm. in COSEWIC 2010). Generally, inshore water temperatures are too low for the thermal tolerance of Loggerhead turtles. Loggerhead turtles were assessed as endangered by COSEWIC in 2010 (COSEWIC 2010).

9.3.3. Pelagic Fish

Contributed by J.Sperl and A.Bundy

The commercially exploited pelagic fish species have been grouped into large pelagics (e.g. sharks), small pelagics (e.g. herring) (Table 18), and diadromous fish (e.g. alewives) (Table 19).

Table 18. Occurrence of pelagic and anadromous fish species in inshore and industry surveys.

Species	Scientific Name	Commercial/ Recreational Fishery	O'Connor 2008	DFO/ FSRS	Simon and Campana	4Vn Sentinel survey	4VsW Sentinel survey	ITQ survey	Number of surveys
Porbeagle Shark	*Lamna nasus*	Y	-	-	-	-	-	Y	0
Blue Shark	*Prionace glauca*	Y	-	-	-	-	-	-	0
Shortfin Mako	*Isurus oxyrinchus*	Y	-	-	-	-	-	-	0
Spiny Dogfish	*Squalus acanthias*	Y	-	-	Y	Y	Y	Y	4
Bluefin Tuna	*Thunnus thynnus*	Y	-	-	-	-	-	-	0
Swordfish	*Xiphias gladius*	Y	-	-	-	-	-	-	0
Atlantic Herring	*Clupea harengus*	Y	Y	-	Y	-	-	Y	4
Atlantic Mackerel	*Scomber scombrus*	Y	-	-	-	-	-	Y	2
Alewife*	*Alosa* spp.	Y	Y	-	Y	-	-	Y	4
Smelt*	*Osmerus mordax*	Y	-	-	Y	-	-	Y	2
Sea Lamprey*	*Petromyzon marinus*	-	-	-	-	Y	-	-	1
American Eel	*Anguilla rostrata*	Y	Y	-	-	-	-	-	1

* Anadromous species are discussed in Section 9.3.4.

Table 19. Diadromous fishes in Nova Scotia, management concerns and COSEWIC status as of 2013.

Common Name	Scientific Name	Advice to Support	COSEWIC Status
Sea Lamprey	*Petromyzon marinus*	Harvest/Recreational Fisheries	None
Atlantic Sturgeon (Maritimes population)	*Acipenser oxyrinchus*	Conservation; Harvest/Recreational Fisheries	Threatened
Blueback Herring / Gaspereau / Alewife	*Alosa aestivalis* *Alosa pseudoharengus*	Harvest/Recreational Fisheries	Not at Risk
American Shad	*Alosa sapidissima*	Harvest/Recreational Fisheries	None
Atlantic Whitefish	*Coregonus huntsmani*	Species At Risk Act listing (Schedule 1 – Endangered)	Endangered
Atlantic Salmon (Inner Bay of Fundy population)	*Salmo salar*	Species At Risk Act listing (Schedule 1 – Endangered)	Endangered
(Outer Bay of Fundy, population)		Conservation;	Endangered
(Southern Upland population)		Conservation;	Endangered
(Eastern Cape Breton population)		Conservation; Harvest/Recreational Fisheries	Endangered
Rainbow Smelt	*Osmerus mordax*	Harvest/Recreational Fisheries	None
Atlantic Tomcod	*Microgadus tomcod*	Harvest/Recreational Fisheries	None
Striped Bass (Bay of Fundy population)	*Morone saxatilis*	Harvest/Recreational Fisheries; Conservation	Endangered
American Eel	*Anguilla rostrata*	Conservation; Harvest Fisheries	Threatened

9.3.3.1 Large Pelagics

Bluefin tuna, Atlantic swordfish and several shark species occur in the inshore of the Scotian Shelf. Most large pelagic species are seasonal visitors, coming to the Scotian Shelf in the summertime to feed (Scott and Scott 1988). They occur in the inshore, but are more frequently found offshore. Other shark species reported infrequently in Nova Scotia waters are White (*Carcharodon carcharias*), Basking (*Cetorhinus maximus*), Greenland (*Somniosus microcephalus*) and Thresher sharks (*Alopias vulpinus*). White Shark was assessed as endangered by COSEWIC in 2006 (COSEWIC 2006a) and has been protected under the Species at Risk Act since 2011.

There are currently no directed fisheries for sharks in the Maritimes Region. Sharks are caught incidentally through other commercial fisheries. An inshore recreational fishery exists for Blue Shark. Detailed information on Northwest Atlantic shark species, biology and research is available at the Canadian Shark Research Lab.

Porbeagle Shark *(Lamna nasus)*

Porbeagle is a large pelagic shark that occurs on both sides of the Atlantic, ranging from Newfoundland to New Jersey in the western North Atlantic (DFO 2005c). They feed mainly upon pelagic fishes such as herring, lancetfish and mackerel, but also eat cod, redfish, haddock, squid and shellfish (Joyce et al. 2002). COSEWIC (2004) assessed porbeagle shark as Endangered due to great reductions in abundance in the NW Atlantic, and this status was reaffirmed in 2014. Recent stock assessments indicate that the population can recover if human induced mortality is kept low (Campana et al. 2011).

Spiny Dogfish *(Squalus acanthias)*

Spiny Dogfish is a small schooling shark that occurs in coastal and offshore regions from North Carolina to Labrador. Although they are managed as one northwestern Atlantic population, the population may consist of several loosely structured stock components with little exchange between areas such as Newfoundland and the southern portion of the Scotian Shelf (Campana et al. 2007; 2009a). The dogfish population on the Scotian Shelf consists of summer migrants from US waters as well as year round residents. Large females may remain on the Scotian Shelf throughout the year, moving well inshore during the summer and offshore during the fall and winter (Campana et al. 2007). Wallace et al. (2009) concluded that dogfish are most abundant in nearshore areas with the highest densities in the southern portion of the Scotian shelf and the Bay of Fundy based on summer RV surveys from 1970-2007. However, ITQ surveys of the inshore region during July (1996-2011) indicate that spiny dogfish are distributed at greater depths (>100 m) and farther from the coast than in the Bay of Fundy (Figure 68). In 2010, the Atlantic spiny dogfish population was assessed as Special Concern by COSEWIC (2010c).

Dogfish are opportunistic feeders on anything smaller than themselves, including every kind of fish, amphipods, crabs, polychaetes, squid, jellyfish and ctenophores (Scott and Scott 1988). Young dogfish and juveniles are vulnerable to swordfish, sharks and grey seals (Scott and Scott 1988).

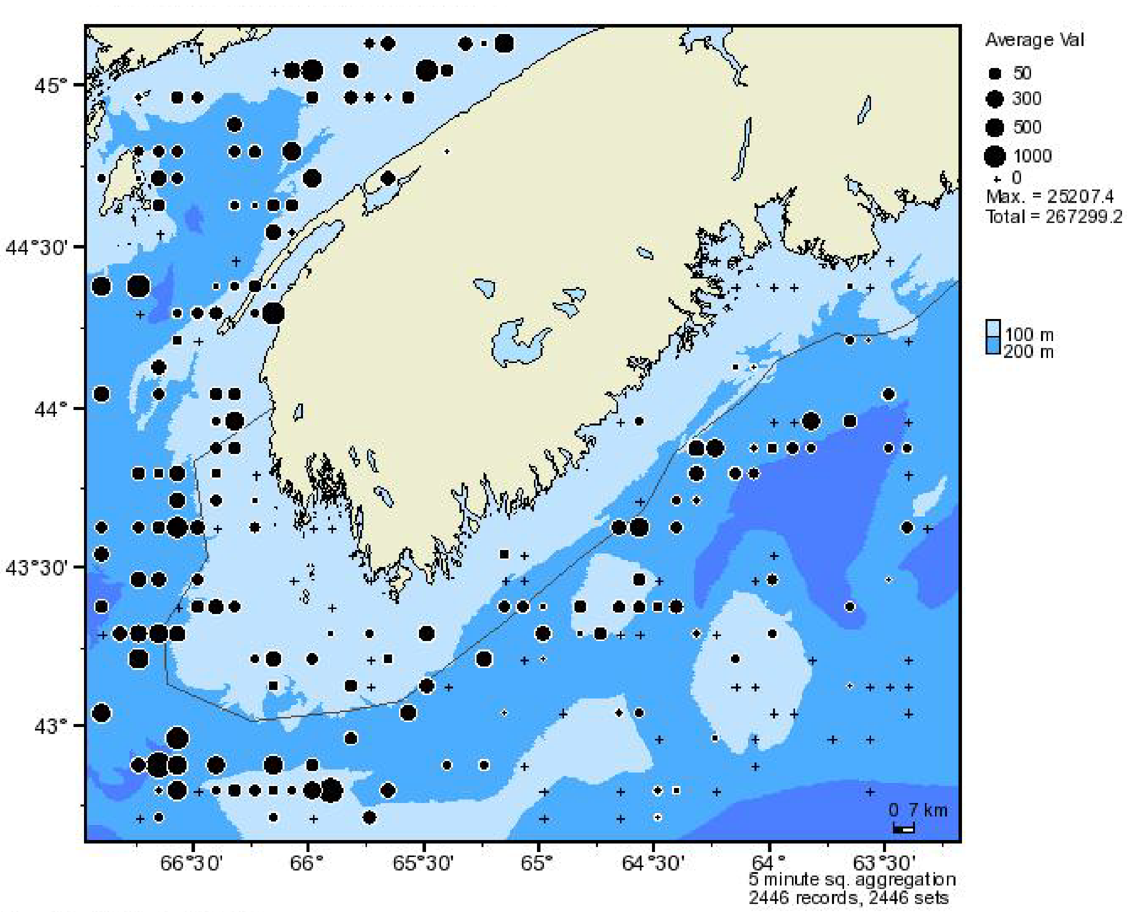


Figure 68. Average weight per tow of spiny dogfish in ITQ surveys from 1996-2011 (inshore region indicated by fine black line: plus signs indicate null catches).

Blue Shark *(Prionace glauca)*

Blue sharks occur in southeastern Newfoundland, the Grand Banks, the Gulf of St. Lawrence, the Scotian Shelf and the Bay of Fundy. They are seasonal visitors in Nova Scotian waters: tagging studies show that blue sharks are highly migratory and part of a single, well-mixed population in the North Atlantic (Campana et al. 2004). They occur inshore, but are more commonly found in the deeper shelf waters.

There is no commercial fishery targeting blue shark and animals caught in longline fisheries targeting swordfish and tuna are rarely landed. Campana et al. (2011) estimated that the bycatch of blue shark in these fisheries was 1414 mt in 2010, of which 99% was discarded. Several communities around Nova Scotia hold annual derbies during the summer to encourage recreational fishing for blue sharks by rod and reel from small boats. In 2011, a total of 99 participants landed 325 sharks (9,406 kg) at derbies in Riverport, Lockeport, Yarmouth, Brooklyn, Jeddore and Petit de Gras (CSRL 2011). The highest numbers of sharks caught in recreational derbies occurred in 2002 (900 sharks, 20,026 kg).

Blue sharks are opportunistic feeders on many types of fish as well as squid, and sometimes seals. Their diet is composed mainly of pelagic fish species such as herring, mackerel, tuna, swordfish and silver hake, as well as white hake, red hake, cod, haddock, pollock, sea raven, and flatfish (CSRL 2011, Cook and Bundy 2011). The Atlantic population of Blue sharks was assessed as Special Concern by COSEWIC in 2006 (COSEWIC 2006b).

Shortfin Mako (*Isurus oxyrinchus*)

Shortfin Mako has a worldwide distribution, ranging in the northwestern Atlantic from the Gulf of Mexico to Browns Bank, along the continental shelf of Nova Scotia and even into the Gulf of St. Lawrence. Makos prefer warm waters and are often found associated with swordfish, which prefer similar environmental conditions. In some years, warm water conditions can bring them closer to shore; for example, several makos were caught in 2002 during blue shark fishing derbies and as part of recreational shark fishing trips about 10 miles outside of Halifax Harbour (CSRL 2011). Mako feed mainly upon squid and bony fishes including mackerels, tunas, bonitos and swordfish, but may also eat other sharks, sea turtles, porpoises and other marine mammals. The Atlantic shortfin mako population was assessed as Threatened by COSEWIC in 2006 (COSEWIC 2006c).

Bluefin Tuna *(Thunnus thynnus)*

Bluefin Tna is a highly migratory pelagic species entering the inshore region between July and November to forage on herring, mackerel and squid (Scott and Scott 1988; Neilson 2009). The majority of tuna occurring in Canadian waters are thought to originate in the Gulf of Mexico, based on results from satellite tagging and otolith chemistry (COSEWIC 2011). They are fished commercially using trapnets and rod and reel, as well as taken as bycatch in swordfish and other tuna longline fisheries. Most are caught offshore; however, inshore fisheries for bluefin tuna in Nova Scotia also occur from July to December in St. Margaret's Bay and Canso and, since 1996, off the coast of Nova Scotia between SW Nova Scotia and Canso, particularly off Halifax (Figure 69). St. Margaret’s Bay is a tuna management area in which tuna trapnets are used at 24 licensed trapnet sites (DFO 2007b).

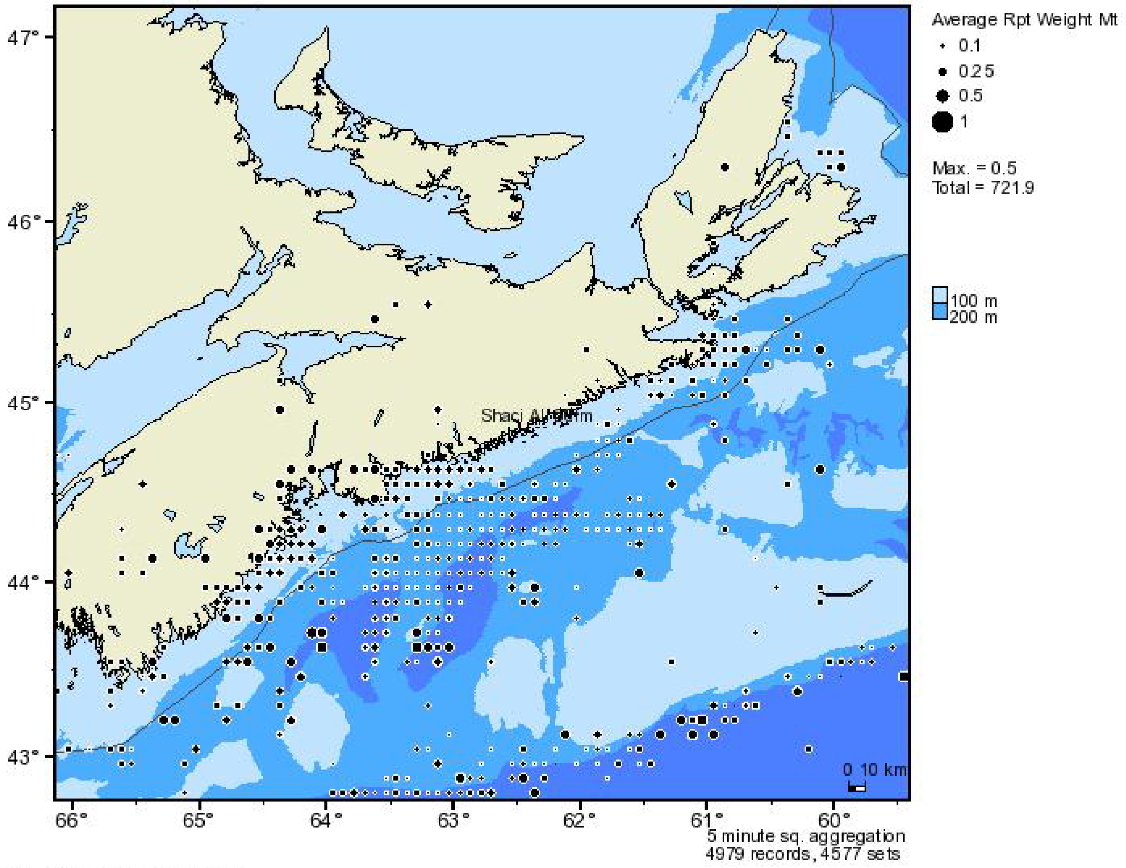


Figure 69. Averaged bluefin tuna landings (mt) in Nova Scotia from 2002-11 (MARFIS 2011).

Conventional tagging results and preliminary electronic tagging results indicate that bluefin tuna show considerable fidelity to foraging areas, often returning precisely to the same area where they were tagged and released 1 year earlier (Neilson 2009). The distribution of bluefin tuna is so closely associated with their prey distribution that their prey could be considered a component of habitat (DFO 2011c). Canadian Atlantic bluefin fisheries occur on foraging aggregations of bluefin tuna and thus the spatial extent of the fisheries are an indication of the habitat of bluefin tuna. For example, a feeding aggregation near Wedgeport Nova Scotia supported an inshore sport fishery from 1935 to 1966 but has since disappeared (Nielson 2009).

Tuna have few predators but killer whales, pilot whales and mako sharks have been observed occasionally to prey upon them (Scott and Scott 1988). The bluefin tuna population in Canadian waters was assessed as Endangered by COSEWIC in 2011 (COSEWIC 2011).

Swordfish (*Xiphias gladius)*

Swordfish are a migratory seasonal visitor to Nova Scotian waters between June and November (Scott and Scott 1988). Their distribution is influenced by environmental conditions, notably water temperature, and most of the commercial fishery occurs offshore on the Scotian Shelf and shelf edge with occasional catches inshore. In the 1960s, the main inshore grounds were along the Eastern Shore of Nova Scotia and particularly off Cape Breton (McCullough et al. 2005). Most swordfish landed in Nova Scotia between 2002-11 was taken over water depths greater than 100 m (Figure 70), however, swordfish have been recorded in coastal waters off Halifax County (McCullough et al. 2005) and the inshore regions of Cape Breton (Fitzgerald 2000).

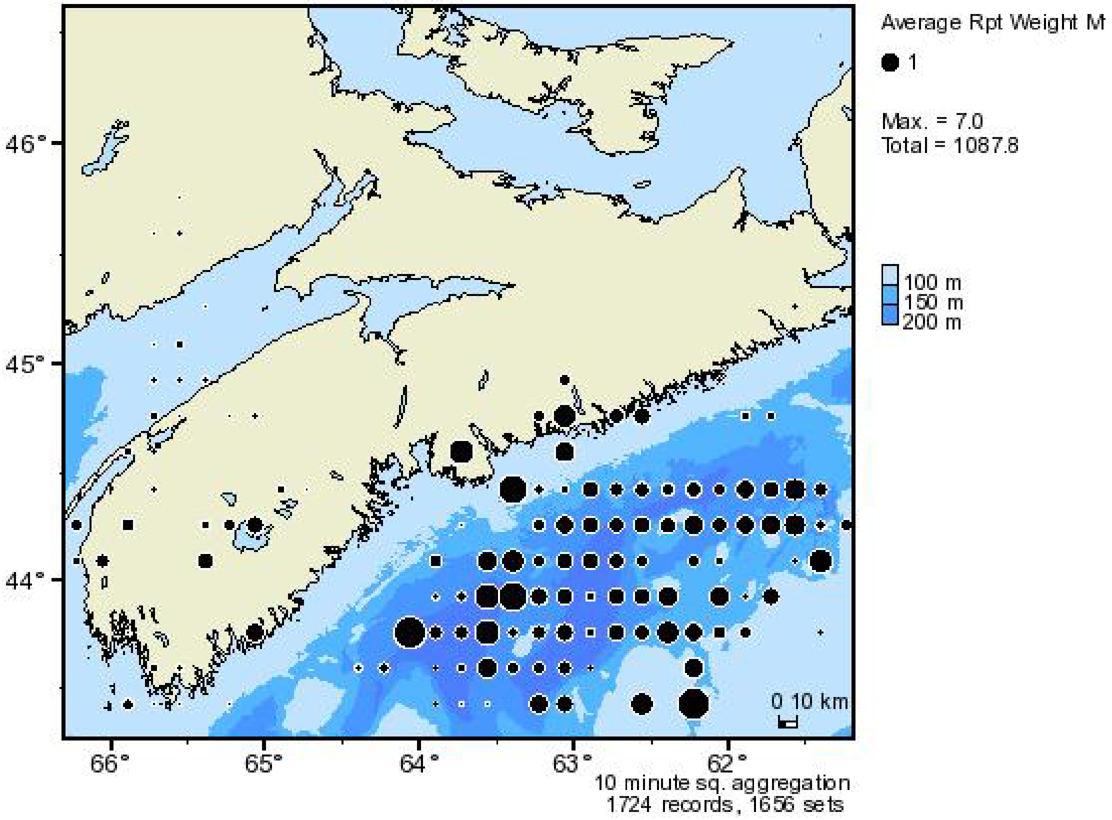


Figure 70. Distribution of averaged swordfish catches (mt) in mainland Nova Scotia from 2002-2011 (MARFIS 2011).

Swordfish are opportunistic on fish species (mackerel, silver hake, herring) and squid. Young swordfish are preyed upon by pelagic species including blue shark, tunas and larger swordfish.

9.3.3.2. Small Pelagics

Atlantic Herring *(Clupea harengus)*

Atlantic Herring is a pelagic schooling species that occurs in the Northeast and Northwest Atlantic. Within the study area (4VWX management unit), there are a number of spawning areas, separated to various degrees in space and time. Spawning areas in close proximity with similar spawning times, and which share a larval distribution area, are considered part of the same component (DFO 2013b). For the purposes of evaluation and management, the 4VWX herring fisheries are divided into four components:

1. SW Nova Scotia/Bay of Fundy spawning component
2. Offshore Scotian Shelf Banks spawning component
3. Coastal Nova Scotia spawning component (South Shore, Eastern Shore and Cape Breton)
4. SW New Brunswick migrant juveniles

Each component except SW New Brunswick migrant juveniles has several spawning areas, and there is mixing of fish among spawning components outside of the spawning period. It is not clear how much mixing there is between them, or between the inshore and offshore components. Herring also undergo overwintering, spawning and feeding migrations. In general, the distribution of herring at various life-stages is a gradient from fixed spawning areas, some variation in overwintering areas and summer feeding areas that change considerably depending on the availability of food (Sinclair and Iles 1985).

Herring are the archetypal forage species. At their various life stages, i.e. eggs, larvae, juveniles or adults, they are prey to a wide range of species including other fish, seabirds and marine mammals. They are a basic food for nearly all pelagic predators. Their eggs and spawn are food for fish including winter flounder, cod, and haddock. They are also an important predator in the inshore. They are visual predators, the young eating plankton, the fingerlings eating copepods, and the adults eating euphausiids (particularly *Meganyctiphanes norvegica*), copepods, fish eggs, pteropods, mollusc larvae, and small fish larvae, including sand lance, herring, and capelin. They mature at 3-4 years and in the inshore areas of the Scotian Shelf, spawning generally occurs in the fall. Known spawning areas include off Glace Bay, in the Bras d'Or Lakes, off Halifax/Jeddore and the Port Mouton/Little Hope area (Power et al. 2006a; Section 10.1.1). In the past, spawning areas were more widespread (Clark et al. 1999, Power et al. 2006b and see Section 10.1.1). Interviews with fishermen and fisheries officers by Sameoto (1971c) identified Chedabucto Bay as a region used by both spring and fall spawning herring, while the only exclusive spring spawning area west of Chedabucto were the inshore areas, Sheep Island, an area off Flying Point and Coddles' Harbour; all other areas are exclusively fall spawning beds.

There are active roe fisheries on the inshore spawning component at the inshore Scotian Shelf spawning sites including Port Mouton, Little Hope, Jeddore, Eastern Shore, and Glace Bay (Power et al. 2006a, Section 10.1). DFO has conducted acoustic surveys in the inshore in 4 areas since 1998 to estimate abundance: Little Hope, Eastern Shore, Glace Bay and the Bras d'Or Lakes. Since 1997, the status of herring in the Bras d'Or Lakes has been a cause for concern (Power et al. 2010).

Atlantic Mackerel (*Scomber scombrus*)

Atlantic mackerel is a migratory, schooling species and a seasonal visitor to Nova Scotia, migrating northwards in May and June along the Nova Scotian Atlantic coast bound for the Gulf of St. Lawrence and its major spawning grounds. They are managed as a single transboundary stock extending from Cape Hatteras to Labrador, with northern and southern spawning components. They overwinter in 70-200 m depths along the continental shelf (Scott and Scott 1988) in temperatures above 7 °C (Sette 1950), migrating inshore and northeastward in spring. Adults prefer temperatures in the range of 9-12 °C and avoid cool areas like the Bay of Fundy except in exceptionally warm years (Scott and Scott 1988).

The majority of fish comprising the northern component spawn in the Gulf of St. Lawrence in May through July, however, the presence of eggs in St. Margaret's Bay indicates that some mackerel spawn in coastal areas of Nova Scotia (MacKay 1967; Bernier and Levesque 2000). Historic catch records indicate mackerel are captured first in late May along the Atlantic coast of Nova Scotia with maximum catches occurring in June and smaller catches ccurring from July through until December (MacKay 1967). Since the 1980s, the mackerel fishery has been mainly a small boat inshore fishery. Atlantic mackerel is harvested using trap nets, gill nets, and purse seines to be frozen, canned, smoked or sold as bait. Canadian commercial landings for the period 1999-2008 have averaged 27,524 mt (TRAC 2010). These statistics underestimate mackerel caught in Canadian waters since they do not include mackerel captured inshore in the bait and recreational fisheries that occur along the shore from St. Margaret's Bay to Newfoundland from June to September, or discarded bycatch in other commercial fisheries (Gregoire et al. 2001, TRAC 2010).

Mackerel filter feed or actively pursue and capture individual prey such as zooplankton (copepods and larval crustaceans and mollusks) and fish eggs and larvae as well as small fish and large crustaceans (MacKay 1967). Predators include porbeagle sharks, spiny dogfish, Atlantic cod, bluefin tuna, swordfish, porpoises, and harbour seals.

9.3.4. Diadromous Fish

Contributed by R. Bradford

Diadromous fishes migrate between salt and freshwater and require both environments to complete their life cycle. Those which spawn in freshwater and spend a portion of their lives at sea are anadromous, of which 11 species occur within Atlantic Coastal Nova Scotia (Table 19). Fishes which spend most of their lives in freshwater and spawn at sea are referred to as catadromous of which only one species, American eel (*Anguilla rostrata*) occurs in the inshore area.

Diversity of freshwater aquatic habitat, variable estuary morphology and ocean forcing, as well as among-species variability in life-stage specific habitat requirements all contribute to substantive variability in both population richness and absolute population size among and between species. No single river drainage system supports all of the 10 federally managed species, although many rivers support several species. Some species are considered to be rare, occurring in only one or a few locations. The status of several species have been assessed as Endangered, Threatened or Special Concern by COSEWIC (Table 19), and others are either under review or there are plans for review. Important commercial and/or recreational harvest fisheries occur for several of these species, including some that have been assessed as at risk.

The inshore area has particular significance for diadromous fishes: it is the interface between freshwater and marine habitat, it serves as a staging area to fulfill life-history functions, it functions as a migratory corridor and as a feeding area (Table 20). Operational definitions of “inshore” and “coastal” -areas of less than 100 m depth, inside the 25 km limit – do not necessarily convey either the functional role of this ocean area in their structuring and population dynamics or the diversity of habitats and oceanographic processes occurring therein.

Table 20. Usage of the inshore tidal waters of the Scotian Shelf by diadromous fish species (X indicates high certainty of use,? indicates possible use; ELH – egg and larval stages; R. Bradford, pers. comm.).

	Spawning		ELH	Juvenile/Adult	Winter
Species	**Habitat**	**Migration**	**Rearing**	**Foraging**	**Habitat**
Gaspereau (Alewife, Blueback Herring)	-	X	X	X	?
American Shad	-	X	X	X	?
American Eel (large)	-	X		X	X
American Eel (elver)	-	NA	X		-
Rainbow Smelt (anadromous)	-	X	X	X	X
Atlantic Sturgeon	-	-	-	?	?
Shortnose Sturgeon	-	-	-	?	?
Atlantic Tomcod	X	X	X	X	X
Striped Bass	-	X	-	X	X
Atlantic Whitefish	-	X	Unknown	X	?
Sea Lamprey	-	-	-	X	-

The Province of Nova Scotia possesses hundreds of primary river drainages and associated estuaries owing to complex physiography (Section 4.2). Supporting habitat for diadromous species within the freshwater and estuarial/near shore realms is accordingly diverse in character, productivity, water quality and availability. Ocean forcing imparts additive complexity to the nearshore area and its use as supporting habitat for diadromous species. Water circulation and mixing can be expected to vary among estuaries as a function of their position relative to important coastal currents, and to predictable gradients in tidal forcing in addition to physiographic factors such as river discharge and estuary morphology (Greenlaw et al. 2011).

Individual river drainages represent the unit of management for most of the anadromous species, that is, most runs are assumed to represent reproductively discrete populations. Obligate freshwater residency times vary from a few hours to several years among species. Estuarial and marine dependency, is equally variable among species. The marine phase of diadromous fishes, specifically their distribution, seasonal occurrences and habitat requirements are not well studied.

Alewife (*Alosa pseudoharengus* and *Alosa aestivalis*)

Alewife occur at sea in depths up to 100 m (Stone et al.1992), They tend to move offshore in winter and inshore in summer (Stone and Jessop 1992), influenced by oceanographic features such as temperature and zooplankton abundance. They migrate up rivers to breed during May-June predominantly in lakes or ponds and return to the sea afterwards. Nearshore marine temperatures may influence the timing of arrival of alewife into estuaries. The juveniles migrate to the sea during the late summer and autumn. Alewife are plankton feeders on ctenophores, copeopods, amphipods, mysids and shrimp (Scott and Scott 1988, Munroe 2002b). Alewife are consumed at sea by a variety of predators including spiny dogfish, silver hake, salmon, cod and pollock (Munroe 2002b). When abundant especially during spawning runs, they are eaten by seabirds and piscivorous fishes (Scott and Scott 1988).

American Eel (*Anguilla rostrata*)

American eel occur in numerous estuaries, streams, rivers, and lakes draining to the Bay of Fundy, Atlantic coastal mainland Nova Scotia, and eastern Cape Breton, including the Bras D’Or Lakes drainages. Eels spend between five and twenty years in freshwater or estuaries before maturation (Smith and Tighe 2002). In late summer and fall, maturing eels develop black and gray pigmentation (silver eel stage) and migrate downstream and seaward. It is believed that they spawn in the Sargasso Sea south of Bermuda from February to July (Scott and Scott 1988). The larvae migrate toward the eastern coast, transforming into a transparent (glass eel or elver) eel stage as they approach inshore waters. Glass eels begin ascending streams progressively later from south to north, entering streams on the Atlantic coast of Nova Scotia during May and June (Jessop 1998) as temperatures reach 8-10 °C (Hutchison and Taylor 1980). Migration patterns are variable with some eels remaining in the estuaries and coastal waters, others inhabiting freshwater until they are mature, and immature eels migrating one or more times between estuary and freshwater (Jessop et al. 2006).

Juveniles and adult eels are predators and scavengers, feeding on almost anything including insects, polychaetes and fish (Smith and Tighe 2002). Eels are fished for commercial, recreational and aboriginal purposes as both large (juveniles residing in rivers and migrating silver migrating forms) and small elvers recruiting from the ocean to rivers and streams (Jessop 1996). COSEWIC (2006d, 2012a) has assessed the status of American eel as Threatened.

Rainbow Smelt (*Osmerus mordax*)

Rainbow smelt is a pelagic, schooling species that spends most of its time in shallow nearshore waters. Smelt may make ocean migrations, but little is known about this part of their life history. Their movement patterns are associated with seasonal changes in water temperatures (Scott and Scott 1988). In summer, schools move to deeper, cooler, waters; in the fall they enter bays and estuaries where they actively feed until the onset of winter. Most populations are anadromous with adults migrating into inland streams to spawn during the spring. Large schools may occur in rivers and estuaries during spawning migrations. Spawning migrations are usually restricted spatially and spawning usually occurs just above the head of tide (McKenzie 1964). Most spawning occurs in fast flowing, turbulent water in stream sections dominated by rocks, boulders, and aquatic vegetation, about the time ice breaks up in late winter. After hatching, larvae are transported to the estuary where they develop. Several studies suggest that larval smelt may use vertical migration to enhance estuarine retention, though there has been disagreement regarding the specific environmental cues involved (see references in Bradbury et al. 2008). Smelt enter estuaries in fall and overwinter, and move offshore into cooler, deeper water during the summer. However, they may only move out of harbours and estuaries far enough to find cooler water at slightly greater depths (Bigelow and Schroeder 1953). Smelt diets shift ontogenetically from consuming copepods and other plankton as larvae to large crustaceans, worms, and small fishes (silversides, mummichog, herring) as juveniles and adults (Scott and Scott 1988). Smelt are prey to many larger species of fish, birds and seals.

9.4. Marine Mammals

Contributed by J. Sperl (FSRS) and D. Bowen (DFO Science)

Some 14 species of marine mammals use the inshore waters on a regular basis or as a temporary feeding grounds or migratory routes. However, the seasonal distribution and abundance of most of these species in the inshore waters off Nova Scotia and their trends over time are poorly known since few species have been studied in this region of the Scotian Shelf. As a result, most of what we know is taken from other sources and for populations of these species that have been better studied elsewhere in their range.

9.4.1. Pinnipeds

The two resident seal species inhabiting inshore Nova Scotian waters are the harbour seal *(Phoca vitulina concolor*) and the grey seal (*Halichoerus grypus*). Both belong to the family Phocidae. The harbour seal is more restricted in its distribution to inshore waters than the grey seal (Hammill 2005), nevertheless both are found along the coast throughout the year. Harp and hooded seals are occasional visitors to inshore waters (Katona et al.1993). Walruses used to be endemic to Nova Scotian waters, but they were extirpated in the early 1800s through over hunting (McCullough et al. 2005).

Grey Seals *(Halichoerus grypus)*

Grey seals are present on both sides of the North Atlantic, and are distributed in three separate populations, the Northwest Atlantic, northeastern European, and the Baltic Sea (Katona et al. 1993). The Northwest Atlantic population extends from Cape Chidley, Labrador to Nantucket, Massachusetts and breeds on sea ice and small islands in the Gulf of St. Lawrence, on several islands along coastal Nova Scotia and on Sable Island, the largest grey seal breeding colony in the world (Katona et al. 1993; Bowen et al. 2003).

Over the past three or four decades, the numbers of grey seals on the Scotian Shelf has increased dramatically from around 9,000 seals in 1970 to 160,000 seals in 2003. The greatest increase is associated with the Sable Island colony, the largest worldwide, near the edge of the continental shelf in the central Scotian Shelf. Population numbers of the Sable Island colony have increased exponentially at an annual rate of 13% per year for the past four decades (Bowen et al. 2003). This increase is not unexpected as grey seals in both areas were recovering from low numbers resulting from hunting. Pup production continues to increase but the rate is slowing, indicating that density-dependent effects are influencing demographic rates (Bowen et al. 2007; 2011). The population has spread to the inshore, where grey seals are becoming increasingly common, and to the south, where they now occur in the Bay of Fundy and Georges Bank. New colonies were discovered on Hay Island in 1993 and Noddy and Flat Islands on the southwestern shore (Figure 71; Section 10.1.4) (Hammil et al. 2007). These latter colonies have since spread to the adjacent islands, Round and Mud (Bowen et al. 2011). Pup production inshore has decreased since 2007, possibly due to the limited area for breeding on Hay Island, where most of the breeding occurs (Bowen et al. 2011).

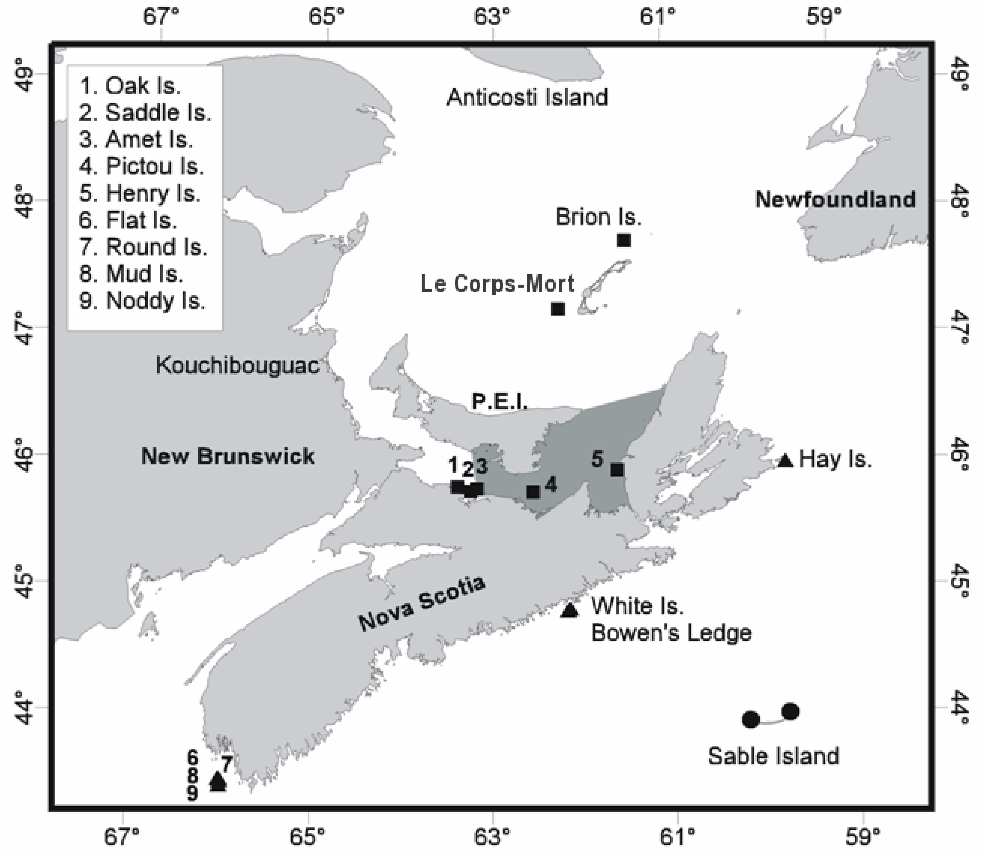


Figure 71. Southern Gulf of St. Lawrence and Scotian Shelf showing location of Sable Island (●), coast of Nova Scotia (▲), Gulf (■) grey seal colonies and general location of ice-breeding animals (dark grey area)(DFO 2011d).

Adult grey seals prey on herring, cod, haddock, pollock, flounder, skate, mackerel squid, capelin, hake, redfish, sand lance and invertebrates (Beck et al. 2007, Bowen et al. 1993, 2006). Grey seals have few known predators but their potential predators include white, blue, shortfin mako and Greenland sharks and killer whales (Bowen 2011).

Harbour Seals *(Pagophilus groenlandicus)*

Harbour seals are distributed along along the east coast of North America from Labrador to Cape Cod (Katona et al. 1993). The most recent study on the biology of harbour seals in the Maritimes combined information collected from surveys completed by fisheries officers, bounty kill records and monitoring of the Sable Island population (Boulva and McLaren 1979). They are non-migratory, coastal and generally found in small isolated populations along the Atlantic coast. Local abundance is related to the availability of islets. Their main concentration is on Sable Island, however, dozens of seal haulout sites have been identified from St. Margaret's Bay through to Liscomb Habour (McCullough et al. 2005).

Females come inshore in April and May to have their pups on sandbars and very small rocky islands. Weaned pups feed on amphipods and shrimp until graduating to the adult diet of Atlantic cod, herring, pollock, alewife, capelin, short-finned squid, hake, and winter flounder (Bowen and Harrison 1996). Considerably less is know about the abundance of harbour seals than grey seals along coastal Nova Scotia, but numbers are thought to be relatively low. There are no recent estimates of abundance for Nova Scotia, however, the abundance of harbour seals has increased over the past several decades along the coast of Maine (Waring et al. 2004).

9.4.2. Cetaceans

Baleen whales (Mysticetes) such as humpback whale (*Megaptera novaengliae*) and blue whale (*Balaenoptera musculus*) pass through the inshore region while migrating to the Gulf of St. Lawrence (McCullough et al. 2005). North Atlantic Right whale (*Balaena glacialis),* sei whale *(Balaenoptera borealis*), fin whale (*Balaenoptera physalus*) (Figure 72), and minke (*Balaenoptera acutorostrata)* are all seasonal visitors and have been reported in the inshore region, particularly in the the waters around St. Margaret's Bay and the approaches to Halifax Harbour (Katona et al.1993, Breeze et al. 2002, McCullough et al. 2005, COSEWIC 2005). Baleen whales feed on krill and copepods, with some species adding small fish such as herring, capelin, mackerel, sand lance, and squid to their diet.

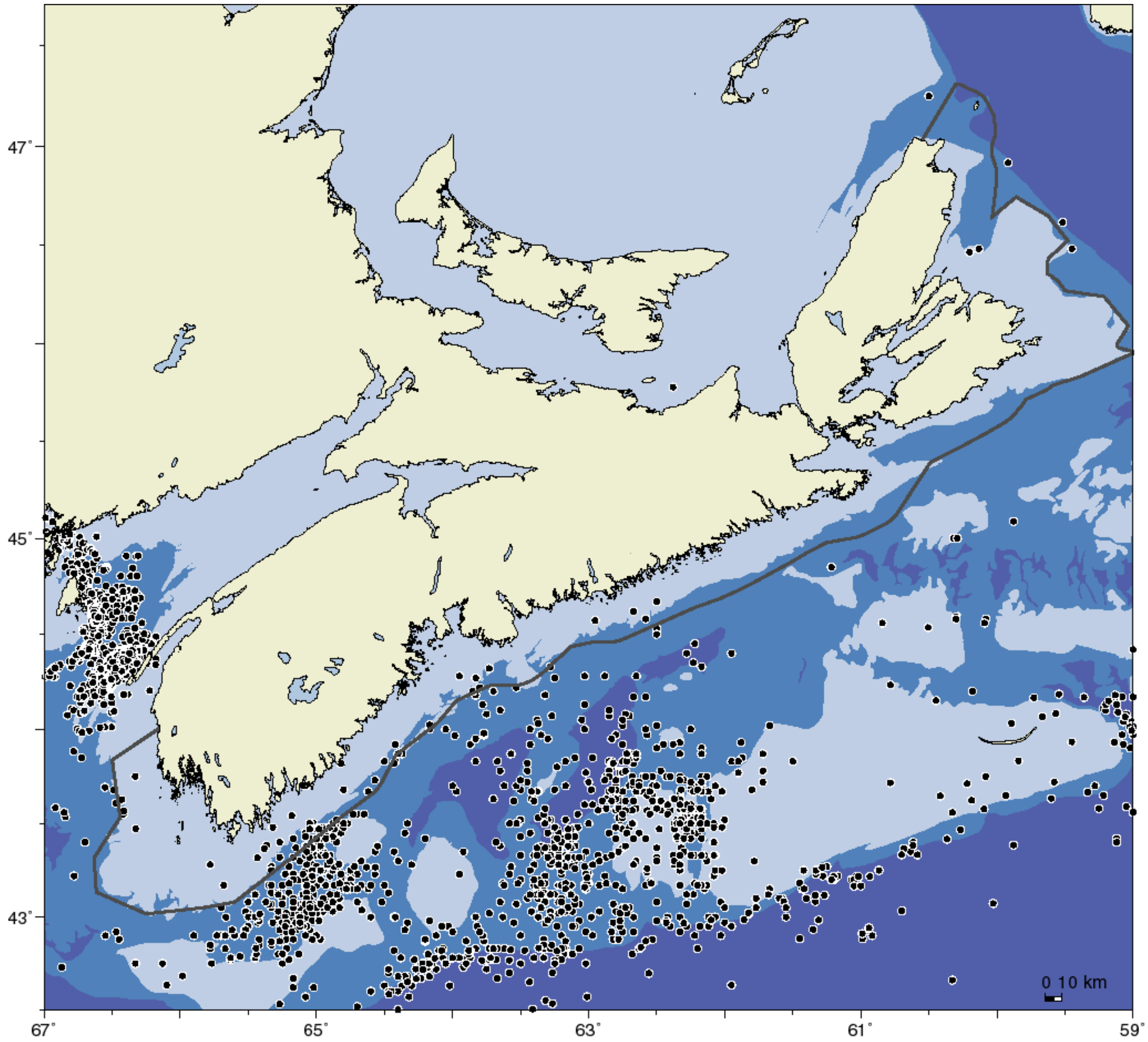


Figure 72. Sightings of fin whales on the Scotian Shelf and Bay of Fundy by vessels of opportunity from 1962-2009 (data from K.Smedbol, DFO Science). Line indicates 100 m contour line.

Toothed Whales

Toothed whale species occurring in the inshore region include long finned pilot whales, (*Globicephala melas*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), white-beaked dolphin (*Lagenorhynchus albirostris*) and harbour porpoise (*Phocoena phocoena*) (McCullough et al. 2005). All of these have been studied at certain locations along Nova Scotia's inshore waters (e.g. the Blind Bay Cetacean Study on dolphins and long-finned pilot whales in Cape

Breton by Dr. Hal Whitehead and students of Dalhousie University). Long-finned pilot whales are often found along the edge of the Scotian Shelf, although they do follow squid migrations to inshore waters where they feed for the summer and fall, particularly near Cape Breton (Katona et al. 1993; Ottensmeyer and Whitehead 2003). They are frequently sighted inshore in the Sydney Bight in summer months (Breeze et al. 2002) and may be using the area for calving (Schaefer et al. 2004). They feed on pelagic species such as herring, silver hake, smelt, squid and sand lance (Katona et al.1993).

Harbour Porpoise (*Phocoena phocoena)*

The smallest cetacean found in inshore waters is the harbour porpoise (Katona et al.1993). It occurs from Cape Hatteras to Greenland, and is most abundant in the Gulf of Maine and along the Scotian Shelf. In the spring they are either alone or congregate in small groups, but between August and September aggregations of 100 – 200 individuals form. They are not found inshore in the winter, and their migration destination is unknown. Harbour porpoises are about 1.5 m long, 64 kg, and live only 10 – 13 years. They mature at 3.15 – 6 years old and calve every year after they mature. Calves are born from April to July after an 11 month gestation period, and nurse for 8 months (Katona et al.1993; COSEWIC 2006e). Prey species include herring, mackerel, capelin, hake, cod, pollock, whiting, squid, krill and other invertebrates (Katona et al.1993).

The northwest Atlantic population of harbour porpoises was assessed by COSEWIC as Threatened in 1990 and 1991 and re-examined and assessed as Special Concern in 2003 and 2006 (COSEWIC 2006e). The species is listed as Threatened under Schedule 2 of SARA (meaning the prohibitions of SARA do not apply). There are no current estimates of the population size. Surveys have been conducted in the Gulf of St. Lawrence and the Bay of Fundy-Gulf of Maine, but there are no estimates of abundance from the inshore Scotian Shelf area (COSEWIC 2006e). Entanglement in fishing gear is the greatest threat to the harbour porpoise; however, they face many other threats as well such as by-catch in fisheries, decrease in abundance of prey such as herring, pollution and chemical exposure, and acoustic harassment (COSEWIC 2006e). Chemicals exposure includes PCBs and organochlorides (COSEWIC 2006e). Acoustic harassment devices emit high frequency sounds to deter pinnipeds from mariculture sites and have been used in the Bay of Fundy. Seismic exploration for oil and natural gas may also be causing acoustic harassment. The harbour porpoise is likely a strong presence in the food web as a top carnivore in the upper trophic levels.

9.5. Seabirds

Contributed by C. Gjerdrum (2007)

Marine birds, comprising petrels, cormorants, gannets, gulls, terns, auks, phalaropes, sea ducks and geese, loons and herons, are ubiquitous over the inshore Scotian Shelf at all times of year. During the summer months, virtually the entire Scotian Shelf coastline is covered in marine bird colonies at which several hundred thousand individuals of more than twenty species breed. During the spring, summer and fall, migrants from the South and North Atlantic, and Antarctic use this area as refuge and feeding habitat. In the winter months, some inland birds move to the coast, joined by large numbers of marine birds from Newfoundland, Arctic Canada, Greenland and northern Europe, which migrate south from breeding areas to overwinter.

Marine birds are an important component of the inshore ecosystem. They use a wide variety of marine species as food sources, and thus can be used as indicators of ecosystem-scale changes in the marine environment. They range from surface pickers, through plunge divers to pursuit divers, and some feed on benthic prey. Typical prey species selected tend to be small-medium size and highly nutritious, such as oil-rich fish (e.g. herring, capelin, mackerel, Myctophids), squid, and plankton such as copepods and krill. Waterfowl include eiders and scoters that prey on shellfish such as mussels; American Black Ducks (*Anas rubripes*), Brant and Canada Geese feed in shallow water on vegetation, such as eelgrass.

The Canadian Wildlife Service (CWS) maintains databases on the distribution and abundance of breeding and non-breeding marine birds in the Atlantic region. The Atlantic Region Colony Database (CWS 2001) contains information on location and numbers of breeding seabirds at more than 500 breeding locations in the Scotian Shelf study area, 75% of which have been surveyed since 1995. The Atlantic Regional Coastal Aerial Survey Database (CWS 2002) contains annual counts of waterbirds from aerial coastal surveys of the Atlantic region. The Eastern Canada Seabird and Sea Database surveys pelagic birds from vessels traveling offshore (Brown et al. 1975; Brown 1986; Lock et al. 1994). For this report, the databases were queried in 2007 to summarize the state of knowledge for marine birds of the inshore Scotian Shelf. As considerably more information has been collected since 2007, an update of the information presented here is needed.

9.5.1. Breeding Marine Birds

More than 380,000 individuals of 14 species are estimated to breed on coastal islands or isolated mainland sites on the Atlantic coast between Cape North and Cape Sable Island, Nova Scotia (Table 21; Figure 73). The most common species based on number of colonies are Herring Gull (*Larus argentatus*), Great Black-backed Gull (*L. marinus*), terns (*Sterna* spp.), and cormorants (*Phalacrocorax* spp.), which are distributed along the entire coastline (Figure 73). Common Eider (*Somateria mollissima*) colonies are more concentrated along the Eastern Shore and southwest coast. Not unexpectedly, these species are also the most common in terms of population size with the exception of the Leach’s Storm-petrel (*Oceanodroma leucorhoa*), which constitutes the most numerous species breeding on the Scotian Shelf coast (over 200,000 individuals), but is found at only a few locations (Figure 74). The Cabot Strait coastline of Cape Breton differs from the rest of the Scotian Shelf area in having fewer islands and more cliff habitat. For these and other reasons probably related to biological oceanography, colonies are more spread out and breeding species are more typical of Newfoundland (for example, Black-legged Kittiwake, *Rissa tridactyla*; Alcids; Figure 74). The breeding season is from May through August, however birds arrive at colonies before this and some, such as the Leach’s Storm-petrel, remain through October.

Table 21. Marine birds that breed along the Nova Scotia coast (modified from Breeze et al. 2002).

Group	Habitat/Time of Year
Storm-Petrels	
Leach's Storm-petrel	Islands along Atlantic coast
Cormorants	
Great Cormorant	Coastal and island colonies along eastern Cape Breton
Double –crested	Rocky shores along Atlantic coast
Herons	
Great Blue Heron	Coastal areas and on islands, some inland
Dabbling ducks	
Green-winged Teal	Saltwater marshes
Black Duck	Wetland habitats
Sea Ducks	
Common Eider	Nest along Atlantic coast
Red-breasted Merganser	Common along coast in fall to spring, a few nest on coastal islands
Shorebirds	
Semi-palmated Plover	Beaches along Atlantic coast
Piping Plover	Beaches in southwestern NS
Willet	Breeds along coast near saltmarshes; occurs on beaches during spring and fall migrations
Gulls and Terns	
Herring Gull	Large breeding colonies along coast; common in summer, some overwinter
Great Black-backed Gull	Common in breeding colonies along coast, some overwinter
Black-legged Kittiwake	Islands off Cape Breton
Roseate Tern	Coastal Islands
Common Tern	Eastern and south shores
Arctic Tern	Eastern and south shores
Alcids	
Razorbill	One breeding colony off Cape Breton and a few on southwest coast
Black Guillemot	Coastal Islands; occurs on coast year round
Atlantic Puffin	One breeding colony off Cape Breton and a few on southwest coast

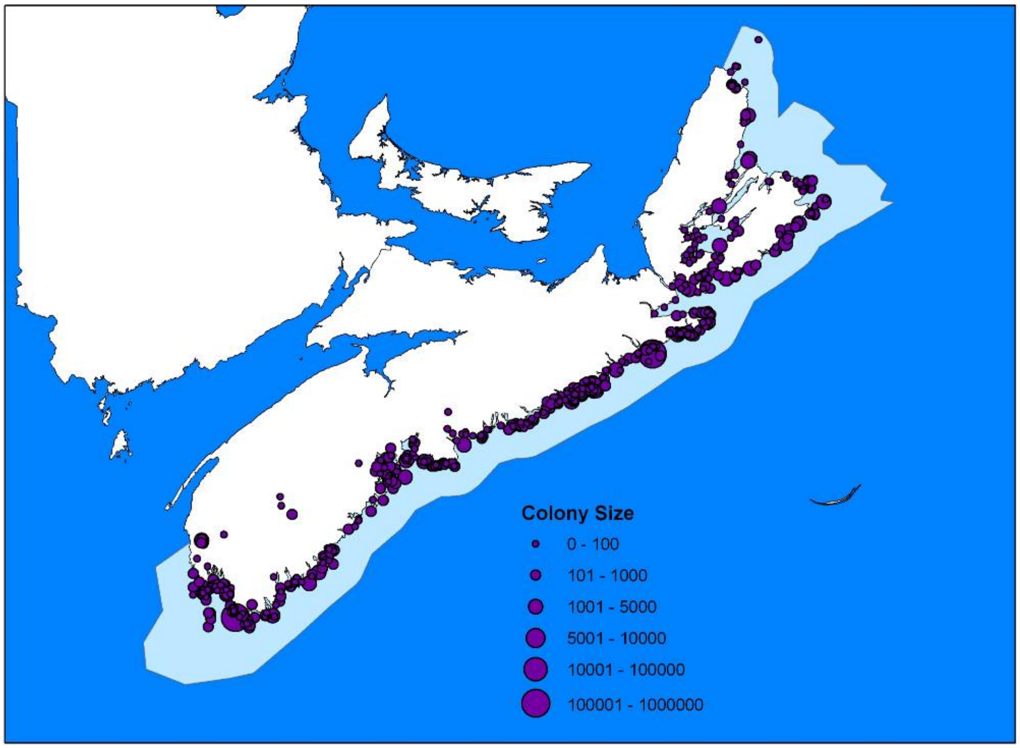


Figure 73. Location and size (number of individuals) of seabird colonies (all species combined) on the Scotian Shelf coastline from the Atlantic Region Colony Database. The inshore is defined as less than 90 metres depth or less than 25 km offshore, and is depicted in light blue.

Gulls breeding on the Scotian Shelf coastline make use of the entire inshore zone, as defined by the 90 metre isobath or 25 km limit, while cormorants, terns and eiders are shoreline or coastal feeders (Figure 74)[8]. For these, numbers diminish rapidly with distance from shore. At the other extreme, Leach's Storm-petrels are pelagic feeders and typically forage out to the shelf edge and beyond. New data collected since 2007 are available to characterize the current avian inshore community, although survey coverage in the very nearshore areas needs to increase. The limited number of cormorant and tern sightings during pelagic surveys (Figure 74) is likely a reflection of this gap in coverage.

9.5.2. Migrating Birds

In addition to breeding birds, the Scotian Shelf is used as refuge and feeding habitat over the spring, summer and fall by migrant species (Table 22). Greater and Sooty Shearwaters (*Puffinus gravis* and *P. griseus*) and Wilson's Storm-petrels (*Oceanites oceanicus*) all breed on remote islands in the South Atlantic but are present in huge numbers on the Scotian Shelf from June through October (Figure 75). Immature, pre-breeding northern hemisphere species from the North Atlantic (e.g. Northern Fulmar *Fulmarus glacialis*; Figure 72) and staging and moulting waterfowl (e.g. Common Eider *Somateria mollissima*) are also common in our area. With the exception of waterfowl, most of these species tend to be pelagic and typically feed in areas of upwelling and high productivity over the offshore shelf and shelf-edge. In the spring and fall, both inshore and offshore areas of the Scotian Shelf are used as a corridor and feeding area for transient species migrating, such as the Northern Gannet (*Morus bassanus*) and phalaropes (Figure 73).

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[8] Data taken from the Atlantic Region Colony Database and Eastern Canada Seabirds at Sea Database (ECSAS).

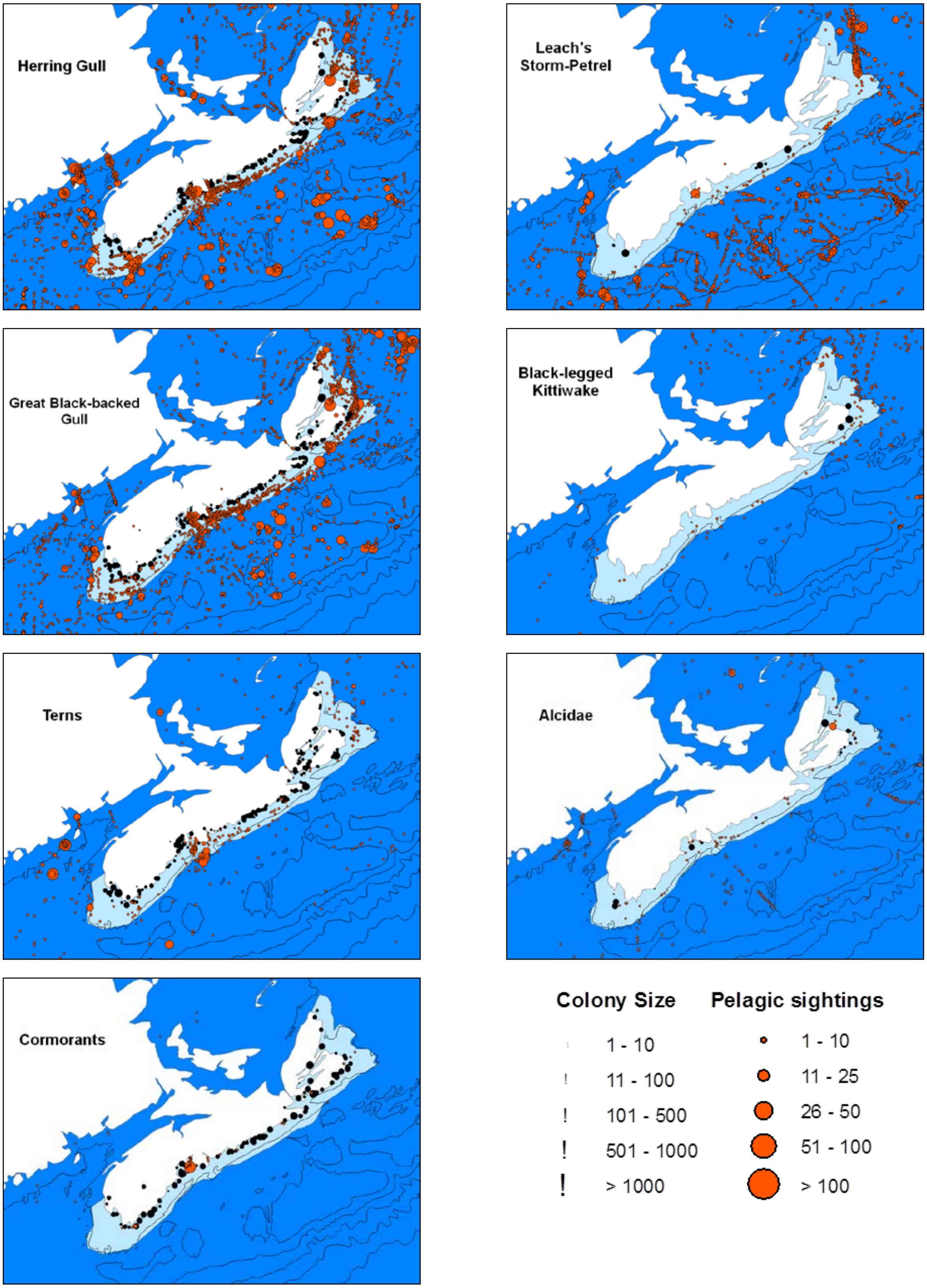


Figure 74. Colony size, location and pelagic sightings between May and August for the most common breeding species on the Scotian Shelf coastline.

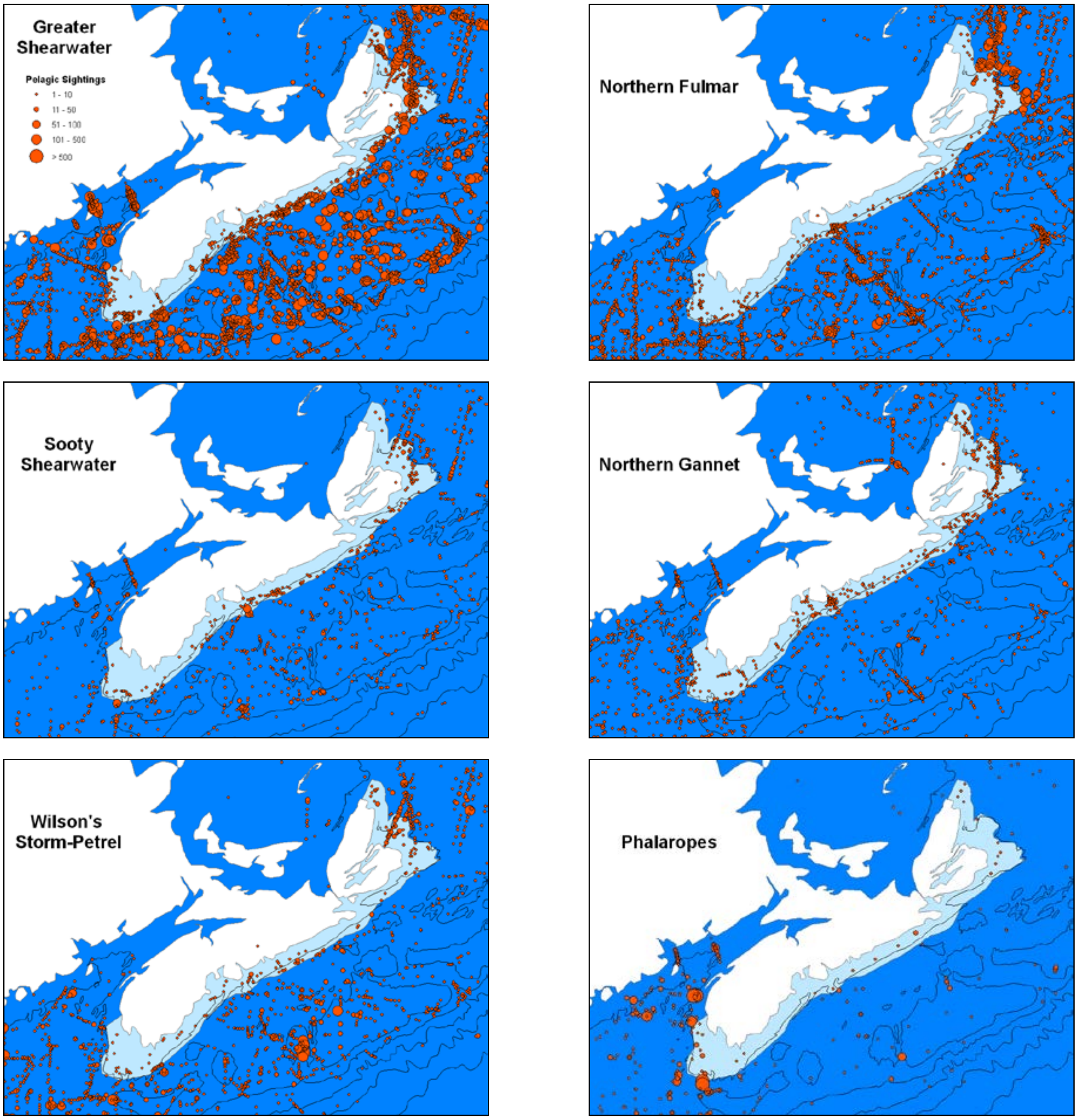


Figure 75. Pelagic sightings for the most common migrant species using the Scotian Shelf.

9.5.3. Wintering Bird Populations

In the winter months, local breeding marine birds disperse to coastal, inshore or pelagic realms and some typically move south off the eastern seaboard of the US. These are replaced by similar species breeding to the north, which use Scotian Shelf waters as a winter refuge and feeding area. In addition, inland breeding birds like the Black Duck, Canada Goose, and Common Loon (*Gavia immer*) move to the coast to feed (Table 22). These species are joined by large numbers of marine birds from Newfoundland, Arctic Canada, Greenland and northern Europe, which migrate south from breeding areas to overwinter. These notably include Common and Thick-billed Murre (*Uria aalge* and *U. lomvia*), Dovekie (*Alle alle*), Black-legged Kittiwake (*Rissa tridactyla*), and Northern Fulmar. Although some like the fulmar and kittiwake are pelagic in habit at this time of year, and would not typically enter the inshore portion of the Scotian Shelf, others like the murres and Dovekie do on a regular basis, sometime in large numbers (Figure 76).

Table 22. Non-breeding birds occurring along the Nova Scotia coast (from Breeze et al. 2002).

Group	Habitat/Time of year
Loons and Grebes	
Common Loon	Winters on saltwater
Pied-billed Grebe	Estuaries and sheltered saltwater coves in winter
Red-Throated Loon	In coastal areas during spring and fall migration
Horned Grebe	Coastal areas during spring and fall migration
Red-necked Grebe	Coastal areas during spring and fall migration
Geese	
Brant	Coastal areas in southwest NS during spring and fall migrations
Canada Goose	Coastal areas in southwest NS during spring and fall migrations; large numbers overwinter at Port Joli and Cole Harbour
Dabbling Ducks	
Greater Scaup	Coastal areas in southwest NS during spring and fall migrations
Harlequin Duck	Migratory transient in fall and spring; some overwinter on southwest coast
Long-tailed Duck	Common in winter along the coast
Black Scoter	Common along the coast during fall and spring migration; uncommon in winter
Surf Scoter	Common along the coast during fall and spring migration; common in winter
White winged scoter	Common along the coast during fall and spring migration;common in winter
Goldeneye	Common along the coast during fall and spring migration;common in winter
Bufflehead	Common along the coast during fall and spring migration; uncommon in winter
Shorebirds	
Black-bellied plover	Common along the coast during fall and spring migration; occasionally some overwinter near Cape Sable
Golden Plover	Uncommon but occasionally numerous in fall migration; few in spring migration
Lesser Yellowlegs	Uncommon during spring migration; more common in fall migration
Ruddy Turnstone	Uncommon during spring migration; common in fall migration; occasionally overwinter near Louisbourg, and Cape Sable Island
Red Knot	Uncommon during spring migration; common in fall migration; occasionally overwinter on southwest coast
Sanderling	Uncommon during spring migration; common in fall migration; occasionally overwinter on southwest coast
Semipalmated Sandpiper	Uncommon during spring migration; more common in fall migration; small numbers on coast in summer
White-rumped Sandpiper	Uncommon during spring migration; common in fall migration;
Pectoral Sandpiper	Uncommon during spring migration; common in fall migration
Purple Sandpiper	Common in some areas during winter on rocky shores
Dunlin	Uncommon during spring migration; common in fall migration; occasionally overwinter on south and eastern shores
Short-billed Dowitcher	Uncommon during spring migration; common in fall migration;
Gulls and Terns	
Common Black-headed Gull	Common along coast in winter
Bonaparte’s Gull	Uncommon during spring migration, more common along South Shore during fall migration
Ring-billed Gull	Common during spring and fall migration, some overwinter
Iceland Gull	Fairly common in winter, Halifax and Sydney harbours

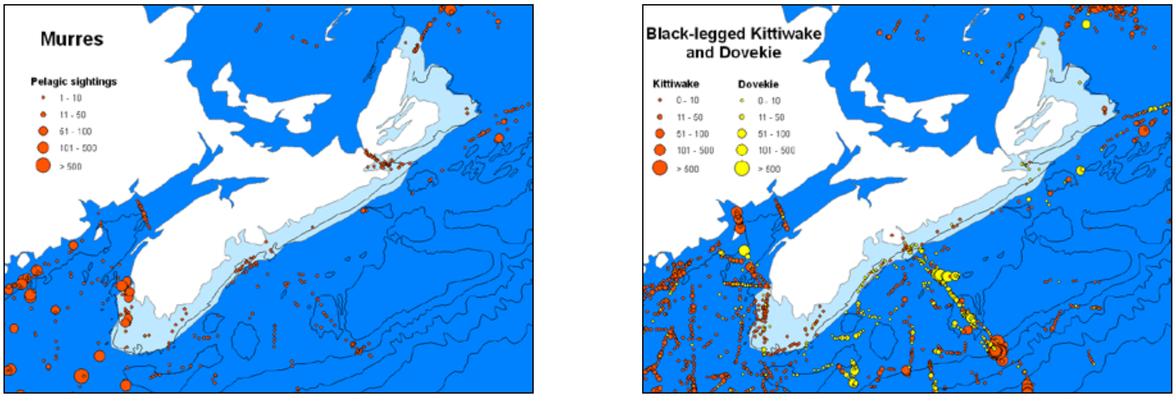


Figure 76. Pelagic sightings for some common species using the Scotian Shelf during the winter.

9.5.4. Coastal Waterfowl

During the summer, Common Eider (*Somateria mollissima*) are the only waterfowl abundant in the inshore Scotian Shelf. Colonies are concentrated along the Eastern Shore and southwest coast (Figure 77), where immature birds are also present. Once the female initiates incubation, the males move to the southwestern coast of Nova Scotia to moult. In July and August, as many as 30,000 moulting eiders can be found between Port Mouton and Shelburne (Lock et al.1994).

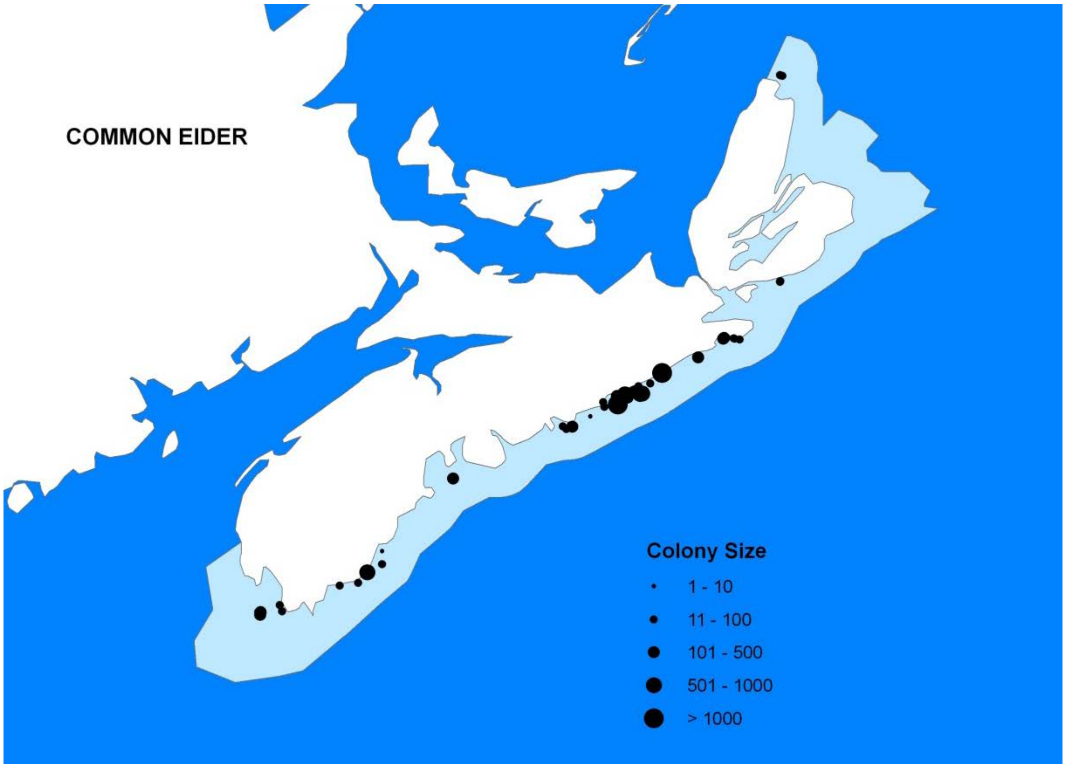
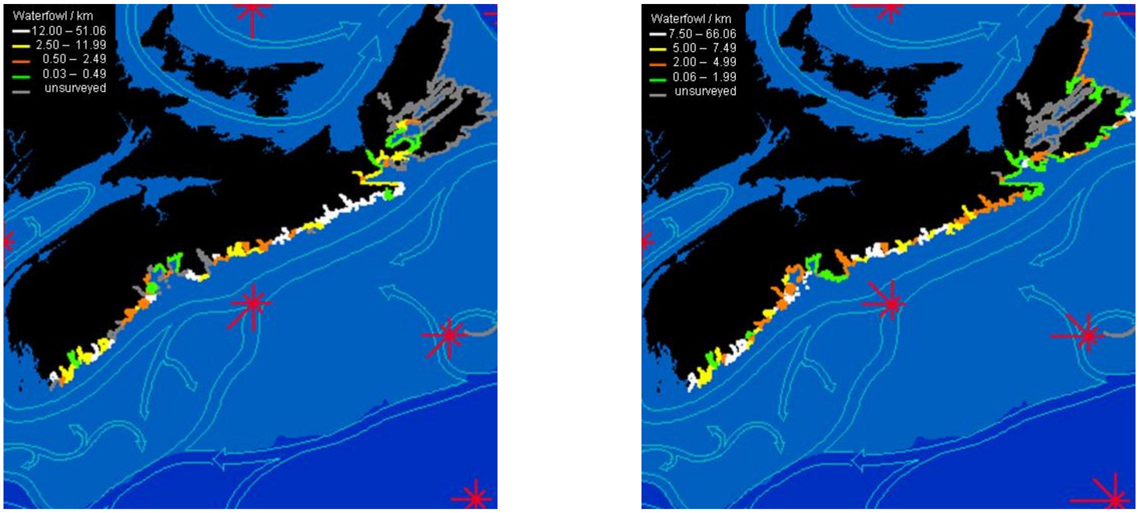


Figure 77. Location and size (number of individuals) of Common Eider colonies on the Scotian Shelf coastline from the Atlantic Region Colony Database.

During the spring and fall, the Scotian Shelf is used as a corridor and feeding area for transient species migrating such as the scoters and Red-throated Loons (*Gavia stellata*) (Figure 78). In October and November, as many as 10,000 scoters gather along the coastline east and west of Halifax (Lock et al. 1994). Total numbers of migrant and transient individuals using the area of interest are unknown but could reach millions over the entire period of use.

In winter, waterfowl are present along most of the coastline between Sydney and Cape Sable (Figure 78). Inland breeding birds like the Black Duck, Canada Goose, and Common Loon (*Gavia immer*) move to the coast to feed. Of note here is the large numbers of Black Ducks that use the coastal areas around Halifax and Musquodoboit Harbour. As many as 10,000 Canada Geese overwinter in the wetlands in the Port Joli sanctuary and the area east of Halifax.

(a) January – March (b) April - June



(c) July – September (d) October – December

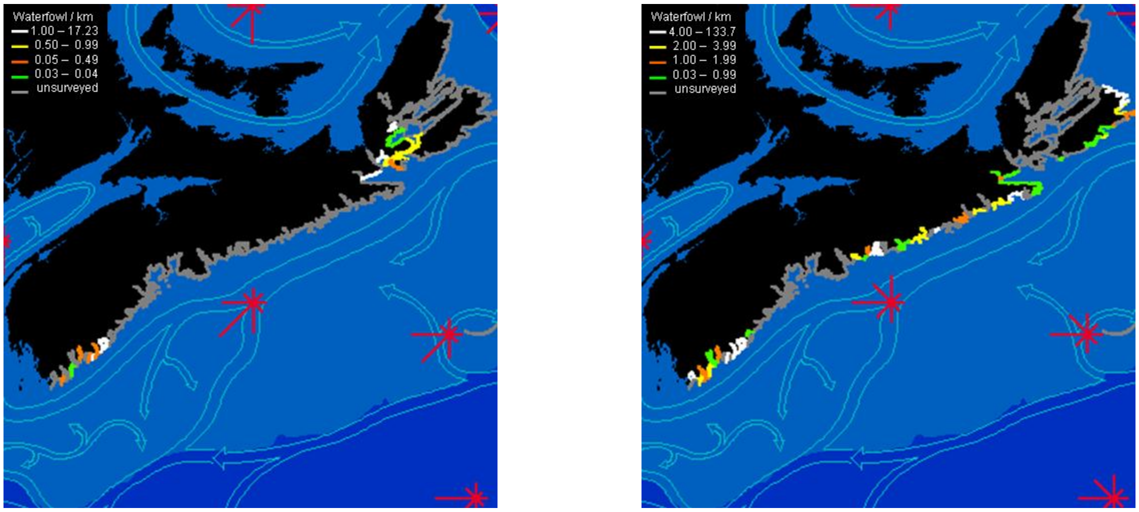


Figure 78. The distribution and abundance of coastal waterfowl from (a) January – March, (b) April – June, (c) July – September, and (d) October - December (from Lock et al. 1994).

9.5.5. Bird Species at Risk

There are currently six avian species at risk, listed under SARA, found in the inshore area of the Scotian Shelf. Two are listed as Endangered - Roseate Tern (*Sterna dougllii*) and Piping Plover (*Charadrius melodus melodus*) - and four are listed as Species of Special Concern - Ipswich Sparrow (*Passerculus sandwichensis princeps*), Harlequin Duck (*Histrionicus histrionicus*), Barrow's Goldeneye (*Bucephala islandica*) and Ivory Gull (*Pagophila eburnea*). Some of the threats to these species include habitat loss and disturbance.

Roseate Terns and Piping Plovers nest along the coast of the nearshore area of the Scotian Shelf (Figure 79), Ipswich Sparrows nest on Sable Island, while Ivory Gulls, Harlequin Ducks and Barrow’s Goldeneye are only found in this area during the winter. Barrow’s Goldeneye and Ivory Gull are quite dispersed during the period of time they are in the area, while Roseate Terns and Harlequin Ducks are found clumped together at breeding colonies and wintering areas, respectively. The Canadian Wildlife Service conducts annual surveys for wintering Harlequin Ducks, and since 1995, Roseate Tern surveys every four years in conjunction with Nova Scotia Department of Natural Resources.

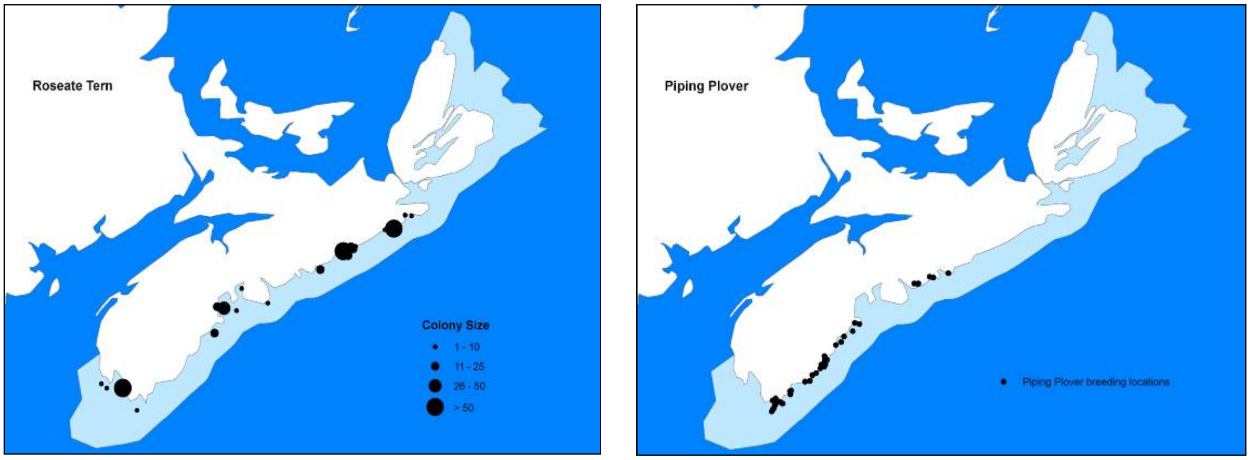


Figure 79. Size and location of Roseate Tern colonies, and location of Piping Plover breeding beaches for the inshore Scotian Shelf.

9.5.6. Knowledge Gaps (Birds)

The databases maintained by the Canadian Wildlife Service contain information on birds using the inshore Scotian Shelf that span 30 years or more. Seabird colony and waterfowl surveys are on-going, and until 2006,very little pelagic data had been collected since the early 1990s, especially during the non-breeding season. In 2006, the Canadian Wildlife Service has developed a pelagic seabird monitoring program for Atlantic Canada with the objective of mapping the relative abundance and distribution of birds throughout the region (Gjerdrum et al. 2012). These programs will contribute significant data for the inshore Scotian Shelf ecosystem and will eventually enable us to evaluate trends in abundance and distribution.

10. HABITAT USE AND FUNCTIONAL AREAS

Contributed by D.Themelis and A. Bundy

A wide range of habitats can be found on the Atlantic coast, including tidal marshes, rocky shores, and sandy beaches (sections 4.1.1. and 11.2). Although some marine species spend their entire lives within one habitat, many use two or more to satisfy their lifecycle requirements for successful reproduction, survival of their offspring, feeding and growth, and overwintering. For example, soft-shell clams live in mudflat burrows as adults, but their pelagic eggs and larvae undergo development in the water column. Other coastal marine species such as marine mammals and birds are highly migratory and utilize habitats outside the inshore region for some of their life cycle functions. Without a comprehensive seasonal survey of the inshore area, the information is not available to fully describe how and when different habitats in the inshore are used, and by which species. The following is based on information from historical studies, commercial fisheries data, sentinel surveys, the Inshore Ecosystem Project, the 4Vn Cod Survey, and sources in the literature. The most recent compilation on bird habitats in the inshore region is Gromack et al. (2010), who used bird diversity and abundance at twenty sites along the Atlantic coast as ecological attributes in support of conservation planning. The two data sources used were the database Key Marine Habitats for Migratory Birds on Eastern Canada’s

Atlantic Coast project, maintained by the Canadian Wildlife Services to identify key sites according to marine habitat type (intertidal salt marshes, mudflats, beaches and rocky shorelines, eelgrass beds, offshore areas) and the database Important Bird Areas (IBA) on the Nova Scotia coast documented by Bird Life International. The IBA process characterizes the relative significance of an area based on the maximum number of birds recorded, or the proportion of a national, continental or global population to achieve national, continental or global significance.

10.1. Mating/Spawning/Breeding Areas

10.1.1. Fish

The 4VWX Atlantic herring stock has a complex population structure (Sinclair 1988) comprising a number of discrete subpopulations that spawn at different locations, specific to each subpopulation (Stephenson et al. 2009). Several locations along the Atlantic shoreline were identified as historical spawning areas for herring (Sameoto 1971c; Crawford 1979). Most spawning occurs in September; however, Sameoto (1971c) identified areas of spring spawning in Chedabucto Bay and further west in Guysborough County (Figure 78). The largest herring spawning area was along the southern shore of Chedabucto Bay between Queensport and Half Island Cove. Since the time of that study, the number of inshore spawning locations has declined (Figure 80, Stephenson et al. 1999).

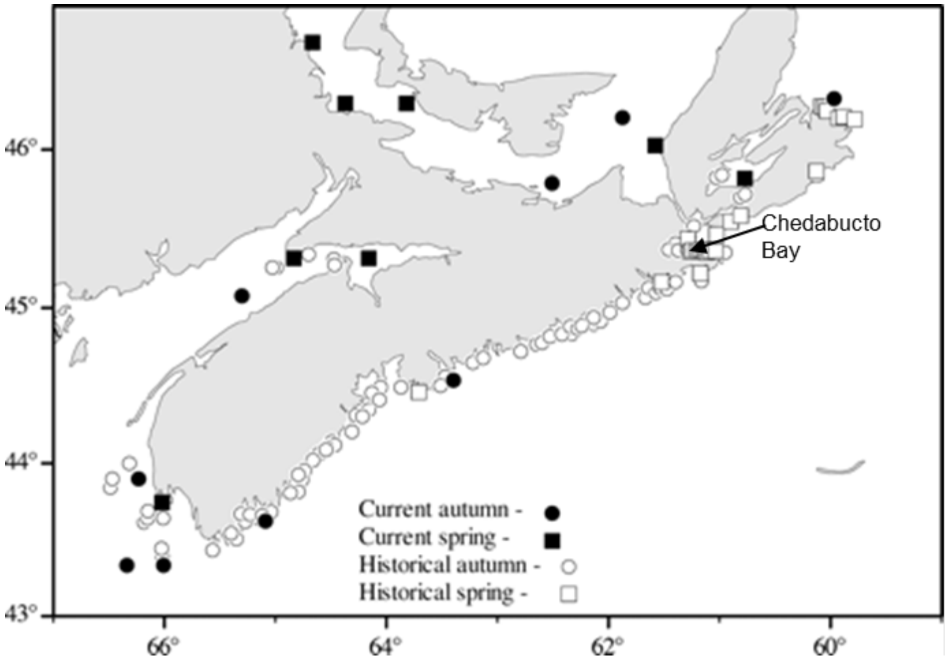


Figure 80. Herring spawning locations on the Scotian Shelf and Gulf of Maine that have been used recently (filled circles, autumn; filled squares, spring) or only historically (open circles, autumn; open squares, spring). (Reprinted with permission from Stephenson et al. 2009).

There are four main inshore herring spawning areas left along the Atlantic coast of Nova Scotia: Little Hope/Port Mouton, Halifax/Eastern Shore, Glace Bay and the Bras D'Or Lakes. Spawning biomass has been estimated from acoustic surveys conducted by herring fishery vessels in three of these areas since 2000 (Figure 81). There is no discernible trend in spawning biomass since the time series are short and there is considerable interannual variability. Estimates from Glace Bay have been very low since 2006, likely due to limited survey coverage (M. Power, pers. comm.). Estimates of spawning biomass from Little Hope/Port Mouton and Halifax/Eastern Shore have declined since 2009, and were below the 5 year average in 2012. The 2012 estimate for Halifax/Eastern Shore was the lowest in the time series (DFO 2013b). There have been no survey estimates for the herring in the Bras D'Or Lakes since 2000.

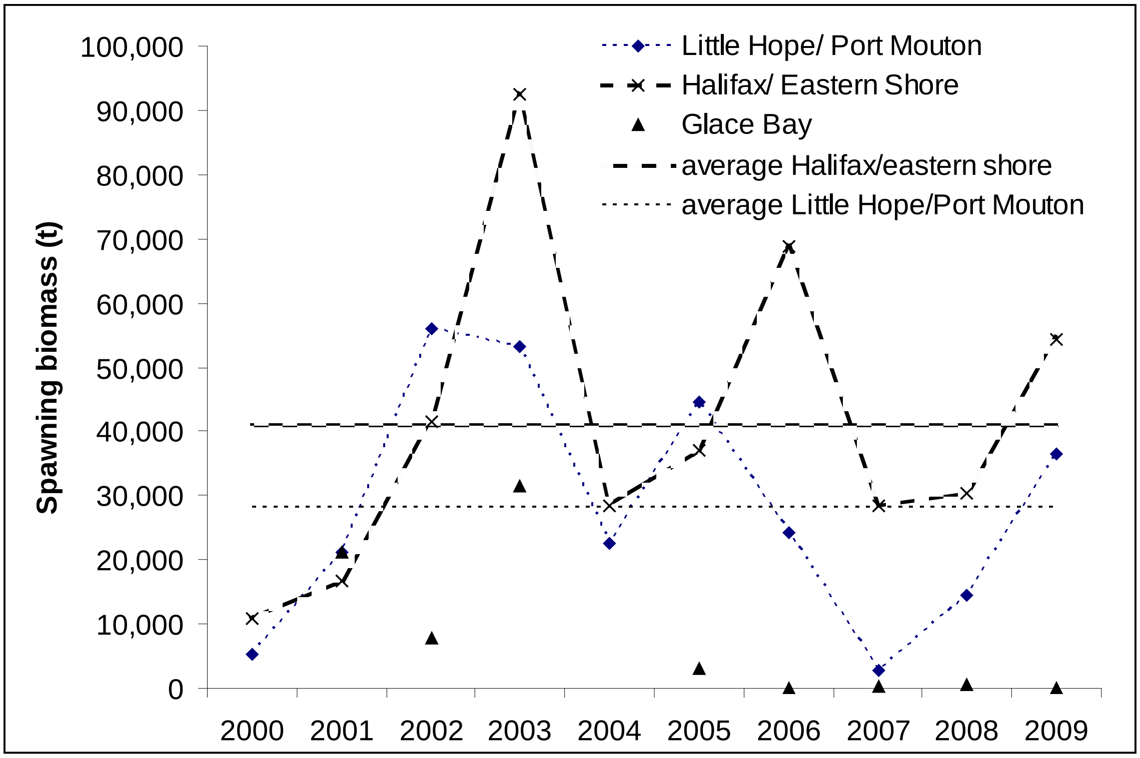


Figure 81. Estimates of spawning biomass (mt) of herring in coastal Nova Scotia based on acoustic surveys (from Power et al. 2011).

Spawning occurs in the spring, summer and fall at locations in inshore areas of Sydney Bight as well as all along the coast from northern Cape Breton to Scatarie Island (Schaefer et al. 2004). Inshore spring spawning herring spawn on beds at depths of less than 7 m while summer and fall spawning occurs at depths from the low tide mark to depths of 35 m (Sameoto 1971c). Preferred spawning substrates are rocky, pebbly or gravelly bottom and never on soft mud (Munroe 2002b). Herring eggs are adhesive, sticking in layers or clumps to sand, stones and seaweeds. Eelgrass beds in the Bras D'Or lakes were a key spawning location for herring (Denny et al. 1998). Larger concentrations of eggs have been found on the brown seaweeds *Phyllophorus* and *Fucus* spp than on Irish moss, suggesting a preference for those seaweeds, except where Irish moss is abundant (Scott and Scott 1988; Munroe 2002b).

Inshore cod populations were once common along the Eastern Shore. The largest stock inhabited Chedabucto Bay and another notable stock occurred in the approaches to Halifax Harbour and eastwards (McKenzie 1940). These stocks were fished out by the early 1970s but, similarly to herring, some limited spawning activity may still be occurring (Gromack et al. 2010). Western Sydney Bight is still a spawning area for cod (Lambert and Wilson 1995), but other than this, no extant spawning populations are known. Young cod (3-10 cm) were found during beach seining at many locations around Nova Scotia in the 1930s (McKenzie 1938), whereas they were found only at Black Rock Beach in Halifax Harbour during a beach seine survey in 2000 (Don Clark, pers. comm.).

The main spawning grounds for Atlantic mackerel are in the Gulf of St. Lawrence but some spawning occurs during spring on the edge of the Scotian Shelf and along the Nova Scotia coast, as indicated by the presence of eggs in mackerel egg surveys of St. Margaret's Bay in

1999 (Bernier and Levesque 2000) and the Scotian Shelf in 2009 (Figure 82; Gregoire et al. unpublished).

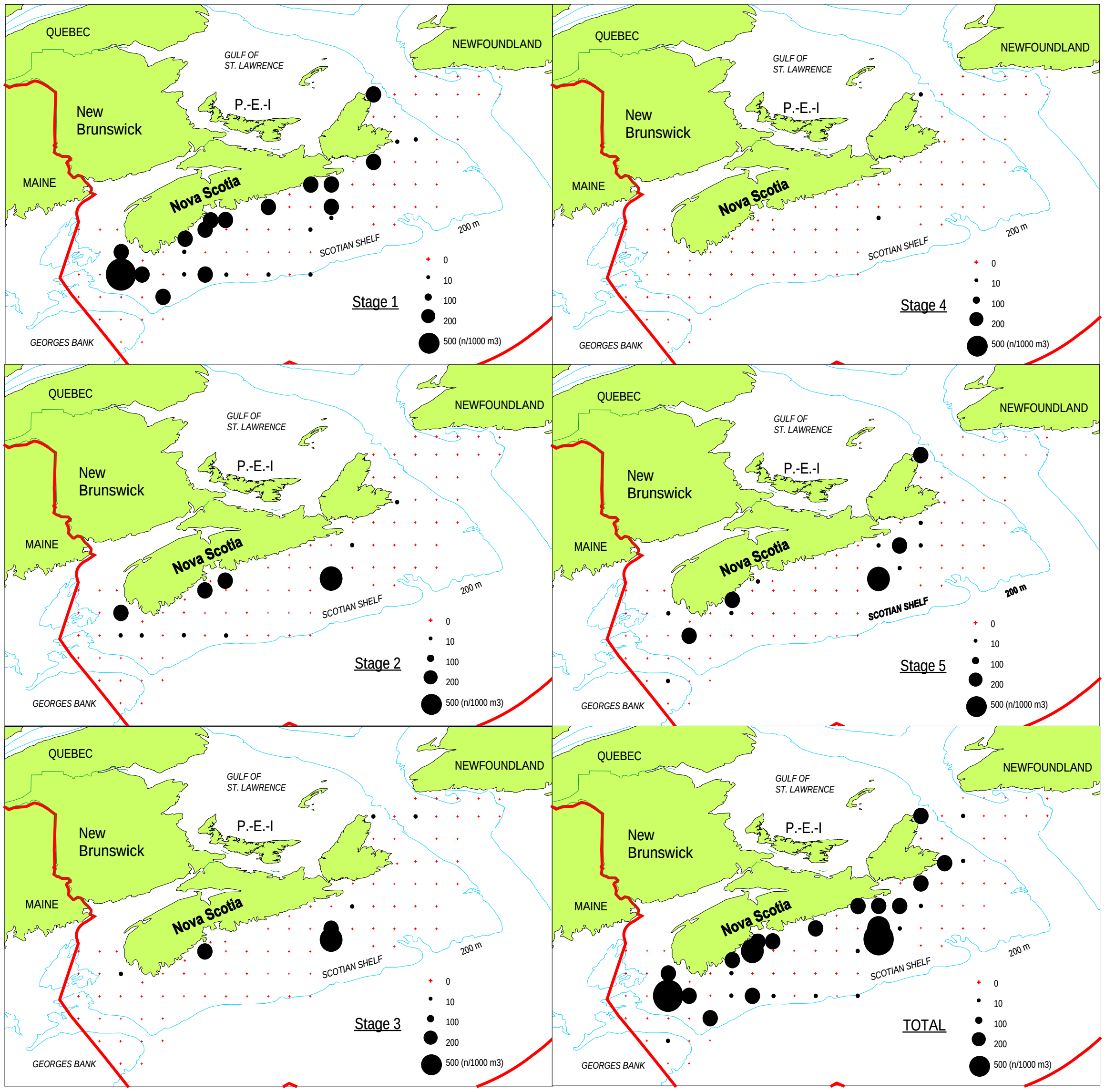


Figure 82. Atlantic mackerel egg distribution and abundance (n/1000 m^3) for the eggs and larvae survey conducted on the Scotian Shelf and in southern Newfoundland in 2009. Egg counts are grouped by stage of development (Girard 2000) from Gregoire et al. (unpublished).

Other fish species that occur in the inshore, such as winter flounder, sculpins, shannies and gunnels are also likely to spawn there. Sticklebacks, mummichogs and silversides spawn in the intertidal and shallow waters of the mudflats and estuaries around Nova Scotia (Section 9.2.5.3). The Sydney Bight may be a spawning area for American plaice, since eggs are concentrated there in May (Neilson and Perley 1988).

10.1.2. Invertebrates

Many commercial invertebrates such as lobster, green crab, rock crab, green sea urchins, mussels and oysters spend their whole life cycle in the inshore, including spawning. Exact spawning locations are not known, although they probably spawn where they most commonly occur since they do not make extensive migrations. Eggs and larvae are dispersed with water currents (Section 9.1.5). The many non-commercial invertebrates in the inshore area, including the infauna, also presumably breed there.

10.1.3. Birds

The coastline and islands of Nova Scotia provide important breeding habitat for fourteen species of marine birds, the most abundant of which are herring and black-backed gulls, terns and cormorants (Section 9.5.1). The rocky shorelines and cliffs of islands and other isolated coastal areas provide protection from predators and are adjacent to rich foraging areas for herring and black-backed gulls, cormorants, common and Arctic terns, storm-petrels and blue herons (Table 23). Common eiders are the only sea duck that regularly breeds on the coast, although red-breasted mergansers may also occasionally nest on coastal islands (Breeze et al. 2002). Eiders feed by diving for sea urchins, crustaceans and molluscs. Red-breasted mergansers feed on fish, molluscs and crustaceans. Three species of dabbling ducks (Table 22) nest in freshwater wetlands but also in salt water marshes, feeding on aquatic plants, small crustaceans and insets (Breeze et al. 2002).

Some shorebirds nest on the sandy, coastal beaches. Roseate terns, an endangered species (Section 9.5.5), nest on small offshore islands and inlets with three islands accounting for 94% of the population (Brothers Islands, Yarmouth Co., Grassy Island (Mahone Bay) and Country Island complex (Stormont Bay). Piping plovers, also an endangered species (Section 9.5.5), nest on white sand and pebble beaches with known nesting sites on the South Shore, Eastern Shore and Cape Breton (IBA 2011, Schaefer et al. 2004, McCullough et al. 2005). Several pairs of willets have been observed nesting in the saltmarsh habitat between Hartlen Point and Clam Bay (McCullough et al. 2005).

Table 23. Inshore breeding areas for seabirds (compiled from Breeze et al. 2002; McCullough et al. 2005; Important Bird Areas (IBA 2011).

Species	**Habitat**	**Nesting range (IBA locations)**
Piping Plover	Sand, pebble beach	Southwestern Nova Scotia (Cape Sable; South Shore; Musquodoboit)
Semi-palmated plover	Coastal beaches	Southwestern Nova Scotia
Leach’s Storm Petrel	Open sea, coastal	Coastwide (Pearl Island, Bon Portage, Country Island, Eastern Shore Islands)
Guillemots, Kittiwakes, Atlantic puffins, Razorbills	Steep cliffs, rocky shores	Southwestern Nova scotia and Cape Breton (Bird Islands)
Eiders	Summer, nests on coastal cliffs, rocky shores	Coastwide (Eastern Shore Islands)
Dabbling ducks (Green-winged Teal, Northern pintail, Black ducks)	Salt marshes	Coastal marshes, wet lands and offshore islands (Musquodoboit and South Shore)
Red-breasted Merganser	Rocky shores of coastal islands	n/a
Arctic Tern	Open sea, coastal	Eastern and South shores (Country Island)
Cormorants	Coastal cliffs, rocky shores	Bird Islands, Basque Islands, Harbour Rocks, Northern and Southern Head, Portnova, Fourchu Head
Common Tern	Coastal cliffs, rocky shores	Eastern and South shores
Roseate Tern	Coastal cliffs, rocky shores	Eastern and South shores (Country Island)
Black-backed Gull	Coastal cliffs, rocky shores	Coastwide (Scatarie Island, Northern Head, Southern Head, Portnova)
Herring Gull	Coastal cliffs, rocky shores	Coastwide
Willetts	Saltmarshes	Eastern Shore
Blue Heron	Coastal areas, rocky shores	Coastwide, islands

10.1.4. Marine Mammals

Grey seals are a coastal species that hauls out on reefs or on the beaches of isolated islands (DFO 2011d). Historically, they were abundant and widely distributed along the Atlantic coast and Gulf of St. Lawrence until hunted to near depletion in the mid 1800s, but they have since recovered (Section 9.4.1). The largest breeding colonies of grey seals are on Sable Island and in the Gulf of St. Lawrence but about 4% of the entire population congregate in small colonies along the coast (Figure 71, Section 9.4.1). A 2007 aerial survey identified five breeding colonies at Noddy Island, Flat Island, White Island, Bowen's Ledge and Hay Island. Minimum pup production was estimated as 2,923 with 87% of the pups born at Hay Island (Lidgard 2007).

Use of the inshore region for breeding by other marine mammals is not well documented. Harbour seals are abundant along the coast, particularly east of St. Margaret's Bay, (Section 9.4.1). Females come inshore in April and May to have their pups on sandbars and in islets, but pupping areas are not well known (D. Bowen pers. comm.). McCullough et al. (2005) reported that the mouth of St. Margaret's Bay is an important calving habitat for white-beaked dolphin between April and June.

10.2. Foraging/Feeding and Overwintering Areas

The sections on planktonic and benthic communities have described the many invertebrate and vertebrate species that spend their entire lifecycle in the inshore region where they fulfill all their life history needs, including the basic need to feed. Several migratory pelagic fish species such as mackerel, tuna and sharks also use the inshore region to feed, entering it as a summer destination or on their way to their summer or wintering grounds (Section 9.3.3). Cetaceans, pinnipeds (Section 9.4) and sea turtles (Section 9.3.2) enter the inshore region, particularly large inlets such as Mahone Bay and St. Margaret's Bay and the approaches to Halifax Harbour to feed on aggregations of their prey. Migrating bird species (Section 9.5.2) use the inshore region for foraging and, during the winter (Section 9.5.3), some inland birds such as Common loons, Canada geese and American black ducks move to the coast where they are joined by marine birds that breed in more northern latitudes but overwinter in the inshore region. Particular areas are noted for their importance to a variety of species, for example the Sidney Bight is known as an overwintering area for migratory populations of cod, plaice, white hake, witch flounder, redfish and herring (Schaefer et al. 2004). The Canso Ledges (Figure 83) is an important feeding area for tuna and marine mammals and supports aggregations of fish, snow crab, seals, porpoises and whales throughout the year (summarized in Gromack et al. 2010).

The food webs associated with inshore habitats are described in Section 11. Information specific to some important species is discussed below.

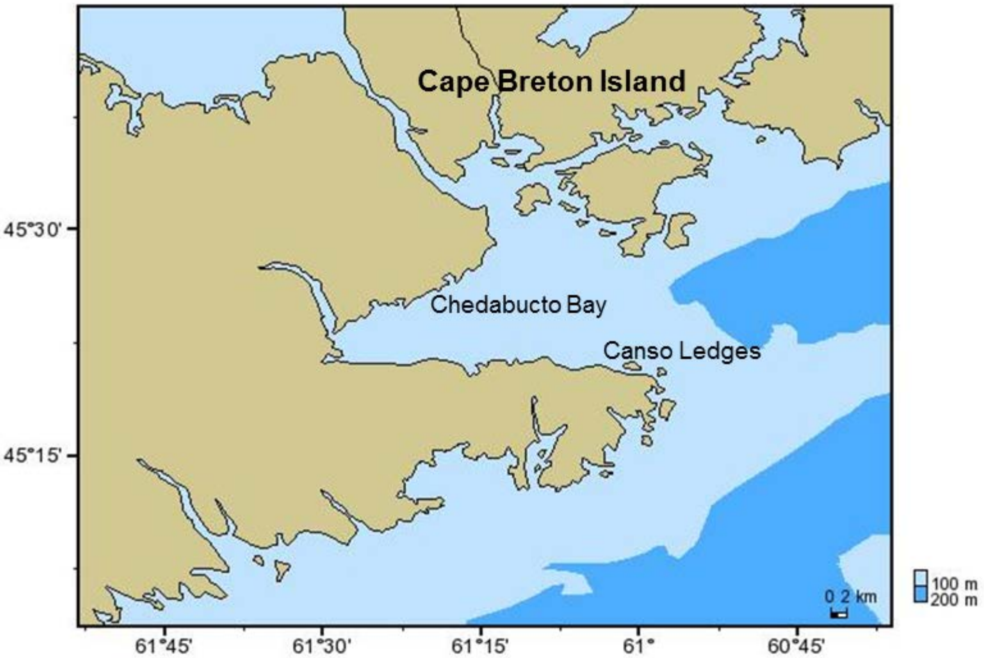


Figure 83. Location of the Canso Ledges and Chedabucto Bay.

10.2.1. Fish

In addition to the estuarine species which rely on the coastal region for all their nutrition (Section 9.2.5.3), many of the diadromous and marine fishes of Nova Scotia spend a portion of their life history foraging in the coastal region. Anadromous species spend time in the estuaries before and after spawning in the rivers (Section 9.3.4) and many groundfish species forage in the coastal regions as juveniles (Section 9.2.5). Both large pelagic (Section 9.3.3.1) and small pelagic (Section 9.3.3.2) species use the coastal region annually, moving inshore in summer to feed. The use of the coastal region by three pelagic species is described below.

Herring feed on various types of zooplankton: euphausiids, copepods, mollusks and fish larvae. As a schooling species, herring follow their prey, from summer feeding areas on the Scotian Shelf to overwintering areas, usually located in nearshore protected waters. Juveniiles and mature fish can form huge schools and large congregations of herring overwinter in Chedabucto Bay and off Chebucto Head near Halifax (Breeze et al.2002; Power et al. 2011). The Sydney Bight area is an important overwintering site for herring from the Gulf of St. Lawrence, Bras d”Or Lakes, Eastern Nova Scotia and Cape Breton area (Schaefer et al. 2004; Gromack et al. 2010).

Schools of juvenile mackerel migrate into inshore areas on their way to the Gulf of St. Lawrence (Section 9.3.3.2); however, little is known about this phase in the mackerel life cycle or of the role coastal habitats play in their growth and survival (Gregoire et al. 2001).

Bluefin tuna migrate to the Scotian Shelf from the Gulf of Mexico (where they spawn) to feed during the summer. Their inshore distribution is known from fisheries catches; they are mainly caught in St. Margaret’s Bay, off Halifax and off Canso (Figure 84). Based on diet studies in the Gulf of Maine and Scotian Shelf (Chase 2002, Golet 2007, Maguire and Lester 2012), their diet in the inshore region likely consists of pelagic species such as herring and mackerel. Chase (2002) suggests the timing of bluefin tuna migrations is associated with seasonal spawning and feeding aggregations of Atlantic herring, and that a northward shift in their distribution in the late 1990s was related to improved foraging opportunities on Atlantic herring in the Gulf of Maine. Aerial surveys in coastal areas of the Gulf of Maine indicate that the distribution of Atlantic bluefin tuna are closely associated with prey distribution (Schick and Lutcavage 2009); therefore, prey species such as herring and mackerel could be considered a required component of tuna habitat (DFO 2011c).

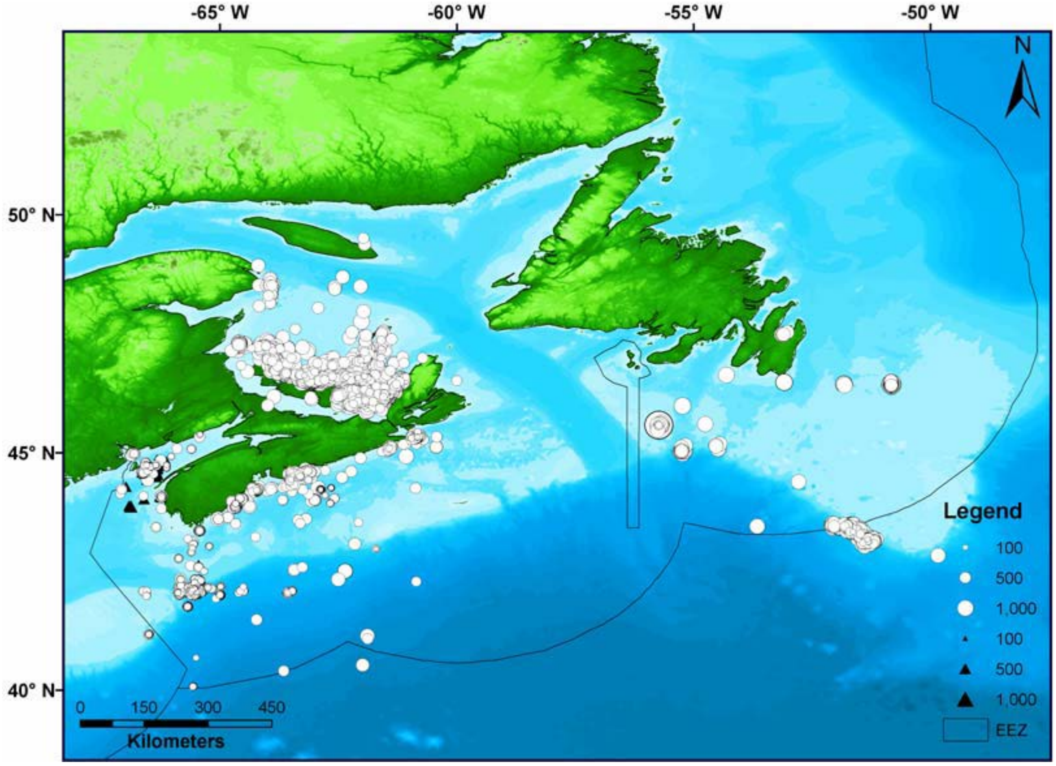


Figure 84.Canadian bluefin tuna catches (lbs) by gear from logbook records from 2000-2009. White circles represent hook and line and black triangles represent electric harpoon. The size of the circles/triangles is proportional to the landed weight. The black line represents the boundaries of the Exclusive Economic Zones (EEZ) (from DFO 2011c).

10.2.2. Invertebrates

Many of the invertebrates living in the inshore region are sessile or have relatively limited mobility compared to fishes, marine mammals and birds. Therefore, the inshore region provides all the food they require to grow and mature. Several of these species such as lobster, sea urchins, soft-shelled clams, scallops and bloodworms support commercial fisheries (Section 9.2.4.1).

Northern shrimp *(Pandalus borealis)* can be found in the largest inlets on the Nova Scotia coast during the winter, in sufficient numbers to support commercial trap fisheries in Chedabucto Bay and experimental traps in St. Margarets and Mahone Bays. These may be portions of the offshore population which migrate inshore in fall as inshore temperatures decline in fall and return to offshore areas as temperatures rise in the spring (Koeller et al. 2007).

The waters surrounding the Bird Islands may be an overwintering area for lobster (Figure 85; Lambert 2010 in Gromack et al. 2010).

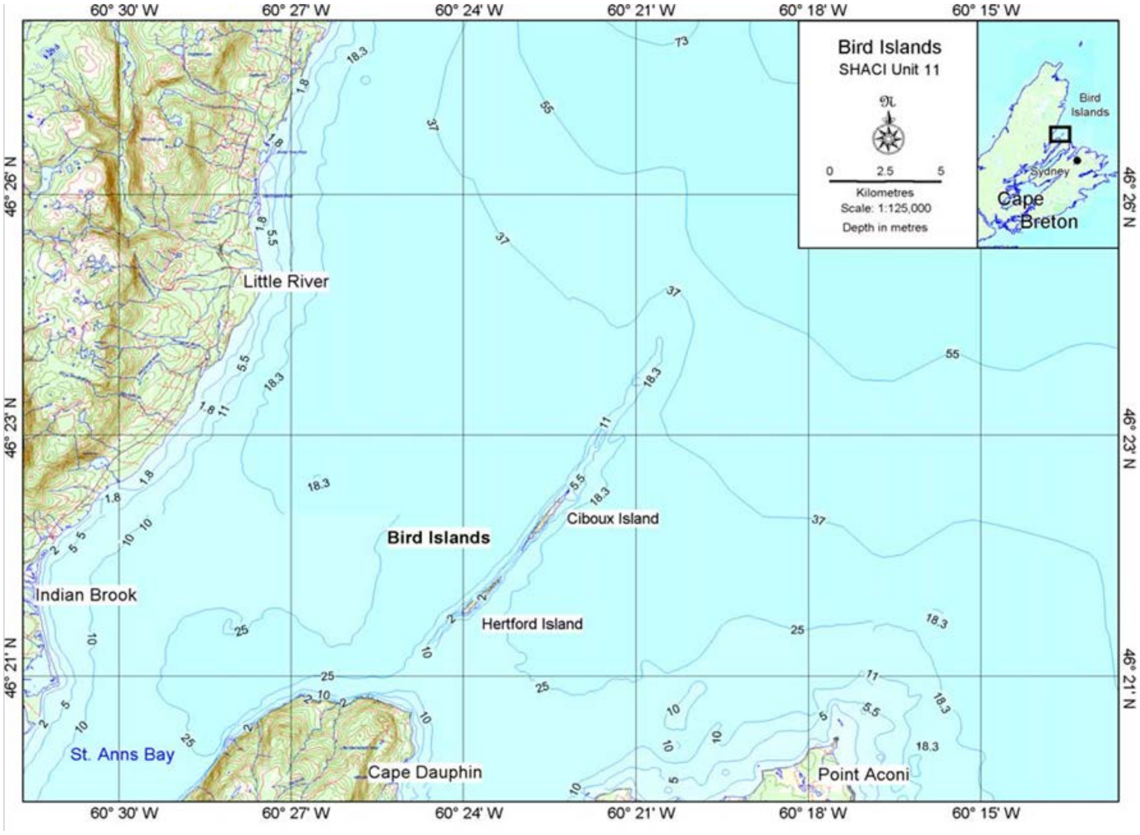


Figure 85. Location of the Bird Islands (from Figure 18-1 in Schaefer et al. 2004).

10.2.3. Birds

The importance of twenty locations along the Atlantic Coast for migrating and overwintering birds was evaluated by Gromack et al. (2010) using Important Bird Area documentation (IBA 2011) and bird distribution and abundance data from CWS databases. Information on specific bird habitats is also available for the Scotian Shelf (Breeze et al. 2002), Halifax County (McCullough et al. 2005), Bras D'Or Lakes (Parker et al. 2007) and the Sidney Bight (Schaefer et al. 2004).

Intertidal habitats such as beaches, saltmarshes, mudflats and eelgrass beds are important stopover and foraging locations for migrating shorebirds, geese and dabbling ducks; several species of bay ducks are associated with shallow protected areas and sea ducks with deeper more exposed coastlines (Gromack et al. 2010). Fish-eating birds including cormorants, great blue herons, osprey, bald eagles, gulls and terns use coastal lagoons, bays and estuaries for foraging (Davis and Browne 1996a).

10.2.4. Marine Mammals

Several cetacean species including fin, pilot, and minke whales, white-beaked and white-sided dolphins, and harbour porpoises visit the inshore region where they are believed to be feeding on herring and mackerel (McCullough et al. 2005). Minke whales occur year-round and fin whales in summer through winter in the outer region of St. Margarets Bay and the approaches to Halifax Harbour. Concentrations of fin whales have been observed in Chedabucto Bay during the winter months when the herring are schooling near the coast (P. Lane Associates 1992 in Breeze et al. 2002). Pilot whales appearing in the inshore waters of Cape Breton in summer months (P. Lane Associates 1992 in Breeze et al. 2002) may be feeding on squid, mackerel, silver hake and herring, based on diet studies in Newfoundland and the Gulf of Maine where similar prey populations occur.

Inshore population of harbour and grey seals feed in the inshore area on herring, cod, pollock, squid, mackerel and capelin (McCullough et al. 2005).

10.2.5. Marine Turtles

Leatherback turtles (listed under the *Species at Risk Act* as Endangered species) migrate from their Caribbean nesting grounds to forage on jellyfish and other gelatinous zooplankton in the shelf and coastal waters of Atlantic Canada from May to November (Bleakney 1965, James et al. 2005a, 2005b). They mainly occur on the shelf but have been observed inshore in southwestern Nova Scotia, near St. Margarets Bay and the approaches to Halifax Harbour (Chebucto Head, Eastern passage), Canso area, Sydney Bight and northern Cape Breton (Schaefer et al. 2004, McCullough et al. 2005, James et al. 2005b, 2006) between early July and mid-November. Variations in temporal patterns in reported sightings may reflect a response of leatherbacks to sea surface temperatures, with turtles entering more northern locations when temperatures reach a seasonal high (James et al. 2006). Most turtles were reported inshore from the continental shelf break and mean SST associated with sightings was 16.6°C (James et al. 2006). Spatio-temporal patterns in sightings may also reflect a response by leatherbacks to seasonal changes in gelatinous zooplankton prey distributions (Section 9.3.2). James et al. (2006) suggest that Canadian waters support one of the highest summer and fall densities of leatherbacks in the North Atlantic, and should be considered critical foraging habitat.

Loggerhead turtles are more common further offshore in water temperatures of 22°C or above. There are a few records of sightings along the Atlantic Coast, including two animals captured near Halifax Harbour (COSEWIC 2010b, McCullough et al. 2005).

10.3. Migration Routes

10.3.1. Fish

The coastal region is a migration corridor for many species. Anadromous species (salmon, alewife, shad, smelt, tomcod, striped bass and lamprey, Section 9.3.4) pass through the coastal area enroute to spawn in freshwater rivers. Adults move into the rivers to spawn in spring and leave these rivers in the summer and fall after spawning. Juvenile salmon and lamprey have an extended freshwater residency, but the offspring of other anadromous species enter the estuaries of their natal rivers by the summer or fall. Maturing American eels migrate seaward from rivers and estuaries in late summer and fall. Smelt migrate in response to water temperatures, moving into cooler, deeper water during the summer months and into estuaries in the fall (Section 9.3.4).

A well known migratory route through the inshore waters of Nova Scotia is that taken by mackerel which migrate northwards in May and June along the Nova Scotian Atlantic coast bound for the Gulf of St. Lawrence, its major spawning grounds. In some years when nearshore waters are warm the mackerel travels close to land and some venture into bays and inlets (Section 9.3.3.2). Adults arrive first in June, followed by immature animals (Grégoire et al.1999).

Bluefin tuna are wide ranging pelagic fish that enter Canadian waters in June and remain there until December (Section 9.3.3.1).

10.3.2. Birds

Shorebirds (plovers, sandpipers, godwits, yellowlegs, ruff, dunlin and willets) and marsh birds (herons, rails, bitterns, snipe, egrets) use coastal habitats as stopovers on transcontinental migrations and some also breed in the area (Table 20; Table 22; McCullough et al. 2005). Tidal marshes are used by Willets for nesting, and by Greater and Lesser Yellowlegs for foraging. Migrants appear during March and June and leave by October.

10.3.3. Marine Mammals

Several whale species use the Scotian Shelf as a migratory route to other feeding areas in the Gulf of St. Lawrence or off Newfoundland. Any cetacean species found within the Gulf of St. Lawrence could be found in Sydney Bight since the Cabot Strait is a known migration route for many species travelling in and out of the Gulf of St. Lawrence (Wimmer 2002 in Schaefer et al. 2004).

10.3.4. Marine Turtles

Leatherback turtles migrate through, or seasonally reside off, Atlantic Canada between May and November (Section 9.3.2).

10.4. Nursery/ Rearing Areas

The early life stages of any species are the most vulnerable. Nursery areas are locations in which the food supply, protective cover, bottom type, salinity levels, water temperature and other factors are all conducive to the development of a particular species. The inshore region contains important nursery areas for the young fish and shellfish of many species, including species usually found offshore, such as white hake and pollock.

10.4.1. Fish

Inshore areas have been shown to be important nursery areas for many species of juvenile demersal fish including Atlantic cod, white hake, winter flounder and pollock. Newly settled juvenile demersal fish in nearshore environments actively select bottom habitats consisting of various combinations of particle size and complexity to enhance their growth rate and survival from potential predators (see references in Lineham 2004 and Section 11.3 for discussion of shallow habitats as refuge for juvenile fish species). The inshore offers refuge from predation by providing cover in its rocky shores, its macrophyte beds and sheltered inlets. The distribution patterns of settling fish are determined by habitat-based differences in predation rates; complex habitats offer more protection whereas simple habitats lead to higher vulnerabilities (Juanes 2007). For example, a study in St. Margaret’s Bay showed that small cod survival was higher in structurally complex habitats, survival was highest in rocky and reefs and cobble bottoms, and growth highest in eelgrass beds (Tupper and Boutilier 1995a). Pollock spend the first 2 years of their life in the inshore where they are dispersed through coastal habitats, but they prefer areas with cover. This is an example of a common ontogenetic shift, where young fish inhabit shallow waters, then move to deeper water as they age. Other species include American plaice, which spend time inshore in the Sydney Bight area between April and May (Locke 2001).

Examples of important nursery areas for fish species are the Cape Sable Island area for herring, alewives and sand lance (O’Connor 2008) and the area around the Bird Islands in Sydney Bight (Figure 86) for Atlantic cod, American plaice, yellowtail flounder and winter flounder (Schaefer et al. 2004; Lambert 2006). Extensive kelp beds provide primary productivity and numerous species of fish and invertebrates contribute to secondary productivity (see Section 9.2.2 for review of role of macrophytes as protective habitat).

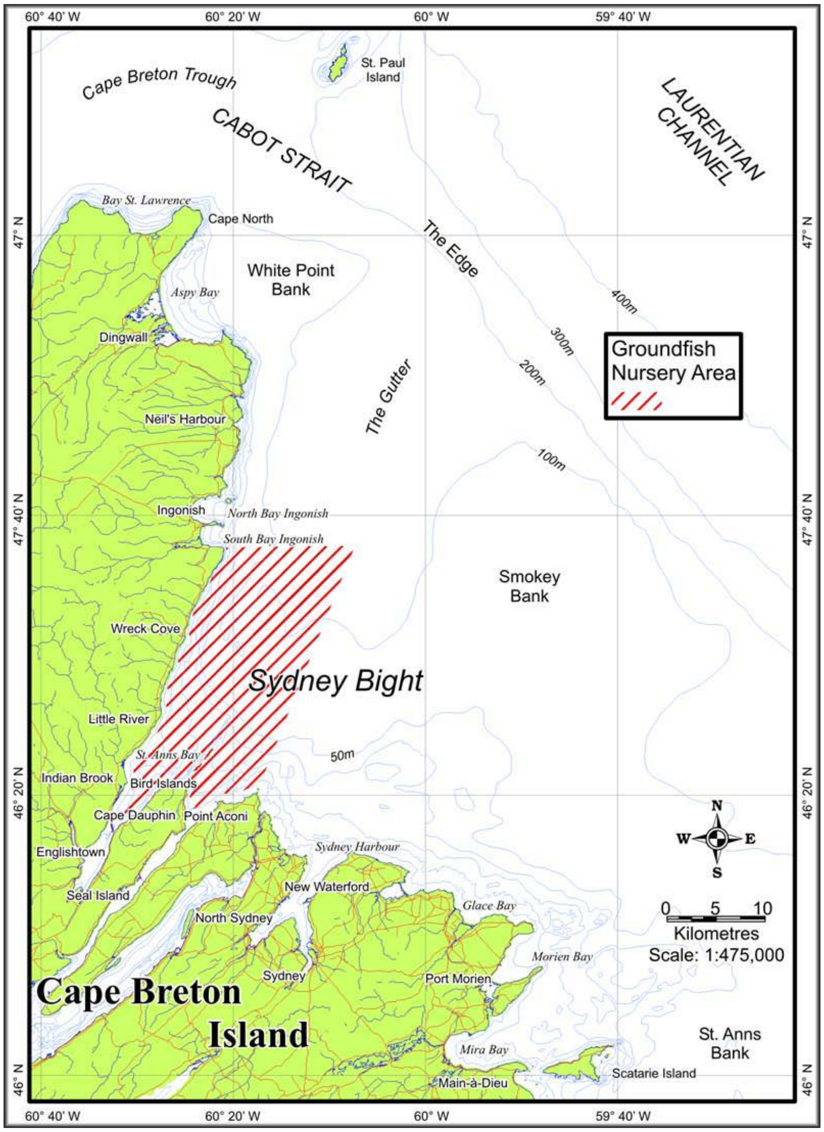


Figure 86. Groundfish nursery areas in Cape Breton (SHACI Unit 11). Figure 8-3 in Schaefer et al. (2004).

10.4.2. Invertebrates

Many of the invertebrates inhabiting the inshore region are relatively sessile as adults. Their strategy for dispersal is to produce pelagic larvae which settle onto suitable substrate and develop the features required for a benthic existence. Suitable substrate depends on the organism. Newly settled lobster larvae prefer cobble bottom that provides shelter. Macrophytes are unique to the inshore and provide permanent seasonal and nursery habitat for a host of species and foraging for sea urchins (see Section 9.2.2 for review of role of macrophytes as protective habitat).

10.4.3. Birds

The many species of marine birds that breed in the inshore region choose nesting locations that provide protection for their nestlings and that are adjacent to rich foraging areas (Section 9.5.1). These include rocky shores, cliffs, islands and saltmarshes (Table 22). For example, the Bird Islands (Figure 86) provide nesting habitat to the largest Great cormorant population in in North America (Gromack et al. 2010). The coastal islands have cliff environments ideal for nesting birds (Schaefer et al. 2004) – other sea birds also nest on the Bird Islands and sea ducks also occur in high numbers. The surrounding waters are rich in marine life for foraging birds.

10.4.4. Marine Mammals

As noted previously, only harbour and grey seals and possibly white-beaked dolphin are known to breed and produce their offspring within the inshore region (Section 9.4).

10.5 Critical Habitat (under the *Species at Risk Act*)

Several vertebrates occurring in the inshore region are protected under national legislation (Table 24) but no Critical Habitat has been identified under the *Species at Risk Act* for the inshore Scotian Shelf as of 2013. Critical Habitat has been identified for two whale species on the offshore Scotian Shelf (i.e., Roseway Basin for North Atlantic Right Whale, and the Gully, Shortland and Haldmind canyons for Northern Bottlenose Whale).

Table 24. Species protected under the Species at Risk Act occurring in the inshore region.

Species	Comments
Atlantic Whitefish	Atlantic Whitefish only occurs in the Petite Riviere watershed (including Hebb, Milipsigate and Minamkeak Lakes, no critical habitat in Marine area.
Atlantic Salmon (Inner Bay of Fundy population)	The Inner Bay of Fundy population of Atlantic Salmon is listed on Schedule 1 of the Species at Risk Act. Freshwater Critical Habitat has been identified in Nova Scotia but outside of the study area.
White Shark	Listed in July 2011, no critical habitat has been defined.
Piping Plover	Under jurisdiction of Environment Canada. A number of sites have been identified as critical habitat for Piping Plover, *melodus* subspecies, in coastal Nova Scotia. A list of these is provided in the Recovery Strategy (Appendix C).
Roseate Tern	Under jurisdiction of Environment Canada. Critical habitat identified in the amended Recovery Strategy includes Country Island and The Brothers, NS, including the entire terrestrial habitat of both islands, as well as aquatic habitat extending 200 m seaward from the mean high tide line of each island.
Leatherback Turtle	Critical habitat is in the process of being defined.

PART D – ECOSYSTEM DESCRIPTION

11. ECOSYSTEM RELATIONSHIPS

Contributed by D. Themelis and A. Bundy

Ecosystems occur at different spatial scales and consist of an interacting biological community together with its abiotic environment, interacting as a system. They are controlled both by internal and external factors, and are defined by the network of interactions among organisms, and between organisms and their environment. These interactions maintain the structure and services produced by an ecosystem and can be grouped into two types. The first are the links between the external factors and the biology, i.e. the physical-biological interactions such as the preferences or tolerances of organisms for particular ranges of temperatures, salinities and sediment sizes as described in Part C. The second are biological interactions and include primary production (production of biomass) and decomposition, competition for resources and trophic (predator-prey) relationships. Organisms within the ecosytem are linked together through nutrient cycles and energy flow.

The inshore area considered in this report (Figure 1) includes a range of different habitat types along the coast and at different depths, each supporting a different ecosystem type. The immediate coastal area consists of a variety of habitats: rocky shores and headlands, large bays and inlets, estuaries, salt marshes and sandy and rocky beaches, forming a heterogenous mosaic of functional ecosystems. However, these ecosystems are subject to common large-scale influences, such as longshore currents and seasonal temperature and nutrient cycles. Materials (primary production, detritus, plankton and migrating organisms) are exchanged between habitats and also between the inshore and offshore region.

Results from the Inshore Ecosystem Project indicate a clear depth gradient for several invertebrates: lobsters and rock crab are within the 10-30 m depth zone; rock crab, whelks and fish in mid depths (30-50 m); and toad crab and snow crab in deeper water (50-100 m) (denHeyer et al. 2010). Taken together, the results from the field studies in the Inshore Ecosystem Project, suggest that there are 3 zones within the 25 km inshore area, to be confirmed by further analysis: the coastal fringe, mid-depths (between 10 and 40 m) and offshore (greater than 40 m). Identification of these depth zones, and their associated habitats and biota, will be a valuable tool for integrated management of the inshore.

Within the depth zones, habitat type and exposure also influence species distribution. Habitat types are most apparent in the coastal fringe and include the intertidal zone, salt marshes, beaches, mudflats, rocky shores, inlets and estuaries. Habitat type also influences the composition of organisms living in the mid-depth zone, but diversity is higher because exposure to waves and ice is less severe and the seasonal range in temperature and salinity is narrower. Macrophytes, a major feature of the inshore region, disappear from depths below the photic zone at around 35 m. Therefore, the inshore area deeper than the photic zone has many of the same attributes as the deeper Scotian Shelf waters. It receives nutrients from the shallower zones, but macrophytes and other shallow water species are lacking, and the species composition is comparable to the composition on the Shelf (Bundy 2007).

The following sections first describe the large scale external factors that influence the inshore area of Atlantic Nova Scotia. Then, the different ecosystem types are discussed along with their plant and animal assemblages and biological interactions.

11.1. Physical-Biological Interactions

11.1.1. Nutrient Cycles, Blooms, Upwellings

Wind forcing over the shelf and within the inlets can alter the temperature and salinity structure through mixing, upwelling and downwelling. Winds from the southwest, the prevailing direction during the summer months, are most effective in generating coastal upwelling; winds of the opposite direction drive downwelling (Petrie et al. 1987). Coastal upwelling causes surface waters to move offshore and be replaced by colder, saltier waters from below. This process can also cause extensive flushing of coastal inlets by offshore waters (Strain 2002).

There is a well-recognized nutrient cycle in the inshore areas of the Scotian Shelf. The main source of supply of phytoplankton nutrients (nitrogen, phosphorus and silicon) is through water exchange with the adjacent coastal waters. Input from the offshore generates high concentrations of nutrients in inshore surface waters in winter. In most bays or inlets, these are depleted by the spring phytoplankton bloom and remain low through the spring/summer period to be replenished in the fall when mixing increases. Nitrate is the most rapidly and extensively removed usually to levels that would limit primary productivity during most of the spring/summer period. This is the normal seasonal cycle of nutrient concentrations that is seen in temperate waters. A few locations along the Atlantic coast of Nova Scotia show elevated nutrient concentrations that can be attributed to anthropogenic sources but more show elevated concentrations in bottom waters in summer and fall that are related to natural sources (Section 8.5).

The annual cycle of phytoplankton occurrence is dominated by a strong peak in the early part of the year (the spring bloom) which is brought to an end by exhaustion of nutrients (nitrate, phosphate). Consequently, during summer there is often a lull in phytoplankton production (Section 9.1.4). However there is usually a second bloom in the fall. Hazardous algal blooms (HABs) are frequently associated with diatoms and dinoflagellates (Anderson et al. 2000; and the resulting high biomass of phytoplankton can deleteriously alter habitat, result in fish kills and accumulation of toxins in the food chain (see Section 9.1.4).

The Nova Scotia Current, with waters originating from the Gulf of St. Lawrence, plays a large role in the oceanography of the inshore Scotian Shelf (Section 7.3), creating a gradient of cool fresh water in the north and warmer, more saline water in the south. Conductivity and temperature at depth profiles (CTD) taken on inshore-offshore transects from Cape Breton to Cape Sable indicate that stratification of the nearshore region decreases from east to west (Horne 2007). This should increase the nutrient supply in the west which should increase the food supply. Having said this, there is no apparent east-west gradient in community structure of phytoplankton (Section 9.1.4) or zooplankton (Section 9.1.5; Beveridge 2005), although these do change with season. All inlets along the shoreline are subject to common offshore forcing, which may deliver nutrients, but may also replace a substantial proportion of water in inlets. Further exchanges occur when processes reverse after strong winds relax. Inshore-offshore CTD transects showed increases in salinity, stratification and integrated chlorophyll biomass seaward, with the transition between onshore and offshore oceanographic conditions occurring around the stations located at 30-50 m depths (Horne 2007).

11.1.2. Physical-Biological Influences: Habitats

The geophysical classification developed by Greenlaw et al. (2011) to classify inlets along the Atlantic coast of Nova Scotia (Section 4.1) was based on abiotic factors, identified through a literature review, important to community structure or species distributions (Table 25). Depth, habitat, temperature and exposure influence species distribution. Preliminary results from the Inshore Ecosystem Project indicate that, of the species sampled along the coast of Nova Scotia, many are ubiquitous, such as lobster, rock crab, and green crab although snow crab has a southern limit around the mid-South Shore (Section 9.2.4). Fish communities are also geographically similar, with differences associated with habitat type rather than geographical location (O’Connor 2008).

Table 25. Important physical variables that determine inlet types in the nearshore (from Greenlaw 2009).

Abiotic Variables	Importance
Sediment Composition	Identified as major contributor to spatial community patterns Homogeneous sediments have lower diversity.
Salinity	Estuarine habitats (in which salinity at least occasionally below 30 ppt) are unique with productive and distinct species.
Exposure	Mechanical stress on organisms. Wave exposure influences attachment ability, ability to withstand scouring.
Depth/Volume	Depth characteristics are important as they influence the mixing and warming regimes, and tide and wave speeds entering an embayment. Depth is associated with changes in light intensity, temperature, oxygen, salinity and energy
Slope	Influences an organism’s ability to colonize an area
Latitude	Latitude affects the major temperature regime (i.e. temperate or tropical) of the region, and systems are subject to spatial autocorrelation
Sill/Non-sill	Sill at the mouth can affect flow rates entering the system, flushing rates, mixing regimes, temperature and substrate type
Temperature	Broad circulation patterns have a direct effect on the temperature of a system: temperatures influences biodiversity and community composition of the marine nearshore. Variability in temperature is one factor that affects physiological stress experienced by organisms

Abiotic Variables	Importance
Catchment Properties	Catchment properties that can influence the inlet include catchment-borne substrate, mineral composition of substrates, and permeability of the substrates.
Current	Currents (tidal and wind driven) determine to a large degree the nature of the bottom substrate, they influence the stability of the sediment, the nature of the food supply for benthic organisms and, in extreme cases, they may impose direct physical stresses on epifaunal communities. Low seabed disturbance = higher competition and suppresses diversity. In very high frequency disturbance, diversity is also suppressed due to the high variability of the environment which increases reproductive stress and decreases the ability of the community to mature or be re-colonized before the next disturbance event.

11.2. Biological Interactions

Marine ecosystems typically span four to five trophic levels ranging from primary producers and grazers to upper level predators and include detrital and other feedback loops (Zwanenburg et al. 2006). Foodwebs for a rocky shore and sandy beach are illustrated in Figures 87-88 using a simple three level trophic structure of low (primary producers, detritus, zooplankton), intermediate (benthic and pelagic fishes and invertebrates) and high trophic levels (birds, marine mammals, large fishes) used by Gaichas et al. (2009) to characterize the Gulf of Maine. Depending on the habitat, the primary producers at the base of the food webs of the inshore region are pelagic phytoplankton, benthic microalgae or macrophytes (kelp, rockweeds, eelgrass and salt marsh). Detritus is derived from phytoplankton or macrophyte production but enough inshore marine organisms feed directly or indirectly on detritus for it to have its own food web.

Macrophytes (seaweeds, salt marsh eelgrass) can be considered a defining biological feature of the inshore since they occur in a wide range of habitats, from very sheltered brackish waters to the full salinity of extremely wave exposed outer coasts (Section 9.2.2). Substrate type determines the two major macrophytes: exposed intertidal and shallow subtidal rocky shores are dominated by rockweeds while soft sediments support eelgrass. Rockweeds and eelgrass create distinct three-dimensional habitats that provide refuge, settlement and foraging opportunities for wide range of species (Rangeley and Kramer 1995; DFO 2009b). Production levels are similar between the two habitats but rockweed has higher standing biomass and therefore greater nitrogen and carbon storage, even when accounting for rhizomes and roots of eelgrass (Schmidt et al. 2011).

11.2.1. Rocky Shoreline

These are areas of stable bedrock on the exposed coastline of the mainland and coastal islands (Section 4.1). Species living here must be able to withstand intense wave action and periodic desiccation in the intertidal zone, and the degree of exposure to the waves of the open Atlantic ocean is a feature that influences both habitat and community composition. Moore and Miller (1983) surveyed 4900 km of shore from Cape Sable Island to northern Cape Breton, half of which was rocky, the other half, soft bottom. Their primary conclusions were that wave exposure and the maximum depth of rock substrate determines the distance seaweed can grow from shore, that wave exposure and sea urchin grazing controls seaweed cover, and that the species mix of large seaweeds changes west to east.

The dominant vegetation of rocky shores is brown algae (Section 9.2.2). The largest subtidal seaweeds are the kelps which create a biogenic environment for many species of invertebrates and finfish to live within, providing cover and shelter, in particular for juvenile fishes like herring. The edges of seaweed beds are prime locations for catching lobster (Breeze et al. 2002). Kelp act to increase the supply of drifting phytoplankton and algae by slowing local currents and generating turbulence. A key trophic process that controls kelp production is provided by sea urchins (*Strongylocentrotus droebachiensis)*. Sea urchins modify the structure and function of this system by grazing on kelp, (Section 9.2.4.1), mediating a stable cyclical transition between two alternate states: one where rich algal beds are dominated by kelp and one described as barren, where kelp has been removed through predation by sea urchins. However, the spread of an invasive species *Codium fragile* (dead man's fingers) to Nova Scotia in the 1990s threatens this cycle (Section 9.2.2).

Rocky shoreline and the associated macrophytes provide food and habitat for a wide variety of invertebrate and vertebrate species. The dominant primary production is by macrophytes which directly support populations of herbivorous invertebrates and break down to supply detritus and nutrients to filter feeders and phytoplankton (Figure 87). Community composition is influenced by both physical stressors (waves, exposure, ice scour) and biological processes. The abundant invertebrates are hard-shelled organisms such as barnacles, sea stars, sea urchins, mussels and crabs. Predation by dogwhelks on barnacles and mussels controls community structure in sheltered sites whereas competition between barnacles and mussels is a major factor at exposed sites (Mann 2000). Mussels are mainly found in crevices and increase in abundance from low intertidal to mid-intertidal; probably excluded from more intertidal areas by wave exposure and ice scour (Scrosati and Heaven 2007, Tam and Scrosati 2011). The distribution of dogwhelk, which preys on mussels, is correlated with mussel density (Tam and Scrosati 2011).

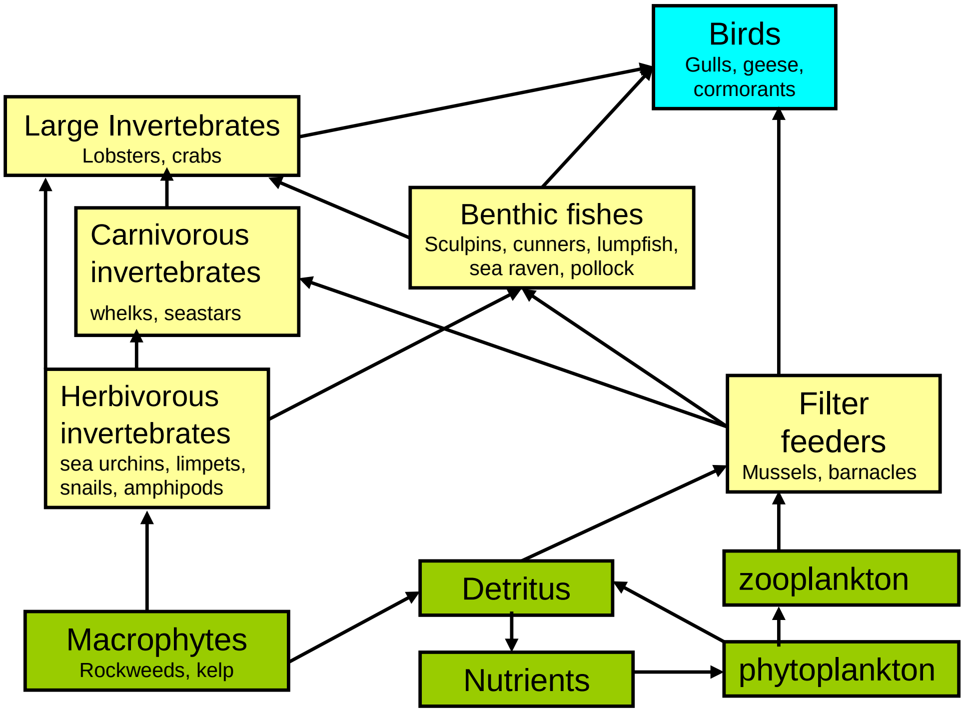


Figure 87.Generalized foodweb for rocky intertidal and subtidal zone. Box colour based on a three trophic level grouping: low (green), intermediate (yellow) and top (blue) trophic levels.

Crabs on rocky shores in the Gulf of Maine show differences in vertical distribution that may be related to differential predation risks between the intertidal and subtidal areas. Donahue et al. (2009) found that green crabs were more abundant in the intertidal zone, while both rock and Jonah crabs were more abundant in the subtidal. They propose that the distribution patterns are due to differential vulnerability to predation by gulls in the intertidal and by lobsters and fish in the subtidal, rather than preferred prey distribution, indicating predominant top-down control of crab distribution.

Fish species include cod, pollock, shorthorn sculpin, cunner, sea raven and lumpfish (Horne and Campana 1989; O'Connor 2008) but the distribution of individual fish species is affected by the wave energy gradient. Lumpfishes, rock gunnels, sea ravens and sculpins have adaptations for physically challenging environments such as adhesive organs, body plans or behaviour (Jordaan et al. 2011). The fish species found in the highest energy environments are pollock and rock gunnels (Jordaan 2010). Pollock move freely into the intertidal zone to feed on crustaceans and molluscs (Rangeley and Kramer 1995), while cod appear to avoid the zones of highest mixing by remaining at depths greater than 4 m (Jordaan 2010). Lobsters are mobile predators which feed within the intertidal zone (Jones and Shulman 2008). Lobster recruitment and the amount of lobster caught in commercial fisheries increase from inshore to offshore. Moving eastward along the Nova Scotia coast, landings, which are related to lobster productivity, are highest in southwest Nova Scotia, decrease from Halifax through the Eastern Shore, and increase again from the Canso area through Cape Breton.

Rocky shores, especially those associated with small uninhabitated rocky islands and islets, provide habitat for many marine breeding bird colonies (Section 10.1.3) that feed upon the rich assortment of invertebrates found in the intertidal zone. Harbour and grey seals use these areas to haulout (Section 10.1.4). The threats to rocky shorelines are mainly from winter storms and ice conditions, sewage and eutrophication, algae harvesting, and recreational activities that disturb nesting birds.

11.2.2. Boulder and Cobble Beaches

Cobble beaches occur under similar exposure conditions as rocky shorelines, but sediments range in size from boulders, which are fairly stable in high energy conditions, to pebbles, which are easily moved by wave action. Boulders provide a more stable surface than cobble for the attachment of macrophytes and the spaces between boulders provide shelter for animals. Cobbles and pebbles move in areas with high wave energy, stripping off colonizing macrophytes. Primary production is low because colonization by macrophytes is limited. Energy also enters from primary production by plankton and suspended organic detritus from adjacent intertidal habitats. The invertebrates occurring intertidally and subtidally are barnacles, amphipods, isopods, periwinkles, dog whelks, green crabs and seastars. Abundance is low in areas of high wave exposure and increases in mid to low energy environments (Davis and Browne 1996a). The periwinkles, limpets and chitons graze upon the foliose and filamentous ephemeral algae on cobbles, but are ineffective in consuming the larger fleshy algae, such as fucoids and kelps (Scheibling et al. 2008). Thus, physical and biological disturbances interact to shape the macroalgal assemblage, resulting in a low lying algal bed dominated by *Fucus evanescens* and *Chondrus crispus*.

Fish species collected on beaches with sediment size gradients ranging from boulders to pebbles include pollock, rock gunnels, sculpins, sea ravens, sandlance and grubbies (Horne and Campana 1989, O'Connor 2008). Juvenile fish abundance, total fish abundance and the number of species were all observed by O'Connor (2008) to increase with decreasing substrate particle size (boulder to pebble-cobble substrates). Boulder and cobble shores support colonies of seabirds and may function as haulout areas for marine mammals (Section 10.1.4).

11.2.3. Sand Beaches

Sandy beaches are areas of sand exposed between extreme high tide and extreme low tide marks. The beaches on the Atlantic coast are mainly storm beaches, formed from the impact of high energy waves on exposed areas and sandy sediments from eroding shorelines (Section 5.1, CBCL Limited 2009). Primary productivity is mainly limited to unicellular algae which live between the sand grains (Stewart et al. 2003). Also, many sandy beaches are near rocky areas with seaweed beds or sheltered areas of seagrass. The currents bringing sand to the beach bring detritus in the form of particulate or dissolved organic material (Mann 2000). The organic material is filtered out as the water drains back through the sand and supports a rich interstitial fauna of bacteria and meiofauna (animals <0.5 mm). Large macrophytes may be deposited on the surf line as wrack. As these decompose, they support large populations of bacteria and crustaceans. These invertebrates are consumed by many types of shorebirds (Figure 88).

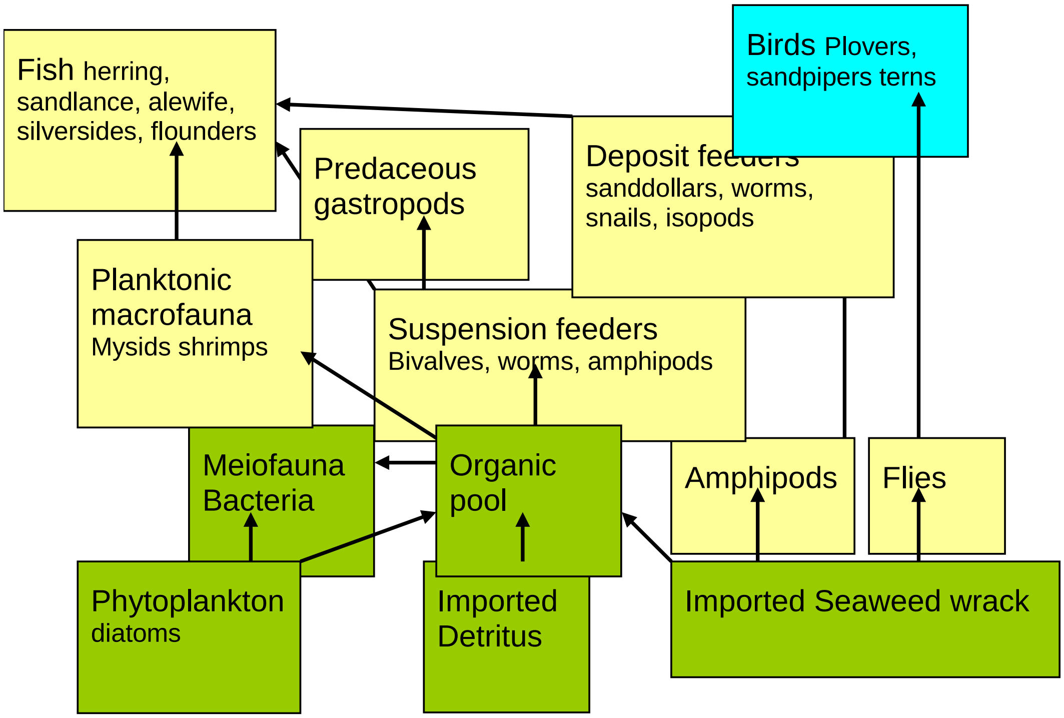


Figure 88. Generalized foodweb for sandy beach and subtidal zone (adapted from Mann 2000). Box colour based on three trophic level groupings: low (green), intermediate (yellow) and top (blue) trophic levels.

The distribution of animal species varies with location and tide level: at low tide levels, animals have to burrow to maintain their position on the beach due to the motion of sand caused by wave action and currents. Species diversity is low in the intertidal zone, and increases with increasing depths. In general, crustaceans (amphipods and isopods) dominate the upper intertidal areas whereas mollusks dominate lower down (Mann 2000). Polychaete worms (*Dispio uncinata, Nephtys bucera*) and molluscs (*Tellina agilis, Spisula solidissima, Ensis directus and Lunatia heros*) occur at low-tide level on more exposed areas. Amphipods (*Talorchestia* spp) are common at the high-tide mark feeding on organic material in weed wrack line. Between mid and low tide levels, isopod and amphipod crustaceans (*Chiridotea caeca, Haustorius canadensis*) are found. Ribbon worms (*Cerebratulus* spp.), polychaetes (*Nereis* spp. and *Nephtys* spp.), bivalves (*Mya arenaria, Macoma balthica)* and mud snails (*Nassarius, Ilyanassa*) are typical in sheltered areas of sand and sandy mud (Davis and Brown 1996a). Subtidally, sandy substrates provide habitat for schooling fish species such as herring, sandlance, silversides and alewife (Bundy 2007b, O'Connor 2008).

Beaches provide breeding areas for Piping Plovers, Arctic Terns and Roseate Terns, and food and habitat for migrating shorebirds which feed upon the variety of invertebrates living in the sand (section 9.2.4).

Sandy beaches occur all along the Atlantic coast. Because sand substrate is very transportable, sandy beaches are highly sensitive to coastal development and construction that affects the longshore transport of sand, as well as sea level rise and the impact of increasing storm events resulting from climate change (CBCL 2009).

11.2.4. Mudflats

Mudflats are an intertidal habitat that occurs in all inlets and estuaries around the coast of Nova Scotia (Section 5.1). Sediment size, sediment chemistry, inundation cycle, salinity, frequency of disturbance, and latitude are all determinants of the biotic community within flats. Primary production is limited to diatoms and filamentous algae and occasionally seaweeds attached to intertidal rocks or subtidal bedrock. Most energy enters the system from the plankton, or as fragmented and decaying salt marsh plant detritus from adjacent tidal marshes (Davis and Browne 1996a). Bacteria are important in decomposition and as a food source (Stewart et al. 2003). The sediment is stabilized by secretions and growth of mats of microscopic algae, bacteria and fungi which grow on the flats (Stewart et al. 2003).

The mudflat infauna are primarily detritus-feeding; species such as polychaete worms (*Spiophanes wigleyi, Clymenella torquata*), amphipods (*Corophium volutator*) and soft-shell and hard-shell clams (*Mya arenaria, Macoma balthica*) are particularly common. Scavengers and carnivorous species include polychaetes (*Neanthes virens*), crustaceans (*Chiridotea caeca, Crangon septemspinosus*) and molluscs (*Ilyanassa obsoletus, Lunatia heros*) (Davis and Browne 1996a).

Mudflats are a foraging ground for fish (flounders, tomcod, hakes), crabs, eels and snails at high tide and feeding areas for many migrating shorebirds at low tide. These habitats are sensitive to eutrophication causing suffocation of infaunal species, pollution and mechanical activities such as bloodworm and clam harvesting. Rising sea levels will lead to changes in mud and sand flat distribution and extent (Stewart et al. 2003).

11.2.5. Spartina Salt Marshes

Spartina grows on salt marshes, vegetated mudflats that form where sediment accumulates in sheltered intertidal areas in estuaries, behind spits, bars or islands, and in protected bays (Sections 4.1 and 9.2.2). Poor drainage, limited input of nutrients and accumulation of detritus create conditions favouring *Spartina* spp., which is adapted to living in anoxic sediments. Spartina accounts for much of the salt marsh productivity which is exported as detritus and supports marine food chains further seaward. Other primary producers are phytoplankton, benthic algae and emergent vegetation (Stewart et al. 2003). Marine species living in salt marshes must tolerate wide ranging salinities and temperatures, as well as high levels of suspended sediment. Species include amphipods (*Gammarus* spp.), isopods (*Idotea* spp.), soft-shell and fingernail clams, mussels, periwinkles and polychaete worms. Common fish species are mummichogs, sticklebacks, silversides and eels.

Salt marshes provide fish spawning habitat and nursery areas for larval and juvenile fishes (Stewart et al. 2003). They are important feeding areas for migrating waterfowl in fall and early winter. They are also overwintering and breeding habitats for waterfowl. In addition to a net export of production, they provide waste treatment and buffering against storm and flood events (McCullough et al. 2005).

11.2.6. Seagrass

Eelgrass (*Zostera* spp.) form beds in sand or mud sediments in the lower intertidal and subtidal zones of shallow inlets, often in areas near high-velocity channels. The rate of development of an eelgrass bed is controlled directly by light, temperature and nutrient conditions and indirectly by hydrodynamic conditions. Meadows with high currents and waves are more densely packed (Thayer et al. 1984) and have more root standing crop (Kenworthy et al. 1982).

Eelgrass has characteristics which meet the criteria for an ecologically significant species (DFO 2009b). The beds are highly productive and perform several functions in their environment (Section 9.2.2). They contribute to overall primary productivity of estuaries through production of detritus and through direct feeding by geese, crabs and fishes. They stabilize sediments by the production of rhizomes and roots, and by reducing currents passing through the beds. They act as a nutrient pump by absorbing nutrients from the sediments and releasing them from their leaves into the water (Zieman 1982). The leaves support a large epiphyte community including benthic micro-algae, bacteria and macroalgae. Other organisms living on blades of eelgrass include protozoans (ciliates, flagellates, and foraminifera), nematodes, and copepods (DFO 2009d). Attached animals living on the blades and at the base of eelgrass shoots include bay scallops, crustaceans, sponges, anemones, bryozoans, tube worms, polychaetes, barnacles, and other arthropods and tunicates (DFO 2009d).

Eelgrass beds are important nursery habitat by providing protection from predators, substrate for attachment of sessile stages and an abundant food supply (Thayer et al. 1984). Fish species in general are positively related to eelgrass habitat complexity and there is a strong tendency for mean fish abundance and biomass to be highest in complex habitat, especially in aquatic vegetation. Greenlaw et al. (2011) suggested that mud sites had the highest fish species diversity of all sites sampled on the Atlantic coast because they provided substantial vegetation to shelter fish from predators.

Furthermore, the functional role of eelgrass habitat to support a diverse and abundant fish assemblage appears to be impaired before the habitat is lost completely (Hughes et al. 2002).

Studies in the Gulf of Maine and Newfoundland indicate a a positive relationship between eelgrass density and juvenile (0-group) cod density (Warren et al. 2010). Other fish species occurring in eelgrass beds include tomcod, winter flounder, three spine sticklebacks, cunners, pipefish, silversides and eels. Species such as Brant and Canada Goose, and several duck species as well as marine organisms such as snails and sea urchins also feed on the live shoots of eelgrass (Hanson 2004; Thayer et al. 1984).

Threats to eelgrass include decreased water quality from nutrient loading, sediment loading (both of which decrease light availability), eutrophication, dredging and infilling, commercial fisheries (scallops, worm and clam harvesting), mussel and oyster aquaculture (nutrient loading, shading by mussel socks), temperature and salinity fluctuations and wasting disease, and green crab invasions.

11.2.7. Estuaries

Estuaries are associated with most of the rivers draining into the Atlantic Ocean along the Nova Scotia coastline. They contain a variety of habitats and are among the most productive of marine ecosystems, partly because they tend to be shallow, receive a continuing supply of nutrients from the river and are mixed by the tidal movements of the sea (Davis and Browne 1996a). The nutrients support phytoplankton growth as well as the development of salt marshes and eelgrass beds. Established beds slow the flow of water and causes further settlement of organic and inorganic sediment, providing mudflat habitat for many species of shellfish. The tendency for estuaries to support a variety of ecosystems dominated by flowering plants means that they are important habitats for a range of birds and insects (Mann 2000). Conditions of a particular estuary are determined by the ratio of freshwater to saltwater input, sediment type and the size of the estuary. The highest productivity levels on the Atlantic coast occur in estuaries with benthic based productivity (Greenlaw et al. 2011).

Warm temperatures, rich food supply and relative absence of predators make estuaries important nursery and foraging grounds for many species of invertebrates, fish and birds. The nutrients support phytoplankton growth as well as the development of tidal marshes and eelgrass beds. Conditions of a particular estuary are determined by the ratio of freshwater to saltwater input, sediment type and the size of the estuary. The highest productivity levels on the Atlantic coast occur in estuaries with benthic based productivity (Greenlaw et al. 2011).

The warm temperatures, rich food supply and relative absence of predators make estuaries important nursery and foraging grounds. A number of fish species (flounder, herring) are linked closely to estuarine environments at important stages in their life cycle. Estuaries are important to various lifestages of diadromous fish species: adults migrate through them prior to entering and after leaving spawning rivers in the spring and summer, juveniles spend time in them during seaward migration in later summer and fall, and American eels may spend their lifecycle there.

11.2.8. Inlets

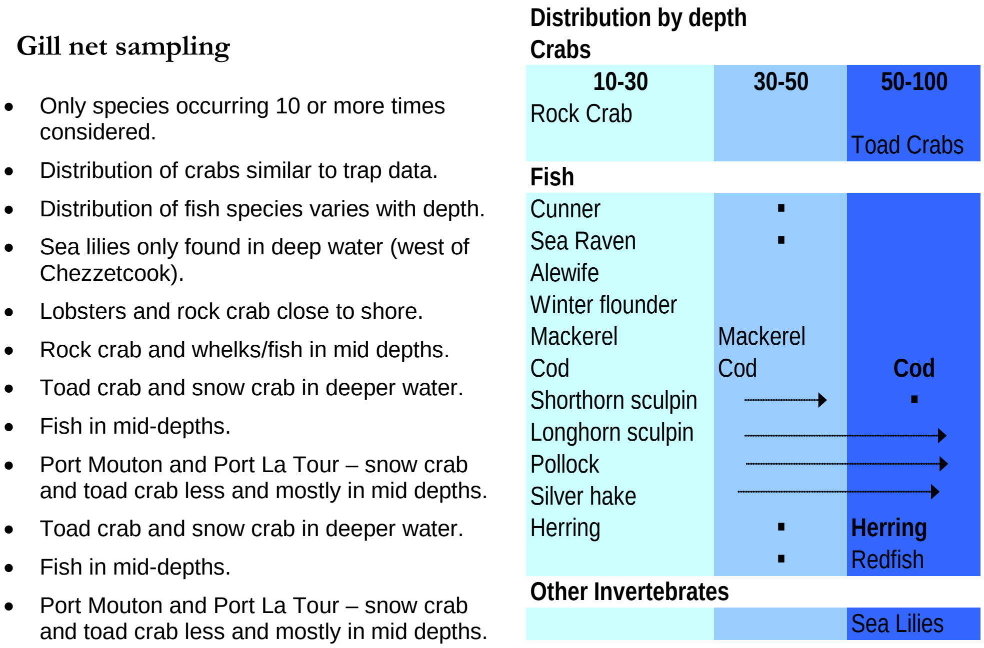
Inlets and bays differ from exposed beaches due to their curved shoreline, which provides protection from wave exposure. They tend to be warmer and more sheltered than exposed coastline (Davis and Browne 1996). Although there may be some freshwater input, the environmental conditions are marine rather than estuarine.

Bays may contain a variety of habitats, depending on their size and depth, and these contribute to the overall character of the species composition. Lobster use sheltered bays and inlets with rocky bottom along the Atlantic coast. Larger and deeper bays will host both pelagic and benthic communities; the largest bays (St. Margarets, Mahone and Halifax), have hydrographic conditions similar to the open ocean and are seasonally attractive to oceanic species such as large pelagic fishes, jellyfishes, krill, and marine mammals. Chedabucto Bay, another large deep bay, is an overwintering site for herring from the Bay of Fundy and southwestern Nova Scotia. Sydney Bight, a large shallow area adjacent to the coast of Cape Breton, is an overwintering site for herring and many groundfish species which move into the bight as pack ice develops in the Gulf of St. Lawrence (Breeze et al. 2002).

11.2.9. Beyond The Coastal Fringe

The composition of organisms living in the mid-depth (10-40 m) and deeper (40-100 m) zones of the coastal region are also influenced by physical features of the seabed such as sediment texture, size and mobility, and movement of the seabed due to tidal currents and waves (Connor et al. 2004; Valentine et al. 2005). Macrophytes only live as deep as the limits of the photic zone which occurs around 35-40 m and communities below this depth are dominated by animals rather than macrophytes (Connor et al. 2004). Inshore waters with depths of 35 m to 100 m have many of the same attributes as deeper waters extending seaward to the shelf break at 200 m.

Preliminary results from the Inshore Ecosystem Project show increasing species diversity between 0-10 and 10-30 m depths (den Heyer et al. 2010). Lobsters and rock crabs were the most abundant large crustaceans close to shore, accounting for 90% of the catch by weight and 75% by numbers in lobster traps set at 5 and 10 m depths (Bundy 2007b). Sampling along inshore–offshore transects using lobster traps and gillnets detected gradients from rock crab and lobster at depths <30 m to toad and snow crab at depths of 50-100 m (Figure 89). The distribution of fish species varied from cunner and sea raven at shallow depths to pollock and cod at mid-depths (Figure 89).



Gill net sampling

- Only species occurring 10 or more times considered.
- Distribution of crabs similar to trap data.
- Distribution of fish species varies with depth.
- Sea lilies only found in deep water (west of Chezzetcook).
- Lobsters and rock crab close to shore.
- Rock crab and whelks/fish in mid depths.
- Toad crab and snow crab in deeper water.
- Fish in mid-depths.
- Port Mouton and Port La Tour – snow crab and toad crab less and mostly in mid depths.
- Toad crab and snow crab in deeper water.
- Fish in mid-depths.
- Port Mouton and Port La Tour – snow crab and toad crab less and mostly in mid depths.

Distribution by depth

10-30	**30-50**	**50-100**
Crabs		
Rock Crab		Toad Crabs
Fish		
Cunner	▪	
Sea Raven	▪	
Alewife		
Winter flounder		
Mackerel	Mackerel	
Cod	Cod	**Cod**
Shorthorn sculpin	→	▪
Longhorn sculpin	→	→
Pollock	→	→
Silver hake	→	→
Herring	▪	**Herring**
	▪	Redfish
Other Invertebrates		
		Sea Lilies

Figure 89. Change in species composition with depth in gillnet (upper) and lobster traps from sampling along transects during the Inshore Ecosystem Project (adapted from Bundy 2007b).

11.3. Inshore-Offshore Linkages

A variety of marine vertebrates use the inshore region during the summer for foraging (Section 10.2) or as a stopover to feed and refuel during migrations (Section 10.3) to their summer of wintering grounds. In general, these migrants probably represent a net loss of energy for the inshore region. Large pelagic fish and marine mammals have few predators, and the migrating shorebirds probably do not stay long enough to become significant prey for resident species.

A large amount of the energy stored by macrophytes is exported to the offshore in the form of fresh and decayed rockweed, eelgrass and salt marsh (Sections 9.2.2).

Large numbers of juvenile fish are found in the shallow waters of the coastal zone. These sites often provide a rich supply of food, are sufficiently warm to encourage faster growth and provide shelter from larger predators (Gotceitas and Brown 1993, Davis and Browne 1996a, Linehan et al. 2001). Due to the high mortality rate experienced in the early life stages of most fish, predation is a primary structuring factor in shallow, aquatic communities. Large piscivorous fish may avoid entering very shallow waters because of the risk of becoming stranded or eaten by fish-eating birds, fish and mammals. For example, juvenile winter flounder migrate inshore into depths of <1 m where the likelihood of encountering piscivorous predators is low (Manderson et al. 2004). The occurrence of smaller (<20 mm) flounder at depths >1 m may be to avoid predation by *Crangon* shrimp. Ryer et al. (2011) suggest that the occurrence of the juveniles of many commercially important fish species in shallow water may be a general paradigm in which juvenile fish choose shallow water habitat to avoid predation, in spite of better foraging habitat in deeper water.

Small pelagic species are crucial to the health and functioning of marine ecosystems (Read and Brownstein 2003). On a very broad scale, they capture energy from lower trophic levels (phytoplankton, zooplankton, and small planktivorous fish) and transfer it to higher level carnivores including mammals, birds, and numerous species of pelagic and demersal fish and marine invertebrates. Because of their seasonal migrations and other life history traits, they also provide a significant link between coastal and pelagic systems by transporting energy and biomass seasonally from coastal embayments and nearshore waters to offshore waters (Gottleib 1998).

Most of the sessile invertebrates of the inshore region release larvae into the water column. These become part of the zooplankton (Section 9.1.5) that feed offshore fish stocks.

11.3.1. Migrating and Anadromous Species

Anadromous fishes are a link between nearshore and offshore regions. By feeding offshore and returning as adults to estuaries and rivers to spawn, they import energy into the inshore region. They are prey in rivers and estuaries for larger predatory fish and birds, and at sea for seals, sea birds, and a wide range of piscivorous marine fish. Those fish which die after spawning import significant quantities of marine-derived nutrients: these are nutrients that were obtained while feeding and growing in the ocean. Declining runs of clupeids and sea lampreys were identified as factors impacting the recovery of Atlantic salmon in the Gulf of Maine (NMFS 2005). Co-occuring runs of anadromous species may support salmon populations by providing alternative forage for bird and fish species preying on larval and juvenile salmon and enriching freshwater habitats with marine derived nutrients (all sea lamprey and 20% or more of clupeids die after spawning), and enhancing the quality of spawning substrate. During spawning, sea lampreys loosen and clean the substrate, improving its suitability for spawning salmonids. Substrate disturbance also increases water quality that may enhance salmon egg and fry survival as well as benefiting aquatic insects and invertebrates (Kircheis 2004 in NMFS 2005). Continuing runs of sea lampreys maintains the suitability of rivers in which Atlantic salmon have become extirpated (R. Bradford, pers. comm.).

11.4. Variability – Seasonal, Inter-Annual and Long-Term Changes

The inshore ecosystem is subject to the seasonal influence of ice scouring in the north, freshwater input in the spring, winds from the southwest in the summer and northwest in the winter causing seasonal upwelling, spring phytoplankton blooms, seasonal movements of fish and invertebrates (feeding, spawning, ontogenetic, temperature regulation).

The main inter-annual variability in the nearshore is the cycling between kelp beds and sea urchin barrens noted above.

Long-term changes in the ecosystem are largely due to anthropogenic activities such as fishing, coastal development and the introduction of invasive species. Four centuries of fishing by European immigrants has left the inshore area low in abundance of traditional fish species and depauperated of spawning areas for species such as cod and herring (Clark et al. 1999, Clark 2006). The extent of this decline has not been recorded, though MacDonald (1979) notes that there were large declines in inshore groundfish in the Maritimes before the extension of jurisdiction in 1977. On the other hand, landings of many invertebrates have increased. For example, all lobster landings have been increasing since the late 1970s throughout all fishing areas, in some cases reaching record landings in recent years (FRCC 2007). This decrease in groundfish and increase in invertebrate landings mirrors changes in the offshore eastern Scotian Shelf (Zwanenburg et al. 2006, Bundy 2005, Frank et al. 2005). Since resource surveys are not conducted in the inshore, the actual abundance of these species is not known.

11.4.1 Invasive Species

Green crab foraging habits can significantly alter benthic community structure and ecological interactions, such as support for higher trophic levels and fisheries production (Cohen et al. 1995, as cited in Klassen and Locke 2007; Morris et al. 2011). Green crab burrowing and feeding activity has been shown to affect the top few centimeters of sediment down to as deep as15 cm searching for prey (Short and Wyllie-Echeverria 1996; Davis and Short 1997; Garbary and Miller 2006), causing changes in infaunal populations through disturbance of the sediments (Gee et al.1985). Effects on community composition may be direct through feeding or indirect by modifying prey behaviour. Trussell et al. (2002) reported that green crabs affected the algal composition of rocky interitidal areas by regulating the density of herbivorous snails (*Littorina littorea*). They did this through both directly feeding on the perwinkles, and production of risk cues which dramatically suppressed snail grazing on rockweeds.

11.4.2. Eutrophication

Activities such as agriculture, aquaculture and sewage disposal can cause excess sedimentation and overfertilization of adjacent waterbodies and downstream coastal estuaries and bays. Nutrient loading increases the concentration of nitrogen and phosphorous in the water and shift the primary producer assemblage from macrophyte to phytoplankton and algae based.(Worm and Lotze 2006). The increase in phytoplankton, epiphytic, and free-floating macroalgae reduces the amount of light reaching seagrass for photosynthesis and growth, while the decomposition of dead algal matter enhances oxygen depletion and the development of anoxic sediments (Duarte 2002, Lotze et al. 2003). Coll et al. (2011) studied food webs associated with seagrass (*Zostera marina*) across 16 sites including four sites on the Atlantic coast of Nova Scotia. Sites with low nutrient loading had similar food-web structures. They concluded that the food webs of sites with higher nutrient loads were degraded, due to fewer trophic groups, a lower maximum trophic level of the highest top predator, fewer trophic links connecting top to basal species, higher fractions of herbivores and intermediate consumers, and higher number of prey per species. These structural changes resulted in functional changes with impacted sites being less robust to simulated species loss. The authors concluded that as seagrass food webs become more degraded they become more vulnerable to the loss of species that highly interact in the web.

11.4.3. Climate Change and Sea Level Rise

Sea levels are rising along the Atlantic coast due to a combination of long term mean sea level rise since the last ice age, regional land subsidence, and global warming and associated climate change (CBCL 2009). These processes affect shoreline habitats through the erosion of cobble and sand beaches and the development of new beaches downdrift from the erosion, flooding and sedimentation of salt marshes, increased volume and increased saltwater volume and tidal exchange in estuaries. Climate change is predicted to increase the frequency and intensity of storms in the North Atlantic (CBCL 2009). The linkages demonstrated by Scheibling and Lauzon-Guay (2010) between sea urchin mortalities, pathogen outbreaks, hurricane activity and water temperature indicate that increased storm activity would also result in sea urchin mortalities. This would lead to a regional shift to kelp ecosystem and the loss of the developing sea urchin fishery. Increasing water temperatures would increase rockweed growth; however, increasing frequency in storm surges (caused strong winds assocatied with storm activity) would result in increased breakage of the fronds and the export of macrophyte production from the inshore region to the offshore (Ugarte et al. 2010; Krumhansl and Scheibling 2011a). Increased water temperature encourages *Membranipora* encrusting on kelp, a process which will also increase the rate of frond breakage and encourage colonization by Codium (Saunders et al. 2010).

11.5. Resilience of the Ecosystem

There is insufficient information to discuss the resilience of the inshore ecosystem in other than general terms. Changes due to fishing may be reversible, although it is unlikely that lost spawning areas (sub-populations) can be regained. This is likely to lead to a loss in genetic biodiversity and possibly species and ecosystem resilience. Coastal development irrevocably changes the coast, and may lead to loss of habitat, changes in nutrient loads, currents and eutrophication. It is not known how resilient the inshore is to invasive species. Once established, these may be impossible to remove and may lead to changes in ecosystem structure and functioning.

CREDITS AND STUDY ADMINISTRATION

PROJECT TEAM, AUTHORS AND COLLABORATORS

The first draft of this document was developed under Oceans Action Plan Funding (OAP). Julie Sperl and Nell den Heyer of the Fishermen and Scientists Research Scociety drafted many of the sections and edited and integrated the work of the other authors. Alida Bundy reviewed this material and sent all sections out to various experts within DFO for review, requested further sections to be written by subject experts and edited and integrated the individual sections into a draft ecosystem overview report. Contributing experts are indicated at the beginning of the relevant sections in the document and in the list below. The report was reviewed in a Maritimes regional science advisory process on March 5-6, 2008. Comments, missing information and more recent information were incorporated into the final version by Alida Bundy and Daphne Themelis in 2012-2013 under Ecosystem Research Initiative funding.

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COASTAL AND RESEARCH INITIATIVES

Coastal and Ocean Information Network (COINAtlantic): Website maintained by the Atlantic Zone Coastal Initiatives Steering Committee to allow access to information on all coastal and ocean management initiatives in Atlantic Canada.

Inshore Ecoystem Project (IEP): Fisheriy Independent surveys of inshore region from Cape Sable to Cape North completed in 2006, data now under analyses.

Key marine Habitats for Migratory Birds on Eastern Canada's Atlantic Coast: Wildlife monitoring Initiative by CWS to identify key sites according to marine habitat type from intertidal salt marshes, mudflats, beaches,and rocky shorelines, eelgrass beds.

Atlantic Zone Monitoring project (AZMP): Long term monitoring of oceanographic features at fixed stations and transects in Atlantic Canada.

Atlantic Coastal Action Plan: Community based program to help communities define common objectives for environmentally appropriate use of their resources. Nova Scotia based sites include:

Bluenose Coastal Action Foundation (BCAF): Monitoring sites in Mahone Bay (Gold River, LaHave River, Roseate tern nesting sites)

Fishermen Scientists Research Society (FSRS Lobster Recruitment Project): Active partnership between fishermen scientists to conduct collaborative research and collect information necessary for long-term sustainability of fisheries, particularly lobster.

HYPERLINKS

Atlantic Zone Monitoring Program:

www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html

Bedford Basin Monitoring CTD Data:

www.bio.gc.ca/science/monitoring-monitorage/bbmp-pobb/bbmp-pobb-eng.php

Bedford Basin Plankton Monitoring Program:

www.bio.gc.ca/science/monitoring-monitorage/bbmp-pobb/bbmp-pobb-eng.php

BioChem Database:

www.meds-sdmm.dfo-mpo.gc.ca/BioChem/biochem-eng.htm

Coastal Shallow Water Temperature Climatology for Atlantic Canada:

www.bio.gc.ca/science/data-donnees/archive/coastal_temperature/coastal_temperature-eng.php

Environment Canada Real Time Hydrometric Data:

www.wateroffice.ec.gc.ca/index_e.html

Environment Canada Climate Normals and Averages:

climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

Important Bird Areas Canada:

www.ibacanada.ca/

Scotian Shelf / Gulf of Maine Marine Climatology:

www.bio.gc.ca/science/data-donnees/archive/tsc/scotia/ssmap-eng.php

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APPENDIX A

Table A1. Table listing the 255 secondary watersheds in Nova Scotia grouped by primary watershed. Compiled by Nova Scotia Department of the Environment (NSE) Jan. 2010.

County	Secondary WaterShed		Primary WaterShed	
	Code	**Name**	**Code**	**Name**
Digby	1DA - 1	Salmon River (Dig. Co.)	1DA	Meteghan
Digby	1DA - 2	Meteghan River		
Digby	1DB - 1	Sissiboo River	1DB	Sissiboo/Bear
Annapolis/Digby	1DB - 2	Bear River		
Annapolis	1DC - 1	Moose River (Ann. Co.)	1DC	Annapolis
Annapolis	1DC - 2	Lequille River		
Annapolis/Kings	1DC - 3	Annapolis River		
Kings	1DD - 1	Gaspereau/Black River	1DD	Gaspereau
Kings	1DD - 2	Cornwallis River		
Kings	1DD - 3	Cunard River		
Kings	1DD - 4	Habitant Creek		
Hants/Halifax	1DE - 1	St. Croix River	1DE	St. Croix
Hants/Lunenberg	1DE - 2	Avon River		
Hants/Kings	1DE - 3	Halfway River		
Hants	1DF - 1	East Noel River	1DF	Kennetcook
Hants	1DF - 2	Noel River		
Hants	1DF - 3	Tennycape River		
Hants	1DF - 4	Walton River		
Hants	1DF - 5	Rainy Cove Brook		
Hants	1DF - 6	Bass Brook		
Hants	1DF - 7	Mill Brook		
Hants	1DF - 8	Cheverie Creek		

County	**Secondary WaterShed**		**Primary WaterShed**	
	Code	**Name**	**Code**	**Name**
Hants	1DF - 9	Cogmagun River		
Hants	1DF - 10	Kennetcook River		
Hants/Halifax/ Colchester	1DG - 1	Shubenacadie River	1DG	Shubenacadie/ Stewiacke
Colchester	1DG - 2	Beaver Brook		
Colchester	1DH - 1	Folly River	1DH	Salmon/Debert
Colchester	1DH - 2	Debert River		
Colchester	1DH - 3	Chiganois River		
Colchester	1DH - 4	North River		
Colchester	1DH - 5	Farnham Brook		
Colchester	1DH - 6	Salmon River		
Colchester	1DH - 7	McClures Brook		
Cumberland/ Colchester	1DJ - 1	Harrington River	1DJ	Economy
Colchester	1DJ - 2	North River		
Colchester	1DJ - 3	Bass River Five Islands		
Colchester	1DJ - 4	East River Five Islands		
Colchester	1DJ - 5	Economy River		
Colchester	1DJ - 6	Bass River		
Colchester/ Cumberland	1DJ - 7	Portapique River		
Colchester/ Cumberland	1DJ - 8	Great Village River		
Cumberland	1DK - 1	Shulie River	1DK	Parrsboro
Cumberland	1DK - 2	Apple River		
Cumberland	1DK - 3	Greville River		
Cumberland	1DK - 4	Fox River		
Cumberland	1DK - 5	Ramshead River		
Cumberland	1DK - 6	Diligent River		

County	**Secondary WaterShed**		**Primary WaterShed**	
	Code	**Name**	**Code**	**Name**
Cumberland	1DK - 7	Parrsboro River (Farrells River)		
Cumberland	1DK - 8	Moose River		
Cumberland	1DL - 1	River Hebert	1DL	Kelley/Maccan/Hebert
Cumberland	1DL - 2	Maccan River		
Cumberland	1DL - 3	Nappan River		
Cumberland/ Westmorland , N.B.	1BT - 7	Missaguash River	1BT	(N.B.Primary WaterShed Names not available)
Cumberland/ Westmorland , N.B.	1DM - 1	Tidnish River	1DM	Tidnish/Shinimicas
Cumberland	1DM - 2	LaPlanche River		
Cumberland	1DM - 3	Shinimicas River		
Cumberland	1DN - 1	River Philip	1DN	Philip/Wallace
Cumberland	1DN - 2	Pugwash River		
Cumberland	1DN - 3	Wallace River		
Cumberland	1DO - 1	Dewar River	1DO	River John
Colchester/ Cumberland	1DO - 2	French River		
Colchester	1DO - 3	Waugh River		
Pictou/Colchester	1DO - 4	River John		
Pictou	1DO - 5	Toney River		
Pictou	1DO - 6	Caribou River		
Pictou	1DP - 1	West River Pictou	1DP	East/Middle/West (Pictou)
Pictou	1DP - 2	Middle River Pictou		
Pictou	1DP - 3	East River Pictou		
Pictou	1DQ - 1	Sutherland River	1DQ	French
Pictou	1DQ - 2	French River		

County	**Secondary WaterShed**		**Primary WaterShed**	
	Code	**Name**	**Code**	**Name**
Pictou	1DQ - 3	Barneys River		
Pictou	1DQ - 4	Baileys Brook		
Pictou/Antigonish	1DQ - 5	Knoydart Brook		
Antigonish	1DQ - 6	Doctors Brook		
Antigonish	1DQ - 7	Malignant Brook		
Antigonish	1DR - 1	North Lake Stream	1DR	South/West
Antigonish	1DR - 2	Wallace Brook		
Antigonish	1DR - 3	Ogden Brook		
Antigonish	1DR - 4	Rights River		
Antigonish/Pictou	1DR - 5	West River		
Antigonish/ Guysborough	1DR - 6	South River		
Antigonish/ Guysborough	1DS - 1	Pomquet River.	1DS	Tracadie
Antigonish/ Guysborough	1DS - 2	Afton River		
Antigonish/ Guysborough	1DS - 3	Monastery Brook		
Antigonish/ Guysborough	1DS - 4	Tracadie River		
Antigonish/ Guysborough	1DS - 5	Little Tracadie River		
Antigonish/ Guysborough	1DS - 6	Havre Boucher Brook		
Guysborough/ Antigonish	1DS - 7	Mill Creek		
Yarmouth	1EA - 1	Argyle River	1EA	Tusket
Yarmouth	1EA - 2	Ste Anne du Ruisseau		
Yarmouth/Digby	1EA - 3	Tusket River		

County	Secondary WaterShed		Primary WaterShed	
	Code	**Name**	**Code**	**Name**
Yarmouth/Digby	1EA - 4	Annis River		
Yarmouth	1EA - 5	Ohio Millstream Brook (Lake Milo system)		
Yarmouth/Digby	1EA - 6	Coggins Brook		
Shelbourne/Yarmouth	1EB - 1	Clyde River	1EB	Barrington/Clyde
Shelbourne/Yarmouth	1EB - 2	Barrington River		
Shelbourne/Yarmouth	1EB - 3	Downeys River		
Shelbourne	1EB - 4	Shag Harbour Brook		
Shelbourne/Yarmouth	1EB - 5	French Lake Brook		
Shelbourne	1EC - 1	Ogden Creek	1EC	Roseway/Sable/Jordan
Shelbourne/Queens	1EC - 2	Jordan River		
Shelbourne/Digby/Yarmouth	1EC - 3	Roseway River		
Shelbourne	1EC - 4	Birchtown Brook		
Shelbourne	1EC - 5	Round Bay River		
Queens/Annapolis/Digby	1ED - 1	Mersey River	1ED	Mersey
Queens	1ED - 2	Five Rivers		
Queens	1ED - 3	Broad River		
Shelbourne/Queens	1ED - 4	Tidney River		
Shelbourne/Queens	1ED - 5	Sable River		
Shelbourne	1ED - 6	East River (Jordan)		
Lunenberg	1EE - 1	Petite Riviere	1EE	Herring Cove/Medway
Queens/Lunenberg/Annapolis	1EE - 2	Medway River		
Queens	1EE - 3	Herring Cove Brook		
Lunenberg	1EF - 1	Marsh Brook	1EF	LaHave
Lunenberg/Kings/Annap	1EF - 2	LaHave River		

County	**Secondary WaterShed**		**Primary WaterShed**	
	Code	**Name**	**Code**	**Name**
olis				
Lunenberg	1EG - 1	Middle River	1EG	Gold
Lunenberg	1EG - 2	Gold River		
Lunenberg	1EG - 3	Martins River		
Lunenberg	1EG - 4	Mushamush River		
Halifax	1EH - 1	East River	1EH	East/Indian
Halifax /Hants	1EH - 2	Northeast River		
Halifax /Hants	1EH - 3	Indian River		
Halifax /Hants	1EH - 4	Ingram River		
Halifax	1EH - 5	Hubbards River		
Lunenberg	1EH - 6	Little East River		
Lunenberg	1EH - 7	East River Chester		
Halifax	1EJ - 1	Cow Bay River	1EJ	Sackville
Halifax	1EJ - 2	Dartmouth Lakes		
Halifax	1EJ - 3	Wrights Brook		
Halifax /Hants	1EJ - 4	Sackville River		
Halifax	1EJ - 5	Kearney Run		
Halifax	1EJ - 6	McIntosh Run		
Halifax	1EJ - 7	Ketch Harbour Lakes		
Halifax	1EJ - 8	Pennant River		
Halifax	1EJ - 9	Partridge River		
Halifax	1EJ - 10	Prospect River		
Halifax	1EJ - 11	Nine Mile River		
Halifax	1EJ - 12	Unnamed -tributary to Blind Bay		
Halifax	1EJ - 13	Woodens River		

County	Secondary WaterShed		Primary WaterShed	
	Code	**Name**	**Code**	**Name**
Halifax	1EK - 1	Musquodoboit River	1EK	Musquodoboit
Halifax	1EK - 2	Little River		
Halifax	1EK - 3	Chezzetcook River		
Halifax	1EK - 4	Porters Lake		
Halifax	1EK - 5	Partridge River - Lawrencetown Lake		
Halifax	1EK - 6	Little Salmon River		
Halifax	1EL - 1	West Taylor Bay Brook	1EL	Tangier
Halifax	1EL - 2	Tangier River		
Halifax	1EL - 3	Newcombe Brook		
Halifax	1EL - 4	Little River		
Halifax	1EL - 5	Fish River – Lake Charlotte		
Halifax	1EL - 6	Salmon River		
Halifax/Guysborough	1EM - 1	East River Sheet Harbour	1EM	East/West Sheet Harbour
Halifax	1EM - 2	West River Sheet Harbour		
Halifax	1EM - 3	Grand Lake		
Halifax	1EM - 4	Mushaboom Lake		
Guysborough	1EN - 1	Gegogan Brook	1EN	Liscomb
Guysborough	1EN - 2	Gaspereaux River		
Guysborough	1EN - 3	Liscomb River		
Guysborough	1EN - 4	ECumberland SeCumberland River		
Halifax	1EN - 5	Smith Brook		
Halifax/Guysborough	1EN - 6	Moser River		
Halifax	1EN - 7	Quoddy River		

County	Secondary WaterShed		Primary WaterShed	
	Code	**Name**	**Code**	**Name**
Halifax	1EN - 8	Salmon River		
Halifax	1EN - 9	Halfway Brook		
Guysborough/ Antigonish/ Pictou	1EO - 1	St. Mary's River	1EO	St. Mary's
Guysborough	1EO - 2	Northwest Arm Brook		
Guysborough	1EP - 1	Isaacs Harbour River	1EP	Country Harbour
Guysborough	1EP - 2	Country Harbour River		
Guysborough	1EP - 3	Indian River		
Guysborough	1EQ - 1	Salmon River	1EQ	New Harbour/Salmon
Guysborough	1EQ - 2	Dickie Brook		
Guysborough	1EQ - 3	Larrys River		
Guysborough	1EQ - 4	New Harbour River		
	*			
Guysborough	1ER - 2	Melford Brook	1ER	Clam Harbour/St.Francis Harbour
Guysborough	1ER - 3	St. Francis Harbour River		
Guysborough	1ER - 4	Clam Harbour River		
Guysborough	1ER - 5	Guysborough River		
Richmond/Inverness	1FA - 1	River Inhabitants	1FA	River Inhabitants
Richmond/Inverness	1FA - 2	Little River		
Inverness	1FA - 3	Chisholm Brook		
Inverness	1FA - 4	Graham River		
Inverness	1FA - 5	Judique Intervale Brook		
Inverness	1FA - 6	Little Judique Brook		
Inverness	1FA - 7	Southwest Mabou River		

County	Secondary WaterShed		Primary WaterShed	
	Code	Name	Code	Name
Inverness	1FA - 8	Mabou River		
Inverness	1FA - 9	Northeast Mabou River		
Inverness	1FA - 10	Mill Brook		
Inverness	1FB - 1	Broad Cove River	1FB	Margaree
Inverness	1FB - 2	Margaree River		
Inverness	1FC - 1	Factory Brook	1FC	Cheticamp
Inverness	1FC - 2	Farm Brook		
Inverness	1FC - 3	Fiset Brook		
Inverness /Victoria	1FC - 4	Cheticamp River		
Inverness	1FC - 5	Corney Brook		
Inverness	1FC - 6	Fishing Cove River		
Inverness	1FC - 7	MacKenzie River		
Inverness	1FC - 8	Grand Anse River		
Inverness	1FC - 9	Red River		
Inverness	1FC - 10	Blair River		
Victoria /Inverness	1FC - 11	Meat Cove Brook		
Victoria /Inverness	1FD - 1	Salmon River	1FD	Wreck Cove
Victoria	1FD - 2	MacDougall Pond		
Victoria	1FD - 3	Wilkie Brook		
Victoria /Inverness	1FD - 4	North Aspy River		
Victoria	1FD - 5	Middle, South Aspy River		
Victoria	1FD - 6	Glasgow Brook		
Victoria	1FD - 7	Effie Brook		
Victoria	1FD - 8	Halfway Brook		
Victoria	1FD - 9	Black Brook		

County	Secondary WaterShed		Primary WaterShed	
	Code	Name	Code	Name
Victoria	1FD - 10	Warren Brook		
Victoria	1FD - 11	Dundas Brook		
Victoria	1FD - 12	Clyburn Brook		
Victoria	1FD - 13	Power Brook		
Victoria	1FD - 14	Ingonish River		
Victoria	1FD - 15	McLeod Brook		
Victoria	1FD - 16	Wreck Cove Brook		
Victoria	1FD - 17	French River		
Victoria	1FE - 1	Little River	1FE	Indian
Victoria /Inverness	1FE - 2	Indian Brook		
Victoria	1FE - 3	Barachois River		
Victoria	1FE - 4	North River		
Victoria	1FF - 1	Baddeck River	1FF	Baddeck/Middle
Victoria /Inverness	1FF - 2	Middle River		
Victoria	1FF - 3	McNaughton Brook		
Victoria /Inverness	1FF - 4	Hume River		
Inverness	1FG - 1	Skye River	1FG	River Denys
Inverness	1FG - 2	River Denys		
Richmond	1FH - 1	Black River	1FH	Grand
Richmond	1FH - 2	River Tillard		
Richmond	1FH - 3	Scott Brook		
Richmond	1FH - 4	River Tom		
Richmond /Cape Breton	1FH - 5	Grand River		
Richmond	1FJ - 1	Marie Joseph Brook	1FJ	Mira
Richmond / Cape Breton	1FJ - 2	Middle River Framboise		

County	Secondary WaterShed		Primary WaterShed	
	Code	Name	Code	Name
Cape Breton	1FJ - 3	Gerratt Brook		
Cape Breton	1FJ - 4	Catalone River		
Cape Breton	1FJ - 5	Mira River		
Cape Breton	1FJ - 6	McAskills Brook		
Cape Breton	1FJ - 7	Renwick Brook		
Cape Breton	1FJ - 8	Southwest Brook		
Cape Breton	1FJ - 9	Northwest Brook		
Cape Breton	1FJ - 10	Sydney River		
Cape Breton	1FJ - 11	Frenchvale Brook		
Cape Breton	1FJ - 12	Smelt Brook		
Cape Breton	1FJ - 13	Benacadie Brook		
Cape Breton	1FJ - 14	Indian Brook		
Cape Breton	1FJ - 15	MacIntosh Brook		
Cape Breton	1FJ - 16	Gillies Brook		
Cape Breton	1FJ - 17	Breac Brook		
Richmond	SD1 to 6	Isle Madame	Isle Madame	

* Note: is no watershed labelled 1ER - 1 on NSE 1:50,000 watershed maps, apparently due to the Goose Harbour Lake water diversion dam. The lake is considered within 1ER-3.