State of the Scotian Shelf Report

M. MacLean, H. Breeze, J. Walmsley and J. Corkum (eds)

Fisheries and Oceans Canada
Oceans and Coastal Management Division
Ecosystem Management Branch
Maritimes Region
Bedford Institute of Oceanography
PO Box 1006
Dartmouth, NS
B2Y 4A2

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P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

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ABSTRACT

MacLean, M., Breeze, H., Walmsley, J. and Corkum, J. eds. 2013. State of the Scotian Shelf Report. Can. Tech. Rep. Fish. Aquat. Sci. 3074: xvi + 352 p.

The Scotian Shelf is a rich ecosystem characterized by a diversity of marine life, communities and habitats. There are a variety of human activities that occur on the shelf, some year-round and others on a seasonal basis.

The State of the Scotian Shelf Report provides information on priority issues for environmental management, decision-making and education. The report is a modular document made up of a context document and a series of theme papers. The context document provides an introduction to the natural and socio-economic environment, providing an overview of the Scotian Shelf. The theme papers provide a more in-depth look at important issues. The themes were selected based on priorities identified through the Eastern Scotian Shelf Integrated Management Initiative. Theme papers will be updated on a regular basis. This technical report is a compilation of the context document and the theme papers completed to date.

RÉSUMÉ

MacLean, M., Breeze, H., Walmsley, J. and Corkum, J., eds. 2013. State of the Scotian Shelf Report. Can. Tech. Rep. Fish. Aquat. Sci. 3074: xvi + 365 p.

Le plateau néo-écossais abrite un riche écosystème défini par la diversité de sa vie marine, de ses communautés et de ses habitats. Diverses activités humaines sont menées sur le plateau, dont certaines se produisent toute l'année et d'autres, de façon saisonnière.

Le State of the Scotian Shelf Report fournit des renseignements sur les questions prioritaires liées à la gestion environnementale, à la prise de décisions et à la sensibilisation. Le rapport consiste en un document modulaire formé d'un document d'accompagnement et d'articles thématiques. Le document d'accompagnement présente l'environnement naturel et socio-économique et offre un aperçu du plateau néo-écossais. Les articles thématiques fournissent un regard plus approfondi sur les problèmes importants. Les thèmes sont sélectionnés en fonction des priorités signalées dans le cadre de l'Initiative de gestion intégrée de l'est du plateau néo-écossais. Les articles thématiques seront mis à jour régulièrement. Ce rapport technique consiste en une compilation du document d'accompagnement et des articles thématiques terminés jusqu'à présent.

1. INTRODUCTION TO THE STATE OF THE SCOTIAN SHELF

Jessica Corkum, Heather Breeze, Melanie MacLean and Jay Walmsley, Oceans and Coastal Management Division, Fisheries and Oceans Canada, Dartmouth, NS

1.1 OVERVIEW

The State of the Scotian Shelf Report is a synthesis of current knowledge of pressures on the environment, biophysical and socio-economic trends, and actions and responses to key issues identified for the Scotian Shelf region. The purpose of this report is to provide information on priority issues for environmental management, decision-making, and education. The report considers the biophysical, social, and economic aspects of the environment (**Figure 1-1).**

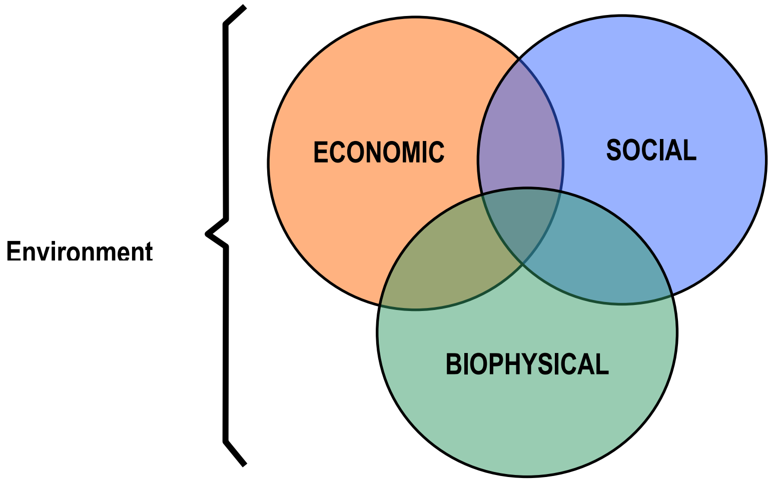

Figure 1-1: The interlinking economic, social and biophysical aspects of the environment.

The intended audience for the State of the Scotian Shelf Report includes:

- the Regional Committee on Coastal and Oceans Management (RCCOM) and its coordinating committee (RCCOMcc);
- federal and provincial government departments;
- Aboriginal organizations;
- key stakeholders including industry associations, coastal community groups, non-government organizations, academics, and members of the public formerly involved with the Forum or Stakeholder Advisory Committee for the Eastern Scotian Shelf Integrated Management (ESSIM) Initiative;
- university and high school students; and
- the general public.

The State of the Scotian Shelf Report is designed as a modular document made up of a context document and a series of theme papers, each of which is presented in the following chapters. The context document, *The Scotian Shelf in Context*, provides an introduction to the natural and socio-economic environment, providing an overview of the Scotian Shelf for those readers who are not familiar with the region. The theme papers provide a more in-depth look at important issues. These issues were selected based on priorities identified through the Eastern Scotian Shelf Management (ESSIM) Initiative. Subject matter experts prepared each paper. The first editions, which are presented in this document, were developed incrementally from 2011 to 2013, and will be regularly updated at time intervals appropriate to each issue.[1]

The project is overseen by the State of the Scotian Shelf Steering Committee, with members from Fisheries and Oceans Canada; the Nova Scotia Department of Aquaculture and Fisheries, and the Atlantic Coastal Zone Information Steering Committee (ACZISC) Secretariat. The context document and theme papers are co-published with ACZISC and can be found on the State of the Scotian Shelf website, http://coinatlantic.ca/index.php/state-of-the-scotian-shelf.

1.2 Eastern Scotian Shelf Integrated Management Initiative (ESSIM)

ESSIM was a collaborative ocean management and planning process led and facilitated by Fisheries and Oceans Canada (DFO), Maritimes Region under Canada's *Oceans Act*. The primary aim of the initiative was to develop and implement an integrated ocean management plan for this large marine region. From 1998 to 2006, the main focus of the ESSIM Initiative was the development of the management plan for the Eastern Scotian Shelf. From 2006–2011, the initiative focussed on implementing the plan. The ESSIM plan identified three high-level goals: collaborative governance and integrated management, sustainable human use, and healthy ecosystems. Within the goal of healthy ecosystems, specific objectives were developed around the core elements of biodiversity, productivity and marine environmental quality. These objectives directly informed the selection of the themes included in the State of the Scotian Shelf Report (for more information on the ESSIM plan see DFO 2007). It was intended that the theme papers help assess progress towards the ESSIM objectives.

Despite the conclusion of the ESSIM initiative in 2012, the results of this multi-year, strategic level initiative continue to provide long-term direction and a common basis for integrated, ecosystem-based and adaptive ocean management at a broader scale. The knowledge gained from the ESSIM initiative is being incorporated into a Regional Oceans Plan that will apply to the full Scotian Shelf-Bay of Fundy bioregion.

1.3 FRAMEWORK

The theme papers in the State of the Scotian Shelf Report follow the driving forces-pressure-state-impacts-response (DPSIR) framework to organize the material. Each theme paper starts with an overview of the topic in an “issue in brief” section that includes a DPSIR diagram tailored to the issue (**Figure 1-2**) and ends with an indicator summary table (**Table 1-1**).

1.3.1 DPSIR

The DPSIR framework provides an overview of the relationship between the environment and humans (**Figure 1-2**). The framework developed out of the simple Pressure-State-Response model developed by the OECD and is used by the European Environment Agency to conduct its assessments (EEA 1999). According to the DPSIR framework, social and economic developments and natural conditions (driving forces) exert pressure on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems, and materials, which may elicit a societal or government response

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[1] The context document and theme papers (chapters) were developed and were made available incrementally, thus in some cases the tense used is inappropriate. For example, there may be references to a linked theme paper being in development when it has actually been completed. As well, the information in each paper reflects the information available at the time of completion of each chapter, not the time of publication of this technical document.

that feeds back on all the other elements. The DPSIR framework is useful in describing the origins and consequences of environmental problems (Smeets and Weterings 1999).

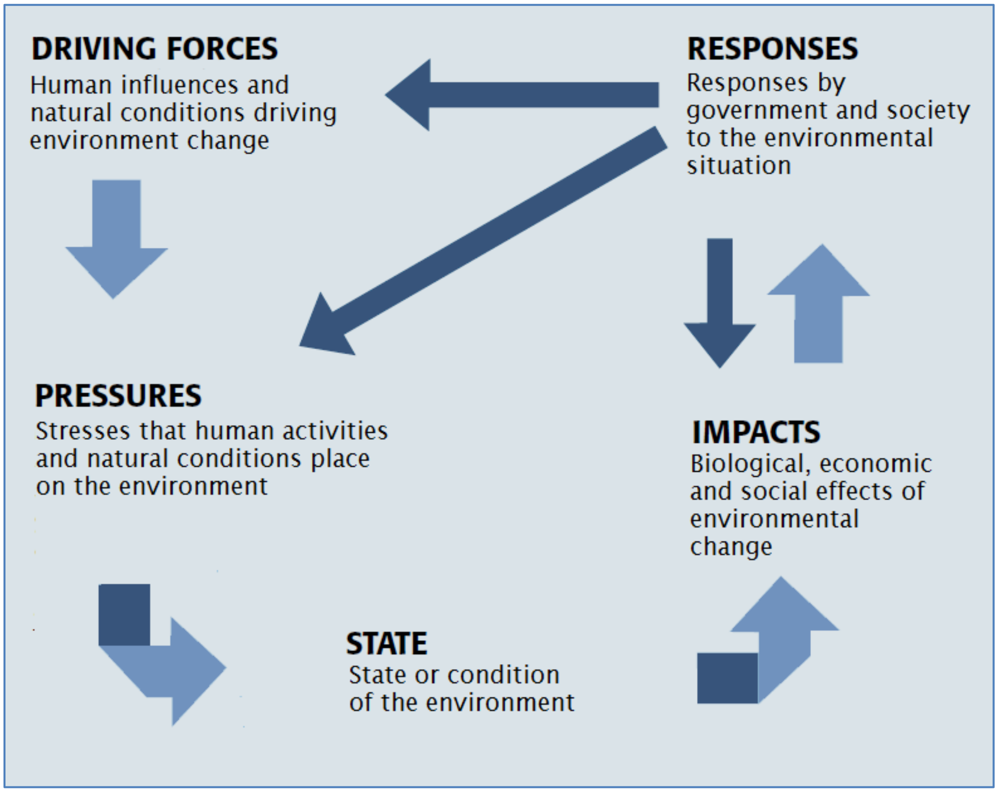

Figure 1-2: A DPSIR (Driving Forces, Pressures, State, Impact and Response) diagram provides an overview of each issue and is included at the beginning of each theme paper.

1.3.2 Indicator Summary

An indicator is a parameter that provides information about an environmental issue with a significance that extends beyond the parameter itself. Indicators have been used for many years by economists to describe economic trends. For example, gross domestic product (GDP) is often used as an indicator of the strength of the economy. More recently there have been efforts aimed at developing indicators that are suitable for measuring sustainable development. The main goal of establishing indicators is to measure, monitor and report on progress towards sustainability. A set of indicators should be broad enough to present a comprehensive picture of environmental quality, yet be few enough to be easily understood by managers, decision makers, and the public.

The indicator summary found at the end of each document identifies indicators relevant to the theme paper and the policy issue it represents (see **Table 1-1**). It identifies the category of each indicator (driving force, pressure, state, impact or response) and provides an assessment/status[2] of the indicator in terms of current impacts on the environment (“good,” “fair,” “poor” or “unknown”). The general trend of the indicator, in terms of future implications for the state of the environment, is also shown. Categories are “improving,” “worsening,” “no

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[2] The first theme papers completed used the term “assessment” in the indicator table; later theme papers used the term “status.”

trend" or "unknown."[3] Improving means that the general trend should result in improvements in the state of the environment. This means that the assessment in the future is likely to improve, such as from poor to fair or from fair to good. Worsening means that the general trend is towards a further decline in the state of the environment, such as from fair to poor. No trend means that there is not a positive or negative trend. Unknown means that it is not clear if the trend will result in a decline or improvement in the state of the environment, or there is not enough data to see a clear trend.

It is important to note that the trend does not necessarily reflect the direction of the indicator; however, it could coincide with the direction of the indicator. For example, for the indicator, "number of regulated chemicals and substances," an increase in this indicator would likely be considered positive for the state of the environment, thus "improving" would be put in the trend column. This also coincides with the direction of the indicator. On the other hand, for the indicator "number of invasive species," an increase in this indicator would be a negative trend for the state of the environment, yet the direction of the indicator would be positive. The trend column for this indicator would have "worsening" to reflect implications for the state of the environment (see **Table 1-1**). Most papers provide a statement on data confidence and data gaps following the table.

Table 1-1: Examples of indicators, drawn from several theme papers.

INDICATOR	DPSIR	STATUS	TREND
Invasive Species: Number of established invasive species	Driving force, Pressure	Poor	Worsening
Waste and Debris: Shoreline clean-up results	State	Poor	Improving
Climate Change and its Effects on Ecosystems, Habitats and Biota: Shifts in species distribution	Impact	Fair	Unknown
Water and Sediment Quality: Number of regulated chemicals and substances	Actions and Responses	Good	Improving

Categories for Status: Unknown, Poor, Fair, Good.
Categories for Trend: Unknown, No trend, Worsening, Improving.

1.4 REFERENCES

DFO (Fisheries and Oceans Canada). 2007. Eastern Scotian Shelf Integrated Ocean Management Plan. http://www.dfo-mpo.gc.ca/Library/333115.pdf

Smeets, E. and Weterings, R. 1999. Enviornmental indicators: Typology and overview. European Environment Agency Technical report No. 25. http://www.eea.europa.eu/publications/TEC25

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[3] Most of the theme papers in this document use different terms for the trend categories: positive (improving), negative (worsening), unclear (not clear if the trend will result in a decline or improvements in the state of the environment), neutral (no trend), no assessment (lack of data). Going forward, theme papers will use the indicator terms described above.

2. THE SCOTIAN SHELF IN CONTEXT[4]

Oceans and Coastal Management Division, Fisheries and Oceans Canada, Dartmouth, NS

2.1 INTRODUCTION

In 1997, Canada became the first country in the world to adopt comprehensive legislation for integrated ocean management. By passing its *Oceans Act*, Canada made a commitment to conserve, protect, and develop the oceans in a sustainable manner. The *Oceans Act* and its supporting policy, *Canada's Oceans Strategy*, affirmed Fisheries and Oceans Canada's (DFO's) mandate as the lead federal authority for oceans and provided a national context for the initiative. Carrying out the Department's responsibilities under the *Oceans Act* requires a great deal of knowledge on the current state of the environment and its users.

The Scotian Shelf is part of the North American continental shelf off of Nova Scotia (Breeze et al. 2002: **Figure 2-1**). Over the years, there have been steps taken to catalogue the collective understanding of the Scotian Shelf and surrounding coastal areas (e.g. *The Scotian Shelf: An Ecological Overview for Ocean Planning*, Breeze et al. 2002 and *Implications of Ecosystem Dynamics for the Integrated Management of the Eastern Scotian Shelf*, Zwanenburg et al. 2006), and there are many examples of reports that address aspects of the region (e.g. *Economic Impact of the Nova Scotia Ocean Sector*, Gardner Pinfold 2005; 2009, and *State of Nova Scotia's Coast Report (2009)*). The State of the Scotian Shelf Report builds on these documents and links the current status and trends observed on the shelf to human and environmental impacts, as wells as management actions and responses.

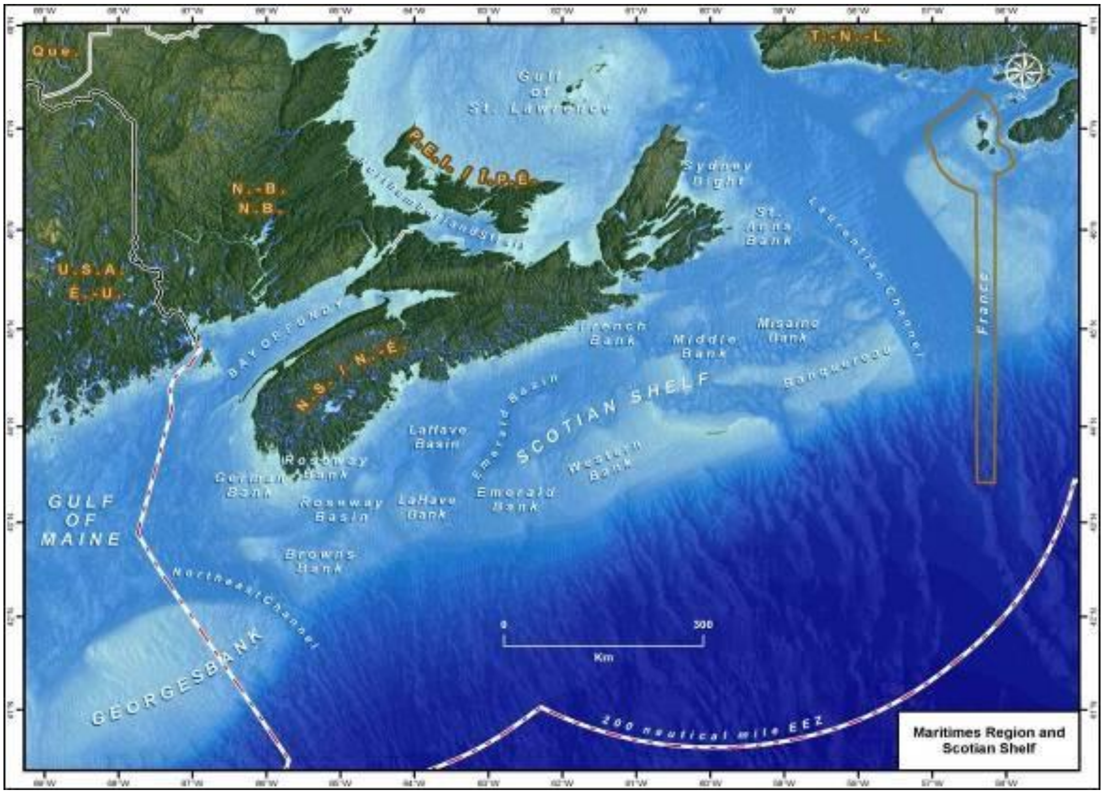

Figure 2-1: The Scotian Shelf (Source: Oceans and Coastal Management Division, Fisheries and Oceans Canada).

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[4] Completed June 2011.

The *State of the Scotian Shelf Report*, of which this chapter is a part, is a synthesis of pressures on the environment, biophysical and socio-economic status and trends, and responses to identified issues. It is a living document that consists of several parts, including this context document and a series of sector reports and theme papers. This chapter, *The Scotian Shelf in Context*, provides an introduction to the natural and socio-economic environment of the Scotian Shelf. The aim is to provide the information in a form that is easily accessible and readable, and familiarizes the reader in the region. It is complementary to the theme papers, which provide a more in-depth look at important issues on the Scotian Shelf (**Table 2.1**). Each theme paper was developed incrementally and will be updated regularly, as appropriate. Theme papers are focused on the priority areas of biodiversity, productivity and habitat.

Table 2-1: Theme Papers for *State of the Scotian Shelf Report*

Priority Area	Theme Papers
Biodiversity	Marine Habitats and Communities Incidental Mortality Species at Risk Invasive Species
Productivity	Primary and secondary productivity Trophic Structure Fish Stock Status and Commercial Fisheries
Marine Environmental Quality	Water and Sediment Quality Ocean Noise Waste and Debris Ocean Acidification
Other	Climate Change and its Effects on Ecosystems, Habitats and Biota Emerging Issues

2.2 THE NATURAL CONDITIONS OF THE SCOTIAN SHELF

The Scotian Shelf is the wide, submerged portion of the continental shelf lying off Nova Scotia, 700 kilometres long and between 125 and 230 kilometres wide. The Northeast Channel separates the shelf from the Gulf of Maine to the southwest, while the Laurentian Channel is the natural boundary with the Newfoundland Shelf to the northeast (figure 1). The shelf edge, where the seafloor begins to fall steeply away, lies at about 200 m depth. For the purposes of this report, the region includes the Scotian Slope and Rise (the area from the edge of the continental shelf seaward to the abyssal plain), and the abyssal plain itself within Canada’s Exclusive Economic Zone.

The state of the Scotian Shelf marine ecosystem is influenced by many complex interactions: interactions between the different factors that constitute the physical environment; interactions between the physical environment and the plants and animals that live there; interactions between the various species; and human interactions with the physical environment, including human activities occurring both in this region and far away. This section describes major features of the marine environment in this region and highlights, both the physical environment and characteristic species that are found here. More comprehensive overviews of the region can be found in *The Scotian Shelf: An Ecological Overview for Ocean Planning* (Breeze et al. 2002) and *Implications of Ecosystem Dynamics for the Integrated Management of the Eastern Scotian Shelf* (Zwanenburg et al. 2006). Worcester and Parker (2010) describe recent trends in the ecosystem, while Davis and Browne (1996) provide a description of the area aimed at the informed general reader. Worcester and Parker (2010) describe recent trends in the ecosystem, while Davis and Browne (1996) provide a description of the area aimed at the informed general reader.

2.2.1 Geology

The ocean bottom, its shape and the types of sediment that overlay it, help define the habitats of the Scotian Shelf and the types of plants and animals that are found in different areas. The shape of the seafloor in this region and its surficial sediments were influenced by long periods of erosion of the ancient bedrock (King 1980) as well as the last glaciation and the subsequent rise in sea level that started about 10 000 years ago (King and Fader 1986).

2.2.1.1 Geomorphology: The Scotian Shelf proper can be divided into three regions based on characteristics of the seafloor, an inner shelf, middle shelf and outer shelf (King and MacLean 1976), while the Laurentian Channel, Northeast Channel, and eastern and western Scotian Slope each have their own characteristics (Davis and Browne 1996, WWF 2009).

The inner shelf borders the coast and can be considered an underwater extension of Nova Scotia's coastal areas. It has rough topography and areas with bedrock outcrops, and extends from the coastline to depths of about 100 -120 m (Fader 1991, Davis and Browne 1996). The eastern region of the inner shelf is distinguished by a couple of small banks, St. Anns Bank and Scaterie Bank, off Cape Breton.

The middle shelf is characterized by a wide, complex network of valleys, ridges and small gravel-covered banks in the east; large, deep basins in the central area; and a smaller bank and basin in the western region, with a narrow strip of rough bedrock at the far western extent (Sankerelli and Fader 1999, WWF 2009). The basins have been filled and smoothed first by glaciers and, more recently, by deposition of silt. In places, boulder-covered till ridges protrude through the mud and crater-shaped depressions known as pockmarks are found where natural gas bubbles through the sediments to the surface.

Several large, shallow banks—Banquereau, Sable, Western, Emerald, LaHave and Browns—are the defining features of the outer shelf (Davis and Browne 1996). They function somewhat as a physical barrier between the waters of the shelf and the deep waters of the ocean (Breeze et al. 2002). Sable Island is the only offshore island and the exposed portion of Sable Island Bank. Various seabed features surround the island: sand waves, sand ridges, ripples and megaripples (Amos and Nadeau 1988; Davis and Browne 1996; Dalrymple and Hoogendoorn 1997).

The seafloor begins to descend more steeply starting at about the 200 m isobath to depths of about 2000 m; this area is known as the Scotian Slope. From that point, the depth increases more gradually until the seafloor flattens out at the abyssal plain, at a depth of about 5000 m. A series of steep-sided submarine canyons are found along the shelf edge and slope. At more than two kilometres deep and fifteen kilometres wide, the Gully is the largest of these canyons (Rutherford and Breeze 2002). Unlike the other canyons, it has a wide basin (the trough) at its head. The size and shape of the Gully are thought to influence water transport to and from the shelf (Rutherford and Breeze 2002). Six smaller canyons are also found along the shelf edge of the eastern Scotian Slope (Piper et al. 1985, WWF 2009); much less is known about these canyons. There are no canyons in the area of the western Scotian Slope (WWF 2009): the slope between Emerald Bank and the Northeast Channel.

The Scotian Shelf is bounded on the east by the Laurentian Channel, a deep trough that originated as a river valley and was later eroded by glacial ice (Davis and Browne 1996). The

Laurentian Fan is a large, delta-like deposition area down the slope from the Channel. Deep parts of the Laurentian Channel carry water from the Atlantic Ocean into the Gulf of St. Lawrence (Davis and Browne 1996).

To the west, the Northeast Channel divides Browns Bank on the Scotian Shelf from Georges Bank and the Gulf of Maine. The channel connects the Bay of Fundy and Gulf of Maine with the rest of the Northwest Atlantic. Strong tidal currents carried through the channel helped shape its seafloor.

2.2.1.2 Surficial Geology: The sediments covering the Scotian Shelf seafloor are an important structural and functional component of the marine ecosystem. Areas with a variety of habitat types, including a diversity of sediment types, may support greater biodiversity than other areas. Surficial sediments are a determining factor in habitat, supporting diverse communities of benthic organisms that contribute to the regulation of carbon, nitrogen and sulphur cycling, water column processes and pollutant distribution (Snelgrove et al. 1997, Snelgrove 1999). The stability of sediments and the communities living on and in them affects the whole ecosystem.

The depth of the surficial sediment layer varies greatly over the Scotian Shelf. Some areas of the inner shelf have exposed bedrock and no surficial sediments, while other parts of the shelf have layers of silty sand a few metres thick. The large, central basins of the shelf have 100 m thick deposits of silt and till (Davis and Browne 1996). The current distribution of sediments on the shelf and slope is a result of geological history and recent physical, biological and chemical processes (Amos and Judge 1991). Although particles continue to be transported to different areas of the shelf, the broad pattern of distribution is relatively stable. Any shifts are caused mainly by storms.

The shallow bank areas are topped by sands and gravel; some areas have extensive shell beds (Davis and Browne 1996). Deeper areas are covered in finer silt and clay interspersed with coarse glacial materials. The Northeast Channel was highly affected by glaciation, with iceberg furrows and glacial till in many areas of the seafloor (Fader pers. comm. Cited in Breeze et al. 2002). The influence of the strong tidal currents is also present: some of the deepest recorded sand waves on the continental shelf are found at depths of 230-260 m (Davis and Browne 1996). On the Scotian Slope, sands and gravels are slumped over the shelf edge in some locations, with silts and clays in others and fine sediments transported by currents moving down the slope (Piper 1991). More details on the surficial sediments of the Scotian Shelf and Slope can be found in publications of the Geological Survey of Canada (e.g., King 1970; MacLean and King 1971; MacLean et al. 1977; Fader et al. 1982; Piper 1991; Fader and Strang 2002; and Piper and Campbell 2002).

2.2.2 Climate

The ocean has a large influence over the province's climate. In the Maritimes, the waters of the Atlantic Ocean, Gulf of Maine and Gulf of St. Lawrence moderate the climate such that winters are generally long and mild, and summers are short and cool. Generally, regional winter temperatures average -50°C, whereas summer temperatures are around 14°C (AECOM 2010). A detailed description of Nova Scotia's climate is provided in *The State of Nova Scotia's Coast Report (2009).*

The conditions of the North Atlantic Ocean and, therefore, the Scotian Shelf, are largely influenced by the North Atlantic Oscillation (NAO). The NAO affects water properties (temperature and salinity), vertical mixing, sea ice coverage, and circulation through air-sea heat exchange and wind stress (DFO 2008; Hurrell and Deser 2009). The NAO index is a measure of the difference of the atmospheric pressure at sea level between the Azores and Iceland in winter. A high index brings increased westerly winds, precipitation, and results in warmer water temperatures for the Scotian Shelf. A low index brings drier conditions, a decrease in storms and cooler water temperatures (DFO 2010a).

Air temperatures for the Scotian Shelf are measured at Sable Island. Sable Island air temperature has a weak long term increasing trend, amounting to 1°C over the length of the record (DFO 2008). In 2007, annual air temperatures over the Scotian Shelf were below normal and cooler than 2006 (DFO 2008).

2.2.3 Sea Level

Relative sea level is measured with respect to a fixed reference point on land (Petrie et al. 2009), averaged over a period of time so that fluctuations due to waves or tides are smoothed out. There are many factors that contribute to short term or periodic sea level changes; however, longer term change can be attributed to two main causes: a change in the volume of water in the ocean and changes caused by the sinking or rising of land. Changes in the volume of water may be due to rising or lowering of temperatures, leading to the thermal expansion or contraction of water, as well as changes in the amount of water stored in polar ice and on land in glaciers, lakes, rivers, and other reservoirs. In Atlantic Canada, the land is still rising and sinking in response to the retreat of the last glacier more than 10 000 years ago. This rising and sinking, known as post-glacial or isostatic rebound is causing a large area, including Nova Scotia, to sink and thus sea levels to rise. Overall, there is a general trend of sea level rise on the Atlantic coast of Nova Scotia. Petrie et al. (2009) estimated a total value of 31.9 cm/century at Halifax, with 23 cm/century attributable to post-glacial rebound (Tushingham and Peltier 1991 cited in Petrie et al. 2009).

2.2.4 Oceanographic Conditions

The Scotian Shelf is most strongly influenced by three currents: the Nova Scotia Current, the Labrador Current and the Gulf Stream. Relatively cool, fresh waters flow from the Gulf of St. Lawrence through the Cabot Strait. Part of this flow turns at Cape Breton to flow southwestward along Nova Scotia’s Atlantic coast, while the rest of the flow continues through the Laurentian Channel to the shelf break. There, it turns and joins with the Labrador Current to flow southwestwards along the shelf edge. The third major current, the Gulf Stream, flows northeastwards. Its warmer, saltier waters mix with the cool Labrador Current waters over the Scotian Slope, forming a water mass known as slope water. The slope water periodically leaks onto the shelf through the channels as well as The Gully submarine canyon. The influence of these currents varies spatially and seasonally, with the cool waters from the Gulf of St. Lawrence and Newfoundland Shelf more strongly affecting the banks of the eastern Scotian Shelf, and the Gulf Stream more strongly affecting the Slope and deep channels and basins of the shelf. Overall, the general flow is from the northeast to the southwest across the shelf, with this flow strongest in the winter and weakest in the summer. Water transports food and oxygen, removes wastes and also conveys certain organisms from place to place. These same currents also distribute human wastes (including municipal, agricultural and industrial wastes) around the marine environment (Zwanenburg et al. 2006). A fuller description, with references, of the major currents and water masses in this region can be found in Breeze et al. (2002) and Zwanenburg et al. (2006).

In addition to the major currents described above, circulation patterns in different areas of the shelf and slope are influenced by local conditions (**Figure 2-2**). The topography of the seafloor interacts with currents and creates localized circulation patterns. For example, tidal currents washing over the edges of the banks results in gyres or partial gyres over same of the banks. These gyres retain particles, such as plankton, for a period of time in one area, and may be important for larval stages of fish and invertebrates (see complete references and discussion in Breeze et al. 2002). Tidal currents have a strong influence on circulation patterns of Browns Bank (Hannah et al. 2001).

Oceanic fronts exist where currents and water masses with different water properties meet and create a boundary. The primary front on the Scotian Shelf is the shelf/slope front (Breeze et al. 2002). Organisms like plankton and jellyfish tend to collect at fronts, attracting predators such as sea turtles and whales to the area (Breeze et al. 2002).

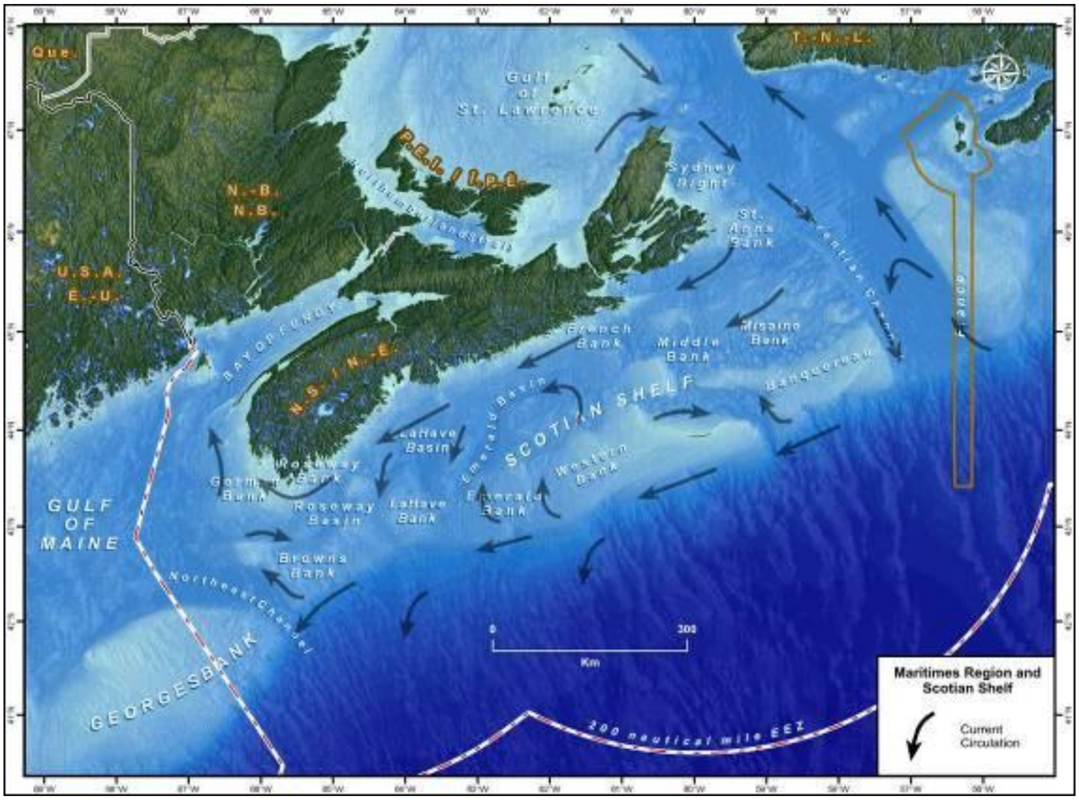


Figure 2-2: Detailed surface circulation on the Scotian Shelf (Source: adapted from C. Hannah in Breeze et al. 2002).

<u>2.2.4.1 Temperature and Salinity</u>: Temperature and salinity have profound impacts on the distribution, growth and survival of marine organisms. Each organism has a particular range of temperature and salinity that is optimal for its success.

Scotian Shelf water temperatures are, from year to year, among the most variable in the North Atlantic Ocean. Temperatures vary widely across the Shelf, with the western Scotian Shelf remaining generally warmer than the eastern Scotian Shelf (Breeze et al. 2002). The temperature regime of the western Scotian Shelf is also seasonally and spatially more dynamic than the eastern Scotian Shelf. Surface temperatures show the greatest seasonal variation and can range in places over 15°C from summer to winter. Trends in the last two decades show that water temperatures between 1987-1993 and 2003- 04 were cooler than normal, while 1999-2000 was warmer than normal (DFO 2010a). In 2007 the sea surface temperatures were above normal on the eastern and central Scotian Shelf and below normal elsewhere. Subsurface and bottom temperatures were cooler than normal (DFO 2009a). Variability in water temperature has been increasing in the past decade (DFO 2010a).

Salinity is another important characteristic of the ocean. The Scotian Shelf waters are less saline than both the Labrador Current and the Gulf Stream, which vary between 34-35 parts per thousand (ppt) and 35-36 ppt respectively, and coastal areas tend to be less saline than slope and basin areas (Breeze et al. 2002).

The density of seawater is dependent on temperature, salinity, and pressure and it increases with depth. The difference in the density of water at different depths is referred to as density stratification (DFO 2009a). Increased stratification can affect vertical mixing, decrease nutrient fluxes and decrease phytoplankton production (DFO 2009a). On the Scotian Shelf, stratification has increased since 1960, but most significantly since the 1990s (DFO 2010a). The waters of the Scotian Shelf typically form layers that vary by region and season. During the winter: a cooler, fresher surface overlays a warmer, saltier layer. In the summer three layers exists with a warm, low salinity surface layer, a cold intermediate layer and a warm, high salinity bottom layer (Breeze et al. 2002).

A full description of historical temperature and salinity trends in this region can be found in Breeze et al. (2002). Current trends are described in detail in DFO Science State of the Ocean reports available through the Canadian Advisory Science Secretariat website http://www.dfompo.gc.ca/CSAS/Csas/Publications/SARAS/2009/2009_054_e.pdf; http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/SAR-AS/2008/SAR-AS2008_025_e.pdf

2.2.5 Habitats

A wide variety of habitats can be found on the Scotian Shelf and Slope, from kelp beds that support large populations of sea urchins to bedrock outcrops with a diversity of corals and sponges to deep waters of the open ocean where anglerfish and other rarely seen species live. Habitat is influenced by the characteristics of the seabed, such as its depth, the surficial sediments overlaying it, the degree of slope of the seafloor and characteristics of the water column, such as salinity, temperature, nutrients and currents. It also includes plants and animals that may be used as homes for other species. These attributes are important both at a fine scale (millimetres) and coarse scale (tens to hundreds of kilometres). The ocean is a dynamic environment and changes in oceanographic conditions can change habitat suitability for particular species or groups of species. Highly mobile species may be able to quickly adapt to changes in habitat by leaving areas with less preferred features; however, more sedentary species do not have that ability. At the same time, there are many general habitat features that persist over the long term. Classification schemes have attempted to divide the Scotian Shelf into different habitats based on these persistent features (see *Marine Habitats and Communities*).

Several different habitat classification schemes have been developed to help describe the environment of the Scotian Shelf and Slope, each with its own strengths and weaknesses. *The Natural History of Nova Scotia* divided Nova Scotia and its offshore waters into several different theme regions (Davis and Browne 1996). Physiographic features were used to divide the offshore/continental shelf region into four large districts. Those districts were then divided into smaller units using the shape of the seafloor as well as other factors that contribute to habitat. Recently, the World Wildlife Fund (2009) produced a seabed feature map that used similar divisions to the *Natural History of Nova Scotia*, but with more up to date information. A "habitat template" approach taken by Kostylev and Hannah (2007); (see also DFO 2005) classifies habitat along two axes, disturbance and scope for growth, and maps the Scotian Shelf based on those features. From those maps, the degree of vulnerability of benthic organisms to disturbance and their ability to recover from disturbance can be inferred (DFO 2005).

In this region, coastal classification systems have focussed largely on aspects of the coast above the water (see e.g., Davis and Browne 1996, Schaefer et al. 2004). However, this does not necessarily reflect the undersea features or the hydrological properties. More recently, Greenlaw (2009) undertook a classification of inlets along the coast of mainland Nova Scotia, which grouped the inlets into various categories based on hydrographic inlet type, productivity regime and "complexity", with complexity made up of several factors that contribute to habitat heterogeneity (i.e. the range of differences in habitat). Most classification schemes focus on the physical aspects of the environment. However, structure-forming species also play an important role in providing habitat. Biogenic habitats are areas where dense concentrations of plants and animals provide habitat for other species (Tyrrell 2005). Seaweed beds, eelgrass beds, salt marshes, mussel beds, and aggregations of cold-water corals and sponges are distinguished by high densities of structure-forming species. Biogenic habitats offer surfaces for attachment, hiding places, and refuge from strong currents; they may also be a source of food for the species they host (Tyrrell 2005).

The Gully

The Gully is a Marine Protected Area (MPA) under Canada's *Oceans Act*. The Gully was Canada's second *Oceans Act* MPA, and the first in the Atlantic Region. The largest submarine canyon in eastern North America, it is located 200 kilometres off Nova Scotia, to the east of Sable Island on the edge of the Scotian Shelf. The canyon plunges to two and a half kilometres in depth below the ocean surface. The Gully was formed thousands of years ago by erosion when sea levels were much lower. Over 65 km long and 15 km wide, the Gully is one of the most prominent undersea features on the east coast of Canada. It contains a rich diversity of marine habitats and species, and is nationally and globally acknowledged as an exceptional marine habitat. The Gully contains the highest known diversity of coral in Atlantic Canada. Many species of marine mammals are attracted to the Gully by the abundant food supply. The deepest part of the canyon is especially important for the Scotian Shelf population of northern bottlenose whales, a population listed as endangered under Schedule 1 of the *Species at Risk Act*. Each whale species that uses the Gully has particular habitat preferences, with distributions determined by prey abundance, temperature and underwater topography. Considering the habitat needs and distribution of these species, waters deeper than 200 m have been identified as a general area of importance to most cetaceans. The northern bottlenose whale is mainly found in areas of the Gully where waters are deeper than 800 m. The Gully has been defined as critical habitat, under the *Species at Risk Act* for the Scotian Shelf population of the Northern bottlenose whale.

Many different species of fish live in the Gully. Halibut are common in ocean bottom environments. Redfish, argentine, dogfish, cusk and several species of hake are among the many demersal fishes that inhabitat the Gully. Swordfish can be found in surface and near-surface waters in the summer and fall when waters are warm. Lanternfishes (small fishes with luminescent organs) are important prey for many larger species. There are still questions about what lives in the deepest parts of the canyon and there are many species yet to be discovered.

2.2.6 Fauna and Flora

It is internationally recognized by scientists that there remains a lack of understanding of what lives in our oceans. In 2000, world scientists came together to begin the Census of Marine Life, aimed at developing a greater understanding of the diversity, distribution and abundance of marine species (Ausubel et al. 2010). The following section provides an overview of the known flora and fauna of the Scotian Shelf. A more detailed description is provided in Breeze et al. 2002.

2.2.6.1 Planktonic Communities: Plankton refers to animals and plants that drift in the water and are unable to swim against currents.

Phytoplankton are the base of the marine foodweb and the primary food source for the animal component of the plankton (zooplankton). Phytoplankton are distinctive among ocean biota in that they derive their energy and structural materials directly from the environment. They require light and nutrients (e.g. nitrate, phosphate, silicate) for their growth. On the Scotian Shelf, diatoms and dinoflagellates are the largest and most common phytoplankton (Breeze et al. 2002). Their abundance is determined by the Shelf's complex physical oceanographic features. There is a distinctive seasonal cycle of growth characterized by a widespread spring "bloom" and a more diffuse fall bloom. Blooms are a high concentration of phytoplankton in an area caused by increased reproduction and resulting in a discoloration of the water (Garrison 2005). Blooms vary in duration and scale. Trends in the magnitude and duration of the spring bloom on the Scotian Shelf indicate that blooms begin earlier now than they did in the 1960s and 1970s and are more intense and longer (Zwanenburg et al. 2006). Zooplankton are divided into three main categories on the basis of size: microzooplankton, mesozooplankton, and macrozooplankton.

Zooplankton are important food sources for higher trophic levels, including juvenile groundfish, pelagic fish species and baleen whales (Zwanenburg et al. 2006). The mesozooplankton on the Scotian Shelf is dominated by copepods. Three species of copepods, known as Calanus, make up > 70% of the copepod biomass. *Calanus finmarchicus* appears to be a significant link in the food chain (Zwanenburg et al. 2006) On the Scotian Shelf, zooplankton levels have been lower in more recent years than in the 1960s/70s (the reverse of the phytoplankton trend) and are beginning to recover from the lows observed in the 1990s (Harrison et al. 2007).

Plankton research and monitoring has been occurring on the Scotian Shelf for decades. A more detailed description of research related to plankton is provided in Breeze et al. 2002.

2.2.6.2 Marine Plants: ***Marine plants*** are macrophytic marine algae commonly referred to as seaweeds. The *Natural History of Nova Scotia* produced by the Nova Scotia Museum of Natural History provides a general overview of marine plants in Nova Scotia. Seaweeds along the rocky shores of Nova Scotia can be grouped into the following categories: green algae, red algae and brown algae. Green algae need a large amount of light and are generally found closer to the surface in intertidal or shallow subtidal areas. Nova Scotia has 82 known species of green algae. Red algae are able to grow at greater depths and are generally found in the intertidal zone, below the low water mark. Common red algae in Nova Scotia include Irish moss. Brown algae are the dominant seaweeds and are exclusively marine. Kelp is the largest of the brown algae and is found in the subtidal zone. Rockweeds are common in the intertidal zone (Davis and Browne 1996).

Seagrass is a general term for flowering plants that live in low intertidal and subtidal marine environments. Seagrass beds are acknowledged to be highly productive areas within coastal waters (Parker and Worcester 2010). Eelgrass is the dominant seagrass found in coastal and estuarine areas of the western North Atlantic. Eelgrass beds rank among the most highly productive ecosystems in the world (DFO 2009a). Eelgrass also plays an important role in stabilizing sediments and buffering the shore line and offers shelter for many species (DFO 2009b). It was estimated that there were once 20 000 ha of eelgrass beds in Nova Scotia during the 1970s (DFO 2009b). Eelgrass on the Atlantic coast of Nova Scotia has been declining in recent decades. There is limited information for the entire coast however, some locations reported declines from 30% to 90% (DFO 2009b).

2.2.6.3 Benthic Organisms: Benthic invertebrate species include species that live within the bottom substrates (infaunal) and on the seafloor (epifaunal). Generally more is known about species that are found on the seafloor.

Invertebrates: Infaunal and non-commercial: The non-commercial benthic invertebrate species found in Nova Scotia's waters represent many billions of animals, stretching from the shallow intertidal organisms to deep water abyssal species (Breeze et al. 2002). Most of these species are not well studied and not well described beyond the intertidal zone (Breeze et al. 2002). As mentioned previously work is underway to classify benthic communities of the Scotian Shelf. Examples of infaunal non-commercial invertebrates found on the Scotian Shelf include various polychaete worms. Epifaunal organisms include certain echinoderms (starfish and sand dollars), anemones, corals, sponges and tunicates. Research is increasing on corals and sponges on the Scotian Shelf.

Cold-water corals are suspension-feeding invertebrates with feathery tentacles that capture food particles from the water column. Unlike their tropical counterparts, cold-water corals do not have symbiotic algae and can live far below the reach of sunlight. Many corals require a hard substrate for attachment; however some species can anchor in soft sediments. Corals can occur in many shapes, sizes and forms and some species can form reefs. They are slow growing and some may be over 100 years old. On the Scotian Shelf, corals are concentrated in areas with high current activity (Breeze et al. 1997, Mortensen et al. 2006). Corals represent a varied habitat for other organisms, such as fish, shrimp and sea stars. They offer shelter from predators, a nursery area for juveniles, and attachment substrate for other organisms (DFO 2010b).

Around 25 to 30 species of corals have been identified off the Atlantic Coast of Nova Scotia. They can be organized in two major groups, hard or stony corals (Scleractinia) and octocorals. Both solitary and colonial (reef-building) forms of corals are found along the slope of the Scotian Shelf (DFO 2006). A live colony of the reef building coral, *Lophelia pertusa*, has been found at the mouth of the Laurentian Channel on the Scotian Shelf. The solitary cup corals are widespread in soft sediments along the Slope and are also found in basins of the Scotian Shelf.

Octocorals include sea pens, sea whips, sea fans and "soft corals." The largest octocorals on the Scotian Shelf are the gorgonian corals: bubblegum and seacorn corals. These corals prefer habitats of hard sea bottom and attach themselves to large rocks and boulders. They have only been found in the channels between the banks and in the canyons. Sea pens and small gorgonians are found on soft sediments and are able to anchor to them. A relatively high concentration of sea pens has been identified near Middle Bank on the Scotian Shelf (Kenchington et al. 2010).

Sponges are marine invertebrates that attach themselves to bottom substrates. Sponges are filter feeders and are generally found at depth below 300 m. Sponges can provide substrate and offer shelter for other organisms (DFO 2010b). A unique and significant population of Russian Hat sponges has been identified in Emerald Basin. This is the only confirmed glass sponge ground on the east coast of Canada (Boutillier et al. 2010) and the largest known aggregation in the world.

More information on corals and sponges on the Scotian Shelf is available in the Coral Conservation Plan (DFO 2006), *The Current State of Knowledge Concerning the Distribution of Corals in the Maritime Provinces* (Cogswell et al. 2009), *Delineating Coral and Sponge Concentrations in the Biogeographic Regions of the East Coast of Canada Using Spatial Analyses* (DFO 2010b) and the *Marine Habitats and Communities* theme paper.

***Invertebrates: Key commercial species*:** There are 28 invertebrate species that have commercial value on the Scotian Shelf. These include crustaceans (lobster, snow crab, Jonah crab, rock crab, northern shrimp), bivalves (sea scallop, Atlantic surf clam, Iceland scallop, ocean quahog), snails (periwinkle, whelk), cephalopods (squid), and echinoderms (sea cucumber, sea urchin) (Breeze et al. 2002). Information on selected benthic invertebrates has been collected on DFO's annual research surveys since 1999. Tremblay et al. (2007) provides survey data of selected invertebrate species captured from research vessel surveys. Survey data are the primary source for monitoring trends in species distribution, abundance and biological condition. The data are used by scientists along with other sources of data to develop assessments of a species status. For recent reports of species found on the Scotian Shelf the reader is directed to the Canadian Science Advisory Secretariat (CSAS) website http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Groundfish spend much of their life near the ocean bottom. Groundfish, including the gadoids (e.g., cod, pollock, haddock), skates and flatfishes (e.g., pleuronectid flounders), are a major component of the marine ecosystems of the Scotian Shelf. DFO has been conducting research vessel surveys on the Scotian Shelf since the 1970s. Clark and Emberley (2009) provide a summary of species captured and trends in abundance for certain species from the 2008 Scotian Shelf summer research vessel survey. Similar to invertebrates, survey data are the primary source for monitoring trends in species distribution, abundance and biological condition. For recent reports of species found on the Scotian Shelf the reader is directed to the Canadian Science Advisory Secretariat (CSAS) website http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

A recent National Science Advisory Report (DFO 2010a) summarizes major changes in the status and trends of Canadian marine ecosystems. A significant change in the Scotian Shelf ecosystem was a community shift from a large bodied groundfish dominated system to a pelagic and invertebrate dominated system. There has also been a decline in the size and condition of a number of groundfish species. More information is provided in *Canadian Marine Ecosystem Status and Trends Report* (DFO 2010a) and *The Ecosystem Status and Trends Report for the Gulf of Maine and Scotian Shelf* (Worcester and Parker 2010). The current status and trends of marine species and communities will be discussed in the theme papers: Fish Stock Status and Commercial Fisheries, and Marine Habitats and Communities.

2.2.6.4 Pelagic Organisms: ***Pelagic fish*** of the Scotian Shelf include highly migratory species such as tuna, swordfish and sharks (Breeze et al. 2002). Pelagic organisms live in the water column and at the surface. There are 19 species of sharks that occur in Atlantic Canada. Five species are considered common residents of the Scotian Shelf: the blue shark, porbeagle, shortfin mako, basking shark and the spiny dogfish (Zwanenburg et al. 2006). Smaller pelagic species include capelin and herring. Although less is known about species that live in the mesopelagic or deeper water of the slope and abyssal plain, over 200 species have been identified in water depths ranging from 1000 to 4000 m. Of these Myctophids (lanternfish) are the dominant family making up about 30% of the species composition (Themelis 1996).

Diadromous fish spend part of their lives in freshwater and part in salt or brackish water. Diadromous species (fish that live in both fresh and salt water) found on the Scotian Shelf include Atlantic salmon, gaspereau, sea lamprey, striped bass, Atlantic sturgeon and American shad (Breeze et al. 2002). Anadromous species, which are born in freshwater, migrate to the ocean and return to freshwater to spawn. Catadromous species live in freshwater and migrate to the ocean to spawn. The only catadromous species found on the Scotian shelf regularly is the American eel.

Pelagic invertebrates Shrimp and short finned squid are two pelagic invertebrates found on the Scotian Shelf. For both of these organisms their distribution is directly related to water temperature (Breeze et al. 2002). Aside from these two species, which are commercially fished, there is limited information on the occurrence and distribution of pelagic invertebrates on the Scotian Shelf (Breeze et al. 2002).

2.2.6.5 Sea Turtles: Three species of sea turtles occur on the Scotian Shelf and Slope. The Atlantic leatherback turtle forages for jellyfish in the waters of the shelf during the summer and fall, migrating to warmer waters for the winter and nesting in beaches in the Caribbean and Gulf of Mexico (ALTRT 2006). The Atlantic leatherback is listed as endangered and is protected under Canada's *Species at Risk Act*.

Immature loggerhead turtles occur regularly at the edge of the Scotian Shelf and on the slope, preferring relatively warm waters (above 20 °C) (Brazner and McMillan 2008). They migrate north to the shelf edge during the summer months and return south for the winter. The Kemp's ridley turtle has occasionally been reported in waters off Nova Scotia; however, it is generally found further south and the Scotian Shelf is not considered to be its regular foraging habitat (Marquez 1994, TEWG 2000).

The occurrence of a fourth species, the green turtle, has recently been documented on the Scotian Shelf (James et al. 2004). It is not expected to occur regularly in the area.

2.2.6.6 Marine Mammals: There are three groups of marine mammals that inhabit the Scotian Shelf throughout the year, large cetaceans (large whales), small cetaceans (small whales and dolphins) and seals.

***Cetaceans*:** Whales are an important part of the regional ecosystem. Waring et al. (2000) reviewed the population status for cetaceans in the northwest Atlantic but in most cases it is not possible to determine what fraction of the population might use the Scotian Shelf. In 2007, DFO conducted a large-scale aerial survey of marine megafauna in the Northwest Atlantic (Lawson and Gosselin 2009). During this survey, 20 species of cetaceans were identified on the Scotian Shelf. Common dolphins were the most abundant species, followed by pilot whales and white sided dolphins (Lawson and Gosselin 2009). Other cetaceans identified on the Scotian Shelf include, fin whale, minke whale, humpback whale, sperm whale, pilot whale, sei whale, Northern bottlenose whale, blue whale, harbour porpoise, North Atlantic right whale, and killer whale (Lawson and Gosselin 2009).

Some whales can be found year-round on the Scotian Shelf, while others are present only at particular times of year. The Scotian Shelf population of Northern bottlenose whales (*Hyperoodon ampullatus*), listed as endangered under Canada's *Species at Risk Act*, are year-round residents of the Scotian Shelf. The most recent analysis estimated a Scotian Shelf population of about 168 whales (DFO 2010c). The Scotian Shelf population of Northern bottlenose whale is primarily found in the Gully, and Shortland and Haldimand canyons on the Scotian Shelf. These areas are used for feeding, socializing and mating and have been identified as critical habitat for this endangered population of Northern bottlenose whale.

The North Atlantic right whale can be found on the Scotian Shelf in the summer months. This whale is listed as endangered under Canada's *Species at Risk Act*. In 2003, the population of North Atlantic right whales in Atlantic Canadian waters was estimated to be 322 whales (Brown et al. 2009). The right whale has been known to occur throughout the central and eastern parts of the Shelf. However, an area of particular importance to this species is Roseway Basin and it has been identified as critical habitat for the North Atlantic right whale (Brown et al. 2009).

Seals**:** Sable Island is a significant area for seals on the Scotian Shelf. It is important for two breeding populations of seals: it has about 80% of the world's largest breeding population of grey seals (Thomas et al. 2007) and a much smaller number of breeding harbour seals (less than 50). The Sable Island grey seal population has increased from about 12 000 in 1977 to 242 000 in 2007 (Thomas et al. 2007). However, since the late 1990s the rate of increase has slowed (Bowen et al., 2007). Seals feed in the waters off Sable Island and in the Gully year-round. Harp, hooded and ringed seals are occasionally found on the northeastern Scotian Shelf but are not usually observed in waters further south than Sable Island.

2.2.6.7 Seabirds: The shallow fishing banks of the outer Scotian Shelf and the edge of the shelf are important foraging areas for pelagic seabirds. Both Sable Island Bank and the Scotian Slope have high concentrations of seabirds year-round (Lock et al. 1994). The area north of Sable Island, where there is mixing of waters caused by a gyre on Sable Island Bank, is an area of consistently high seabird numbers (Lock 1998). Few of the species found in the offshore nest in the region; however, Sable Island has been designated a Migratory Bird Sanctuary and is an important tern nesting area. The endangered Roseate Terns nests on the island as do Common and Arctic Terns. The most abundant seabirds on the Scotian Shelf are terns and large gulls (Gaston et al. 2009). The eastern Scotian Shelf has high numbers of wintering Dovekie, Sooty Shearwaters and Greater Shearwaters (Brown 1988; Zwanenburg et al. 2006). The area generally marks the southern wintering range for species like the Thick-billed Murre, Common Murre, Atlantic Puffin, Northern Fulmar, and Glaucous and Iceland gulls (Zwanenburg et al. 2006), although there are a few breeding colonies of Atlantic Puffins in the region (Lock et al. 1994). During the spring and fall migrations, the shelf also lies on the flyway for many species, including birds that nest along Nova Scotia's coasts as well as those that nest much farther north (Lock et al. 1994). During the summer, Leach's Storm Petrels nest on coastal islands but range widely offshore. The Wilson's storm petrel can also be found in the region from the summer (southern hemisphere winter), migrating from its southern hemisphere breeding grounds (Lock et al. 1994), as can the Greater and Sooty Shearwaters.

Common Pelagic Birds of the Eastern Scotian Shelf

- Greater Shearwater
- Herring Gull
- Great Black-Backed Gull
- Northern Fulmar
- Black-legged Kittiwake
- Thick-billed Murre
- Dovekie
- Sooty Shearwater
- Wilson's Storm Petrel
- Leach's storm petrel

(Bundy 2004)

In 2005, the Canadian Wildlife Service began a renewed effort to survey birds in the marine waters of Atlantic Canada (Gjerdrum et al. 2008). Results from these surveys should improve the understanding of seabird distribution on the shelf and slope. More information on seabirds on the Scotian Shelf and slope can be found in Brown (1986); Lock et al. (1994); Huettman (2000); Breeze et al. (2002); and Gaston et al. (2009).

2.3 SOCIO-ECONOMIC OVERVIEW

This section provides an overview of the current social and economic environments in Nova Scotia with respect to their importance to the Scotian Shelf and sets the context for the ocean use sectors outlined in the subsequent pages. Although the focus is the Scotian Shelf, much of the data relates to the province as a whole. Unless specialised studies have been undertaken, it is often not possible to separate Scotian Shelf information from provincial information, particularly in the socio-economic context. The socio-economic environment includes demographic and economic considerations, public health and safety, culture, and aesthetic factors. Humans have been an integral part of Nova Scotia and activities on the Scotian Shelf since the earliest settlers in the region. To understand the human impact to the marine ecosystem, we must consider the historic and current patterns of human activity within the region.

2.3.1 Historical Perspective

The ocean has shaped human activities in Nova Scotia from the earliest inhabitants to the present day. Resources from coastal and marine environments have played a major role in the province's history and economy. Human interaction with coastal and offshore waters has shaped Nova Scotia's landscape and human-settlement patterns (Davis and Browne 1996). The Atlantic Ocean and its harbours provided a livelihood, a means of transportation and a portal to the rest of the world.

2.3.1.1 First Inhabitants: Before European contact, coastal and offshore waters provided transportation routes, abundant food, and other resources for the Mi'kmaq. They travelled seasonally from the coast to inland areas to take advantage of different resources; along the coast, they fished, collected shellfish, hunted seals and waterfowl, and gathered bird eggs (Davis 1997). While we do not know how far offshore they travelled, the Mi'kmaq had large ocean going canoes that were capable of travelling across the Bay of Fundy and from Nova Scotia to Newfoundland and Prince Edward Island (Davis 1997). They fished for porpoise, swordfish and small whales in deeper waters off the coast (Whitehead and McGee 1983).

John Cabot's arrival in North America in 1497 and the lure of the cod fishery off its shores began a phase of European exploration of the lands and waters of present-day Nova Scotia. While no permanent European settlements were established in the province until 1605, Portuguese and Basque fishermen began travelling to the rich fishing banks off Newfoundland and Nova Scotia before then (Davis and Browne 1996). They established temporary "fishing stations" on land to dry their fish, with Canso ("Canseau") being one of the earliest, frequented by French vessels from the mid-part of the sixteenth century (Morandière 1962). In 1521, the Portuguese established a fishing station, San Pedro, at the present site of St. Peter's, Cape Breton (Hamilton 1997) and were reported to have left cattle on Sable Island in the early to mid-1500s (de Villers 2004). The early fishermen and explorers traded with the Mi'kmaq, and there were metal pots and European clothing in use by the Mi'kmaq by the time of the first permanent settlement in Nova Scotia in 1605 (Whitehead 1991). Interaction with Europeans and the diseases they carried devastated the population of Mi'kmaq, which is estimated to have been reduced by 80 to 90 percent in the first century after contact (Davis 1997).

2.3.1.2 European Settlement: Samuel de Champlain mapped much of the coast of Nova Scotia and New England in the period 1604-1607, and the expedition he was part of added several enduring place names to maps and charts of the province, including LaHave (from "La hève"), Port Mouton, and Rossignol. French colonists trickled into Acadie over the next century, and the population grew from about 500 in 1680 to 14 000 in 1755 (StatsCan 2011a, StatsCan 2011b). Although most of the colonists settled around the Bay of Fundy, there were a few communities on the Atlantic coast: Cape Sable Island, Petite Rivière, Lingley (Liverpool), as well as St. Pierre (formerly San Pedro, now St. Peter's) and Port Dauphin (Englishtown), Cape Breton (McLennan 1918, Brown 1922).

Throughout the first half of the eighteenth century, the British and French exchanged territories in North America, largely due to outcomes of European wars. In 1713, mainland Nova Scotia became British. In 1719, the French began construction of the Fortress of Louisbourg, intended to be a strategic centre that would allow it to defend its remaining possessions in North America and the Caribbean. The fortress was captured in 1745, returned to the French in 1748, and surrendered again in 1758. In 1763, Cape Breton was ceded to Britain as part of the Treaty of Paris.

The British initially valued Nova Scotia more for its strategic position than for its settlement potential. In 1749, they set up a fortress in Chebucto Harbour and renamed the area, Halifax. Strategically it was intended to be Britain's primary North Atlantic naval station, to rival Louisbourg. However, the British were uneasy about the large number of Acadians and their level of loyalty to the British Crown. This unease was compounded by the close relationship of the Mi'kmaq with the Acadians. The British did not have good relations with the Mi'kmaq, as evidenced by several scalp proclamations in the mid-1700s (Paul 2000).

The British encouraged German, French and Swiss Protestants to settle in the province to counteract the Acadian Roman Catholic population. The immigrants, known as the "foreign Protestants" settled largely along the Atlantic coast of Nova Scotia, particularly in the Lunenburg area, although their descendants were granted land in Halifax, Guysborough and Queens Counties (Bell 1961). These were the founders of many of the fishing communities that used the resources of the Scotian Shelf to the present day. Still concerned about the Acadians, in 1755, British officials deported the vast majority, significantly diminishing the population of the province. The Acadian presence continued in the province: some Acadians hid or were imprisoned and avoided deportation; others returned a few years later. On the Atlantic coast, several coastal communities in Yarmouth County, Halifax County and Guysborough County were founded by Acadians; they also continued to have a strong presence in Richmond County, particularly on Isle Madame.

By the nineteenth century, lands were being reserved for the Mi'kmaq that represented a small fraction of their original territory. In Cape Breton, several reserves were on the coast of the Bras d'Or Lakes, allowing the Mi'kmaq access to the resources of the Lakes. There were only a few small reserves provided on the Atlantic coast of Nova Scotia; these were reduced even further with the twentieth century policy of centralization (Paul 2000). The Mi'kmaq continued to use the resources of the coast and the inland waterways; however, their way of life had drastically changed.

Other waves of immigration affected settlement on Nova Scotia's Atlantic coast. New England Planters arrived following the Acadian expulsion, largely settling on the former Acadian lands in the Annapolis Valley but also founding Liverpool on the South Shore (Brown 1922).

Twenty-five thousand Loyalist refugees came to Nova Scotia following the American Revolution. They settled along the coast near fish and lumber resources. Shelburne and many communities in Shelburne County were founded by Loyalists, as were Country Harbour and other Guysborough County communities. Black Loyalists founded several coastal communities, such as Birchtown, Shelburne County and Isaac's Harbour, Guysborough County (NS Museum 2001). Another major influx of settlers occurred in the 1770s and early 1800s, when large numbers of Highland Scots and Irish immigrated to eastern Nova Scotia (Davis and Browne 1996).

2.3.1.3 Industry and Marine Resources: Although Sydney was first settled in the late 1700s, it was the development of industrial coal mining starting in the 1820s that drove expansion of the city and communities in the surrounding area. The mines and subsequent industrial development attracted a diversity of immigrants and drove development of the port. There were coastal mines in other parts of the province as well: nineteen mining companies flocked to Sherbrooke when gold was discovered near there in 1861 (NS Museum 2011).

While there were efforts to farm in most areas of the province, fishing and forestry were the main industries in most rural coastal communities. As the province's timber industry grew, so did the shipbuilding industry, with Yarmouth County one of the nineteenth century shipbuilding centres of the Maritimes (Nova Scotia 2009). Shelburne, Lunenburg, Sherbrooke, and Guysborough were some of the many other coastal communities that had shipyards.

In the early part of the 19th century, boat services connected Halifax with settlements along Nova Scotia's Atlantic coast, such as Arichat, Lunenburg, Shelburne and Yarmouth (Davis and Browne 1996). Halifax developed into the largest trading port, with ties to Britain, the West Indies and the US East Coast (Nova Scotia 2009). Several deep-water shipping terminals were constructed to take advantage of Halifax's ice-free deep water harbour. The industrialization of Halifax Harbour and its growing importance as a hub for trading and shipping allowed manufacturing to thrive.

From the late 19th Century, sailing ships were replaced by steamships and rail. The development of railways changed trading patterns. As central Canada became more accessible through rail connections in the 1900s and new technology changed the fishing industry, the Maritimes' position in the world market diminished (Davis and Browne 1996). During the two World Wars, Halifax was revitalized as a central port and harbour. Its position as a military base continues today. Much of the Halifax waterfront is still occupied by large naval and industrial uses. The waterfront, however, is also increasingly used for special events and cultural activities (Nova Scotia 2009). The number of active fishing ports and coastal communities with working waterfronts in the province has declined, as some traditional marine-related industries, such as fishing and fish processing, have experienced decline or consolidation. While traditional industries remain an important part of coastal economies, there has been a shift towards tourism, recreational and residential development (Nova Scotia 2009).

2.3.2 Demography

Approximately 934 100 live in Nova Scotia (Statistics Canada 2009) with about 70% living in coastal communities (Coastal Communities Network 2004). The population in Nova Scotia has remained relatively stable, growing by only 0.0005% per year between 1996 and 2006 (Nova Scotia Community Counts 2008). According to the 2006 Census, about 40% of the province's population lives within Halifax Regional Municipality (372 855 people), followed by

Cape Breton Regional Municipality (CBRM) with 11.6% of Nova Scotia's population (105 930 people). Although there are people from varying ethnic backgrounds that live in Nova Scotia, the majority of the population (88.5 %) is of British origin and speaks English as a first language according to the 2006 Census.

It has become increasingly common for Nova Scotians to leave rural communities and move to the urban core of Halifax Regional Municipality. The closure of the groundfish fishery and the steel and coal industries in Cape Breton contributed to making areas outside of HRM less economically attractive (Coastal Communities Network 2004). More recently, there are a greater number of youth completing high school and moving to the urban centre to attain post-secondary education. As a result, there is an increase in the percentage of Nova Scotians with a Bachelor's degree or higher (Nova Scotia Department of Finance 2007).

Another important demographic shift is the aging population. The largest segment of the population is found in the age group from 40 to 60 years. About 15.1% of Nova Scotians are older than 65, and the population of seniors is expected to increase by 70% within the next 20 years (Nova Scotia Department of Finance 2007). Other trends include a decrease in the unemployment rate, a decrease in the number of marriages and a decrease in the number of women having babies (Nova Scotia Department of Finance 2007).

More detailed information on Nova Scotia's demography is available in the *State of Nova Scotia's Coast Report* and *Nova Scotia Social Profile 2001-2006*.

2.3.2.1 Coastal Communities: Most of Nova Scotia's population lives within 20 km of the coast, reflecting both the Nova Scotian's connection to the ocean and the desirability to live and work near the ocean. Coastal communities of the Scotian Shelf include all areas of the region that border the coast and stretch from Clark's Harbour (Shelburne County) to Cape North (Cape Breton). The area encompasses nine out of eighteen counties in Nova Scotia - Shelburne, Queens, Lunenburg, Halifax, Guysborough, Richmond, Cape Breton, Victoria and Inverness.

Coastal communities are changing. The decline of traditional maritime livelihoods, such as fishing is challenging Nova Scotia's coastal communities' sustainability. Coastal communities are also impacted by coastal development, rising property prices, and seasonal residents.

Smaller coastal communities within commuting distance of larger urban centres are experiencing rising household incomes and property values, and stable to growing populations. These changes are driven largely by commuters and seasonal residents from the larger centres (CBCL Ltd. 2009).

Much of the recent discussion about coastal communities has focussed on small rural coastal communities with economies at least partly dependent on their working waterfronts (Coastal Communities Network 2004). In addition to fisheries, this infrastructure supports a thriving tourism industry, boat building activities, public coastal access and is the foundation for numerous additional activities and spin-off businesses (Coastal Communities Network 2004). The *State of Nova Scotia's Coast Report* provides detailed information on Nova Scotia's working waterfront.

2.3.2.2 Aboriginal Communities: Today, the Mi'kmaq live throughout the province. In 2006, there were 24 175 Aboriginal people in Nova Scotia, making up 2.7% of Nova Scotia's total population (Nova Scotia Department of Finance 2008). That is an increase from 1.4% in 1996. Nova Scotia has 13 Mi'kmaq First Nations with community populations ranging from 240 in the Annapolis Valley First Nation to approximately 4000 in the Eskasoni First Nation. In total, there are 13 518 registered Indians in Nova Scotia and of these, 4 752 live off-reserve (Nova Scotia Office of Aboriginal Affairs 2011). The Registered Indian population in Nova Scotia is represented by 13 band councils and two tribal councils, the Confederacy of Mainland Mi'kmaq and the Union of Nova Scotia Indians. The Union of Nova Scoti a Indians tribal council represents the five First Nation communities within Cape Breton (We'koqma'q, Wagmatcook, Membertou, Eskasoni, and Chapel Island First Nations) along with two First Nations located in mainland Nova Scotia (Indian Brook and Acadia First Nations). The remaining six communities are represented by the Confederacy of Mainland Mi'kmaq (Bear River, Annapolis Valley, Glooscap, Millbrook, Paq'tnkek, and Pictou Landing First Nations). In 2006, the Aboriginal population was comprised of North American Indian (63%), Metis (31.8%); Inuit (1.3%) and others (3.8%) (Nova Scotia Department of Finance 2008).

Aboriginal Fast Facts

- The Aboriginal population is much younger than the general population with a median age of 25.4 versus 41.6 for the total population;
- 9557 people (less than 1/3 of the aboriginal population) live on reserve in Nova Scotia.
- There are 34 reserve locations across Nova Scotia;
- A growing portion of the Aboriginal population resides in Halifax (5320).
- 4980 aboriginal people have knowledge of an aboriginal language.

NS Office of Aboriginal Affairs 2008

Other Aboriginal organizations are the Native Council of Nova Scotia and the Maritime Aboriginal Peoples Council, which provides a range of services to Aboriginal people living off-reserve and the Native Women's Association which provides Aboriginal women with a voice in the social, cultural and economic development of the Aboriginal community (Nova Scotia Office of Aboriginal Affairs 2011).

Treaty Rights

Section 35 of the *Constitution Act*, 1982, recognises existing aboriginal and treaty rights. Aboriginal rights are those rights that peoples have due to traditional use and occupancy of land. These rights encompass all aspects of life, including culture, land and traditions. The term "treaty rights" refers to those guarantees explicitly and implicitly agreed upon through historical treaties. Those that affect the Aboriginal people of Nova Scotia include: Treaty of 1725 (and subsequent ratification treaties); Treaty of 1752; Treaty of 1760; The Royal Proclamation 1763, and Treaty of Watertown 1776. These provide the Aboriginal peoples with rights to coastal resources, but do not currently give them legislated jurisdictional responsibilities (State of the Nova Scotia Coast 2009). In Nova Scotia, a tri-partite forum, *The Made-in- Nova Scotia Process* has been established between the Mi'kmaq, Nova Scotia and Canada to resolve issues related to treaty and Aboriginal rights. On February 23, 2007, the Parties signed the *Mi'kmaq-Nova Scotia-Canada Framework Agreement*, which outlines procedures that will guide the negotiations and the topics to be covered (http://www.gov.ns.ca/abor/office/what-we-do/negotiations).

Duty to Consult

The Government of Canada has a duty to consult, and where appropriate, accommodate Aboriginal peoples where the interests of Aboriginal peoples may be affected by a Crown action or decision. In 2007, Nova Scotia and Canada developed a policy to reflect the province's commitment to meaningful consultation with Mi'kmaq of Nova Scotia (Nova Scotia Office of Aboriginal Affairs http://www.gov.ns.ca/abor/office/what-we-do/consultation/). As part of the commitment, the Mi'kmaq-Nova Scotia-Canada Consultation Terms of Reference was developed and was formally approved in 2010.

2.3.3 Economic Overview

By improving our understanding of the role of the ocean in the economy, decision-makers are more informed when developing policies aimed at protecting the marine environment, supporting sustainable activities and communities, and providing leadership in ocean stewardship. Nova Scotia's gross domestic product (GDP) in 2009 was $34 billion (Nova Scotia Department of Finance 2011). Between 2003 and 2007, the economy of the province grew by 4.9%. Nova Scotia's economy is largely service based, with 76% of its GDP generated by service industries and only 8% arising from natural resource based industries (CBCL Ltd. 2009). Activities dependent on the ocean make a substantial contribution to the Nova Scotia economy. In 2005 an overview of the *Economic Value of the Nova Scotia Ocean Sector* was prepared by Gardner Pinfold and subsequently updated in 2009. Gardner Pinfold (2005) defines the ocean economy as "all private sector activities with a direct dependence on the ocean or ocean resources. This includes extractive uses (e.g., fishing, oil and gas production) as well as non-extractive dependence (e.g., shipbuilding, transportation). It also includes public sector organizations and agencies with direct ocean responsibilities." The direct GDP impact of the ocean sector in the Nova Scotia economy is estimated at $2.6 billion and accounts for 8.1% of the provincial GDP (**Table 2-2**; Gardner Pinfold 2009). When spin-off effects of ocean activity in the broader economy are considered, the GDP impact rises to just under $5 billion, just over 15% of Nova Scotia's GDP. The Scotian Shelf economy has not been separated from the Nova Scotia ocean economy as a whole.

Table 2-2: Economic impact of ocean activities in Nova Scotia (Gardner Pinfold 2009)

Indicator	Ocean Impact	NS Total	Ocean % of NS Total
GDP ($ millions)	2,620	31,737	8.10%
Income ($millions)	1,565	27,527	5.70%
Employment	29,499	432,590	6.80%

Household income, a major component of provincial GDP, also benefits greatly from ocean activity. Just over 5.7% of provincial household income is directly attributable to ocean activities. The impact rises to over 10% when spinoff effects are considered. Employment impacts are similarly impressive. With the equivalent of just over 30 000 direct full-time jobs created, the ocean sector accounts for about 6.8% of total provincial employment. The impact rises to just under 14% when spinoff effects are included (Gardner Pinfold 2009).

Offshore oil and gas and fishing are large contributors to Nova Scotia's economy, accounting for 23% and 22% of the overall ocean-related GDP respectively. Although National Defence ranks slightly ahead of offshore oil and gas and the fishing industry in its contributions, accounting for 24% of the overall ocean-related GDP. Water transportation (shipping, ferries, ports and harbours) also makes a major contribution, accounting for 11% of the overall ocean-related GDP. National Defence is the largest ocean sector employer accounting for 30% of employment followed by the fishing industry at 23%. Water transportation and tourism are next at 13% and 11% (Gardner Pinfold 2009). As the largest ocean economy employer, National Defence also has the largest income contribution, accounting for 32% of the ocean economy total, followed by fishing at 23% (Gardner Pinfold 2009).

2.3.4 Key Ocean Use Sectors

There are numerous users of the Scotian Shelf; this context document focuses on eight key ocean use sectors in the area. They were chosen because they are the sectors most often considered in regional ocean and coastal management processes. Each section provides a brief history of the industry and reports on current status and trends.

2.3.4.1 Commercial Fisheries: Commercial fishing started in the mid-1500s. In 1602, Samuel de Champlain reported meeting a Basque fisherman called Savalet making his 42nd voyage to the Scotian Shelf (Innis 1954) indicating that Savalet would have started fishing there in about 1560. Based on this, Savalet was one of the first Europeans to fish these waters. By 1700, Nova Scotia was exporting cod, mackerel and herring. Exports continued to increase through the centuries. In 1973, total landings of fish from the Scotian Shelf peaked, exceeding 750 000 t (Worcester and Parker 2010). Throughout the 1980s the fishing industry on the Scotian Shelf continued to thrive. However, a few years later, the fisheries resources that many thought could never be exhausted were quickly declining. This had significant impacts on the coastal communities that were dependant on them. In September 1993, the fisheries for the most important groundfish stocks (cod and haddock) were closed due to a collapse in stock. Total estimated biomass of cod was around 2 million tonnes in the mid-1980s and fell to a little over 200 000 tonnes in the early 1990s. On the Newfoundland-Labrador Shelf and eastern Scotian Shelf, this decrease exceeded 90% (Breeze et al. 2002). As of 2011 these fisheries remain closed and groundfish effort is limited in many parts of the area. This, however, did not signify the end of fisheries on the Scotian Shelf. With the collapse of the groundfish species, other species began to flourish. Lobster, scallop, shrimp, crab and surf clam fisheries have increased in significance and shellfish are now the main targeted species group. Large pelagic species such as swordfish, tuna and shark also support extensive fisheries along the outer shelf and slope. The fishing industry has also expanded beyond traditionally fished species. There are now fisheries for species such as sea cucumber, whelk and hagfish occurring on the Scotian Shelf.

Economic Overview: The Nova Scotia fishing industry (harvesting and processing) is a major source of direct and indirect employment and income and is the province's leading source of export earnings. In 2006, 26% of the total volume of commercial marine fisheries in Canada was landed in Nova Scotia (DFO 2008b). An important element of the industry's economic significance is derived from its rural location. Fishing and fish processing, together with the industries dependent on them, form the economic base for many of Nova Scotia's coastal communities (Gardner Pinfold 2005).

Fisheries Governance

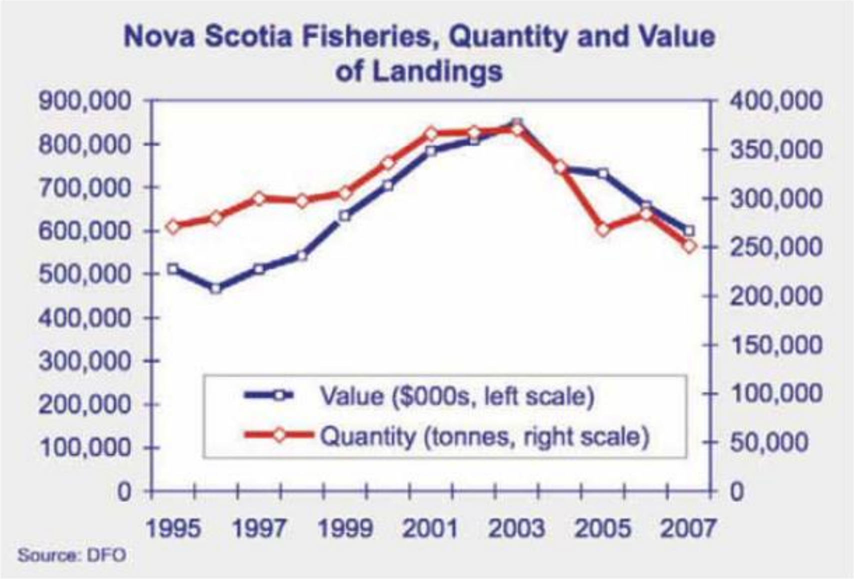
The key department regulating the Fisheries sector on the Scotian Shelf is Fisheries and Oceans Canada (or DFO).

DFO is the lead federal department for fisheries and fish habitat conservation and protection. DFO responsibilities for fisheries include managing the harvest of commercial fish species, licensing, conservation and enforcement. This is done under the *Fisheries Act* and associated policies and regulations. The focus of DFO's fisheries management program is to ensure that Canada's fisheries are environmentally sustainable, while supporting economic prosperity. Fisheries are managed through the development of Integrated Fishery Management Plans (IFMPs). The IFMP is based on peer-reviewed scientific advice through DFO's Canadian Science Advisory Secretariat (CSAS) and other information from Departmental and stakeholder sources. The IFMP provides a clear and concise summary of the management objectives for the fishery, the measures used to achieve these objectives, and the criteria by which their attainment will be measured. The IFMP incorporates new tools and policies that are being developed through a Fisheries Renewal initiative to include precautionary and ecosystem approaches in fisheries management. For further information on the new tools and policies, such as the sensitive benthic area and new fisheries for forage species, the reader is directed to the DFO website http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/index-eng.htm

The past decade has seen an increase in the value of fisheries in the Scotian Shelf/Bay of Fundy (Scotia- Fundy region) (**Figure 2-3**), from a landed value of about $496 million in 1998 to $800 million at its peak in 2002-03. The landed value has since declined to $538 million in 2009 (Gardner Pinfold 2005; 2009; DFO 2010d).

The relative importance of marine fisheries to the Nova Scotia economy has increased gradually over the past decade, with the contribution to the GDP rising from $235 million in 1995 to over $500 million in 2006 (Gardner Pinfold 2005, 2009). Employment is difficult to estimate. Limited entry licensing, seasonal limits, quotas and weather determine the duration of the fishing season and, therefore, employment. Out migration from coastal communities is also making it difficult to recruit crew members (Gardner Pinfold 2009). The fishing industry (commercial fisheries and processing) generated $672.6 million in household income, accounting for 31.3% of the ocean sector total. This is particularly important to the province, given the largely rural nature of the industry.

Fish landed are sold either to local processors or exported directly. The primary market for Nova Scotia seafood exports is the United States with secondary markets in the European Union, Japan and China (Gardner Pinfold 2009). Much of this export value is accounted for by lobsters (sold live), and also species such as northern shrimp and scallops, where all or most of the processing occurs on the harvesting vessel. Exports attributable to the fisheries sector have more or less followed the pattern of landings, rising from $389 million in 1995 to over $600 million in 2002-03 and have since declined to just over $500 million in 2007 (Gardner Pinfold 2005, 2009). The strong Canadian dollar and weak market conditions have contributed to the declines (Gardner Pinfold 2009).



Source: DFO

Figure 2-3: Nova Scotia Fisheries, Quantity and Value of Landings (Gardner Pinfold 2009; DFO http://www.dfo-mpo.gc.ca/stats/commercial-eng.htm).

Aboriginal Fisheries: In 1990, the Supreme Court of Canada's Sparrow decision upheld the Aboriginal right to fish for food, social and ceremonial purposes. In response to this decision, DFO initiated the Aboriginal Fisheries Strategy (DFO 2003). This strategy provided a framework for the management of fisheries for food, social and ceremonial purposes. In 1999, the Supreme Court of Canada's Marshall decision affirmed a treaty right to hunt, fish and gather in pursuit of a “moderate livelihood” arising out of Peace and Friendship Treaties of 1760 and 1761 (R v Marshall 1999). Since that time DFO has implemented a number of programs to facilitate the integration of Aboriginal communities affected by the decision into Atlantic Canadian fisheries. The Marshall Response Initiative (MRI) was created to provide the 34 Mi’kmaq and Maliseet First Nations with increased access to the commercial fishery through the provision of licenses, vessels and gear. The Aboriginal Aquatic Resource and Oceans Management (AAROM) program was instituted to facilitate the participation of Aboriginal groups in advisory and decision-making processes for oceans and fisheries resource management (DFO 2008c). The Atlantic Integrated Commercial Fisheries Initiative (AICFI) was developed to build upon the accomplishments of the MRI by increasing the capacity of Aboriginal commercial fishing enterprises and supporting their participation in the co-management of the integrated commercial fisheries along with other commercial harvesters (DFO 2010e). In the decade since the Marshall decision, Aboriginals throughout the Maritimes have participated in training, established administration, governance and business infrastructure, and have substantially increased their involvement in Atlantic commercial fisheries and in the integrated management of ocean resources (Atlantic Policy Congress of First Nations Chiefs 2009).

Economic Overview: Inclusion in the commercial fishery has shown benefits to Aboriginal communities, such as increased employment (DFO 2010f). The landed value of Aboriginal fisheries tripled between 2000 and 2006, while fishing employment increased 60% between 2000 and 2007. In 2009, 11% of Aboriginal jobs in Atlantic Canada were in the fishing sector (Atlantic Policy Congress of First Nations Chiefs 2009). Aboriginal fishing licenses generated an economic return of approximately $35 million in 2009 compared to just over $4 million in 1999 (Atlantic Policy Congress of First Nations Chiefs 2009).

2.3.4.2 Aquaculture: From its start in the mid-1970s, aquaculture grew slowly in Nova Scotia (Gardner Pinfold 2005). The industry experienced rapid growth in the late 1990s, then production took a downturn in the early 2000s (Gardner Pinfold 2005, 2009). Currently, the main species produced are Atlantic salmon and blue mussels, as well as rainbow trout, American oyster, bay quahog and Arctic char. Several other species are produced in very small numbers or are under development, including scallop, striped bass, Atlantic halibut and European oyster.

Different parts of Nova Scotia’s coast are considered suitable for different aquaculture products. The Atlantic coast of Cape Breton and the eastern shore from the Strait of Canso to Halifax are considered good areas for blue mussel, sea scallop and steelhead salmon. The south shore from Halifax to Yarmouth is considered suitable for the same species, as well as European oysters. Warmer parts of this area, such as Shelburne Harbour and St. Margaret’s Bay, may be suitable for Atlantic salmon. The Bras d’Or Lakes have American oyster and Atlantic salmon leases presently (NSDFA 2011d).

The sector is largely made up of small, independent producers. However, production is concentrated in a few farms and it has been estimated that less than 20 % of the farms produce more than 80 % of the fish and shellfish (Gardner Pinfold 2005). As of 2010, there were about 380 aquaculture sites in the province, however not all of them are in production (NSDFA 2011d).

Aquaculture Governance

Several government departments are involved in the regulation and licensing of aquaculture in the province. The main departments involved are:

Nova Scotia Department of Fisheries and Aquaculture grants leases and licences for aquculturists and coordinates review of applications by other relevant government departments.
Fisheries and Oceans Canada reviews applications for compliance with *Fisheries Act* provisions.
Transport Canada reviews applications to examine impacts on navigable waters.

Environment Canada, the Canadian Food Inspection Agency, and the Nova Scotia Department of Environment and Labour review aquaculture applications; other departments may also be involved. (NSDFA 2011a)

Economic Overview**:** The aquaculture sector generated more than $50 million in revenues in 2007 from 10 000 t of product (Gardner Pinfold 2009). There were about 750 full and part-time workers in the industry in 2009 (NSDFA 2011c). In 2006, the industry was estimated to have contributed $33.5 million to Nova Scotia's GDP from direct and spin-off effects.

2.3.4.3 Offshore Oil and Gas: Offshore hydrocarbon exploration on the Scotian Shelf began in 1959 when Mobil Oil Canada was issued the first offshore exploration permit covering the Sable Island area. The first exploration well was drilled on Sable Island in 1967, followed two years later by the first discovery of significant quantities of natural gas on the Scotian Shelf by Shell Canada just south of Sable Island (CNSOPB 2011a). Between 1972 and 1979, several significant hydrocarbon discoveries were made in the Sable Sub-basin with local reserves potentially exceeding 18 trillion cubic feet (Tcf) and about 1 billion barrels (BB) of oil and gas liquids (Breeze and Horsman 2005).

There are similar estimates for hydrocarbon reserves in other, less explored basins in Nova Scotia's offshore: the deep water Scotian Slope, the Laurentian Sub-basin, and the Shelburne Sub-basin (Georges Bank) (Breeze and Horsman 2005).

The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) manages petroleum exploration and development in most areas of offshore Nova Scotia. Currently, certain areas of the offshore are closed to petroleum exploration. One of those areas is Georges Bank, where a moratorium has existed since 1988 and remains in effect to December 31, 2015.

An exploration licence is needed for most petroleum exploration activities, including seismic exploration and exploratory wells. The CNSOPB issues a "call for bids" for particular parcels of offshore crown lands for which companies may bid for the exploration licence for that parcel. Exploration licences give the exclusive right to explore a particular area and have a maximum term of 9 years (CNSOPB 2011d). A significant discovery licence may be granted after an initial discovery in an area and maintains an explorer's rights during the period between the first discovery and eventual production. Twenty-five year production licences are granted after the operator proves that a discovery has commercial potential (Chao et al. 2004). The time limit may be extended if production is still in progress or likely to restart (CNSOPB 2001d).

Guysborough County Sustainable Aquaculture Initiative

In 2002, the Guysborough County Sustainable Aquaculture Initiative (GCSAI) was initiated to promote sustainable aquaculture development in Guysborough County that considers community values. The ultimate product of the initiative was the GCSAI Tool, a GIS-based program that helps select more favourable areas for aquaculture. The Guysborough County Regional Development Authority uses the tool to assist potential aquaculturists in selecting a site.

The tool has water quality data for several different areas and can compare the properties of the water with the requirements of 6 common aquaculture species. The tool helps narrow down possible sites, but any site chosen will still undergo environmental review and public consultation. As well, the Guysborough County Regional Aquaculture Development Advisory Committee will review the application. Regional Aquaculture Development Advisory Committees (RADACs) make recommendations to the Minister of Fisheries and Aquaculture for approving or disapproving applications for Aquaculture Licences and Leases. RADAC members are appointed by the Minister from the local community; however, there are RADACs in only a few areas of the province (MDG 2011, NSDFA 2011).

After an active period of petroleum exploration in the late 1990s and early 2000s, there was a slowdown of activity. There was only one call for bids between 2002 and late 2007 (CNSOPB 2011b) and many of the exploration licenses granted earlier had expired.

For the most recent call for bids (closing date June 24, 2010), no bids were received (CNSOPB 2011c). As of March 9 2011, there were four active exploration licences, thirty-three significant discovery licences and ten production licences on the Scotian Shelf and Slope (CNSOPB 2011d). In contrast, in March 2003, there were fifty-seven active exploration licenses, thirty-three significant discovery licences and six production licenses (Chao et al. 2004).

There have been three petroleum projects in production in Nova Scotia’s offshore. The Cohasset-Panuke Project produced 44.5 million barrels of light crude oil from eleven production wells on two fields west of Sable Island. The project began in 1992 and was completed in 1999 (Breeze and Horsman 2005).

The Sable Offshore Energy Project operated by Exxon Mobil and partners, has been producing gas since 1999 and has a total project life expectancy of about 25 years. The project is made up of six production platforms that tap natural gas fields near Sable Island, approximately 225 km off the east coast of Nova Scotia. The project also involves a subsea pipeline with landfall at Goldboro, Nova Scotia, a gas plant at Goldboro, a fractionation plant at Point Tupper and an associated pipeline on land, the Maritimes and Northeast Pipeline (NSDoE 2011a).

Encana’s Deep Panuke Project is not yet in production. It will extract natural gas from the Deep Panuke field, about 250 kilometres southeast of Halifax on the Scotian Shelf. The natural gas will be transported through a subsea pipeline to Goldboro and then distributed via the Maritimes and Northeast Pipeline constructed as part of the Sable Offshore Energy project. Deep Panuke is expected to go into production in 2011 and is expected to continue for about 13 years (NSDoE 2011b).

Economic Overview: Offshore oil and gas projects are usually international in scope and a proportion of the spending, therefore, occurs outside the national economies where the development occurs. This proportion varies depending on the capabilities and competitiveness of domestic suppliers as compared with international suppliers (Gardner Pinfold 2005).

For the period ending March 31, 2008, the Nova Scotia government had received approximately $900 million in royalties from the Sable Offshore Energy Project. Over the life of the project, the Province expects to receive between $1.5 and $2 billion in royalties (NSDoE 2011c). As required by the Canada-Nova Scotia Offshore Petroleum Resources Accord, Nova

Scotia also receives Crown share payments from the federal government. Based on Nova Scotia's share of offshore petroleum projects, the Province expects to receive $860 million in total Crown share payments for Deep Panuke (NSDoE 2011c). The contribution made by the oil and gas sector to the Nova Scotia economy is summarized in **Table 2-3**.

Sable Offshore Energy gas production has several more years of sizeable production, but will soon begin a slow decline. Growth of the offshore industry will depend on the development of the Deep Panuke field and also on further exploration and the discovery of new recoverable reserves. While there was growing demand for natural gas in the US and the Maritimes for a period in the 2000s, and a proposal to develop a liquefied natural gas terminal (LNG) near Goldboro (Gardner Pinfold 2009), the demand for LNG decreased in the wake of the recession and the company decided not to go ahead with the project (Park 2010).

Table 2-3: Economic Impact of offshore oil and gas (2006). (Source: Gardner Pinfold 2009)

	Development			Production		
	Direct	Spin-off	Total	Direct	Spin-off	Total
GDP ($000s)	15,105	43,675	58,780	809,041	143,394	952,435
Employment	234	839	1,073	426	2,352	2,778
Household Income ($)	11,364	28,585	39,949	29,778	95,285	125,063

Oil And Gas Governance

The principal regulators of the offshore petroleum sector in Nova Scotia are the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB), the Nova Scotia Department of Energy and the National Energy Board (NEB).

CNSOPB is an independent joint agency of the governments of Canada and Nova Scotia and is responsible for regulating petroleum activities in the defined Nova Scotia offshore. The board manages petroleum exploration and development in most areas of offshore Nova Scotia under the Canada-Nova Scotia Offshore Petroleum Resources Accord. It reports to the federal Minister of Natural Resources and the provincial Minister of Energy. The Board has entered into Memoranda of Understanding with Environment Canada and Fisheries and Oceans Canada but maintains the lead in coordinating regulatory activities.

Nova Scotia Department of Energy is responsible for business and economic development of the sector and administers the offshore royalty regime.

National Energy Board (NEB) is responsible under the *Canada Oil and Gas Operations Act* for the regulation of oil and gas operations in offshore areas outside the jurisdiction of the CNSOPB and the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). It cooperates with the CNSOPB and C-NLOPB to reduce regulatory overlap. Among its responsibilities are regulation of the construction and operation of pipelines.

2.3.4.4 Ports and Shipping: A significant amount of international and domestic commercial shipping traffic occurs over the Scotian Shelf (see **Figure 2.4**). The strategic location of Nova Scotia on the Great Circle Route (i.e., shortest distance over the earth's surface) between eastern North America and Europe makes it important for international shipping. The Cabot Strait links trans-Atlantic shipping routes to the St Lawrence Seaway and the Great Lakes. Commercial shipping in this area is generally in the form of tankers, general bulk and containerized cargo carriers. The area is also transited by a range of fishing vessels, cruise ships and various government vessels. Marine transportation also includes marine towing, ship chartering, cargo handling, harbour and port operations, ferries, pilotage and shipping agencies. The primary commodities being moved in the region include crude oil and gas, minerals and chemicals, paper and forest products, coal and coke and various containerized goods. Other significant cargoes include gypsum, crude and refined oil as well as automobile imports and exports.

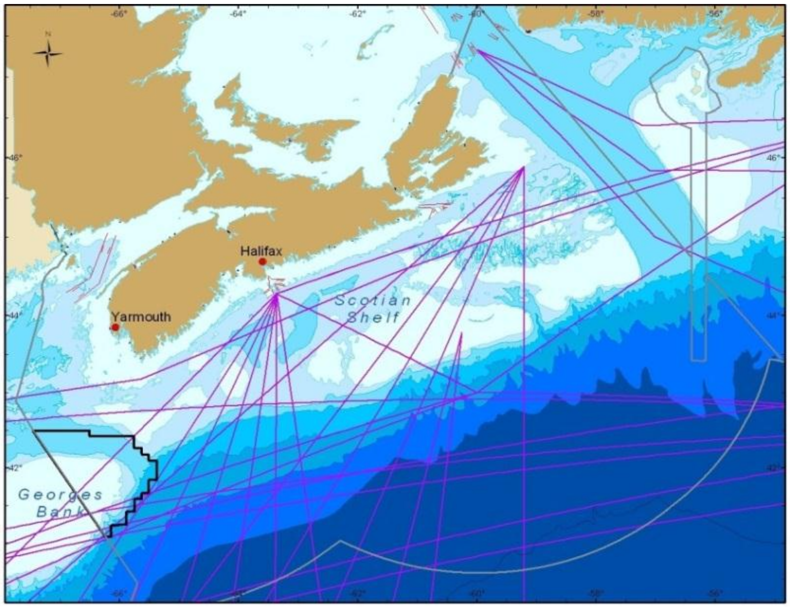


Figure 2-4: Shipping routes (Source: DFO 2010).

Halifax is the largest port, in terms of size, in Nova Scotia with the most diverse cargo base. In 2010 it handled 9.5 million tonnes of cargo (Port of Halifax 2011). It is the largest short sea shipping port in the country, the second largest cruise port in Canada after Vancouver and the third largest container port in Canada (Gardner Pinfold 2005).

On the Strait of Canso, the Strait Superport consists of the Mulgrave Marine Terminal and the Port Hawkesbury Pier. In 2009, it handled 33.5 million tonnes of cargo and had 1 380 vessel movements (Strait Superport 2011). Port Hawkesbury is the largest port in terms of tonnes of cargo handled in this region. Most of the volume is accounted for by the petroleum facility operated by Statia Terminals. Bulk exports of gypsum, paper products, aggregate and imports of coal make up the balance. The Mulgrave Marine Terminal services the offshore oil and gas industry. In addition to Halifax and Port Hawkesbury there are a number of smaller ports along the Scotian Shelf including Sydney, Liverpool, Shelburne and Sheet Harbour. These ports deal with cargo such as fish, lumber, oil and newsprint (Gardner Pinfold 2005).

Ferry services are another part of the transportation sector that operates on the Scotian Shelf. There are ferry services that link Nova Scotia to Newfoundland and Labrador, and until recently the United States. There are also planned activities that could increase vessel traffic on the Scotian Shelf. These include proposals for a new Liquefied Natural Gas terminal at Bear Head, a new container terminal in Melford (Chedabucto Bay) and the expansion of port facilities in Sydney.

Ports and Shipping Governance

The shipping industry is regulated internationally by the International Maritime Organization (IMO). National governments are required to implement and enforce international regulations through their domestic legislation, such as the *Canadian Shipping Act*. Much of Canada's legal framework regarding marine transportation operations is from the implementation of international agreements like the International Convention for the Prevention of Pollution from Ships and the International Convention for the Safety of Life at Sea.

The regulation of shipping operations in Canadian waters falls under the jurisdiction of several federal departments and agencies:

Transport Canada's mandate encompasses the full spectrum of responsibilities related to ship safety and the protection of the environment, including marine pilotage and the provision of marine expertise for general and policy matters.

Fisheries and Oceans Canada – **Canadian Coast Guard** provides services for safety and environmental response, marine navigation, marine communications, traffic management and ice breaking.

National Defense – Maritime Forces is the lead agency for the national Search and Rescue Program. Maritime Forces Atlantic (MARLANT) provides maritime surveillance, monitoring and control functions in the areas of shipping, marine pollution and safety.

Environment Canada addresses a broad range of pollution concerns and issues. They are also responsible for the *Canadian Environmental Protection Act* and for pollution prevention under the Fisheries Act, including the control of discharges into the marine environment.

Port and Harbour Authorities are the primary managers of all ports in Canada. Their responsibilities include environmental management regimes for port related activities.

Economic Overview: The marine transportation sector is an important component of the Nova Scotia coastal economy. Maritime transportation in Nova Scotia generated direct revenues estimated at $500-600 million in 2006 and created about 8000 fulltime jobs (Gardner Pinfold 2009). The Port of Halifax's direct and spin-off impacts of port related activities include $1.58 billion in gross output and $671 million in GDP (Port of Halifax 2011).

The port of Halifax has seen steady growth in shipping cargo volumes in 2010, relative to 2009 (Port of Halifax 2011). In 2010, containerized, breakbulk and roll on/roll off cargo all increased from 2009. Roll on/roll off (Ro/Ro) cargo (mostly automobiles) is a unique speciality of the port of Halifax. The Halifax Autoport Terminal is one of the largest vehicle processing facilities in North America. The Strait Superport has also experienced steady growth since 2001 (Strait Superport 2011).

2.3.4.5 Ocean and Coastal Tourism: A variety of tourism activities occur off the coasts of Nova Scotia, such as whale and seabird watching, sport fishing, sea kayaking, yachting, scuba diving and visits to coastal beaches and parks. Cruise ships visit Halifax and Sydney regularly and several other coastal communities occasionally. Comprehensive statistics on the marine tourism industry are not kept, making it difficult to track trends. As well, in most cases it is not possible to separate tourist activities occurring along the Atlantic coast adjoining the Scotian Shelf from those occurring along the province's other coasts. There were at least 174 marine tourism businesses throughout the province of Nova Scotia in 2003 (**Table 2-4**, Praxis 2004).

The industry suffered a decline in the first few years of the twenty-first century and there may now be fewer operators (Gardner Pinfold 2009).

Whale and seabird watching tours made up the largest category of marine tourism operators, with sport fishing and boat tours the second and third largest categories (Praxis 2004). All tourism activities tend to be concentrated in coastal rather than offshore areas although yachts and cruise ships transit offshore areas. Ocean and coastal tourism is described here under three key themes: cruise ship activity, recreational coastal tourism activities, and marine recreational fishing. However, much of the overall tourism in the province can be attributed to coastal features such as the coastal landscape, waterfronts, and natural features (CBCL Ltd. 2009).

Table 2-4: Tourism and recreational businesses in Nova Scotia 2003 (Praxis 2004)

TOURISM/RECREATION ACTIVITY	NUMBER OF ENTERPRISES
Whale and Seabird watching tours	57
Diving Operators	7
Canoe/Kayak tour organisations	6
Sport Fishing Tours (Saltwater)	25
Sailing Tours	11
Other Boat Tours	28
Marinas	23
Yacht Clubs	11
Total	174

Cruise Ships: The main ports of call for cruise ships in Nova Scotia are Halifax and Sydney. The number of vessels has been increasing steadily in the last few years, with 127 vessels and 261 000 passengers to Halifax in 2010, up from 89 vessels and 170 000 passengers in 2006 (Cruise Halifax 2011). Halifax has benefited from the trend towards four- to five-day cruises and most of its growth has come from this segment (Gardner Pinfold 2005).

Coastal Tourism Activities: Coastal tourism includes whale and bird watching tours, sea kayaking, yachting, boat tours, and scuba diving. It also includes activities for which the economic value is not well tracked, such as visits to provincial parks or beaches for which there are no expenditures. Even for activities that are tracked, statistical agencies do not systematically track all aspects of these activities. Consequently, reliable statistical information about coastal tourism is minimal. Accurate information on the economic contribution of activities such as whale watching, bird watching, ocean tours, diving, kayaking, sailing and cruising is not widely available (Gardner Pinfold 2005, 2009). Coastal tourism experienced a decline in the early 2000s, along with the overall tourism industry (Gardner Pinfold 2009). However, prospects for coastal tourism are expected to improve over the next few years with improved economic conditions (Gardner Pinfold 2009). Highlighted below are two components of the coastal tourism sector.

Whale watching and birding tours are expanding components of the tourism economy. Research carried out by the Nova Scotia Department of Tourism indicates that five percent of all visitors to the province participated in whale/seabird boat tours in 2000 (Corporate Research 2001), while nine percent participated in 2004 (Corporate Research 2005). With about 2.2 million visitors to Nova Scotia in both 2000 and 2004 (NS Economic and Rural Development and Tourism 2011), this would equate to about 110 000 boat tour passengers in 2000 and

198 000 in 2004. Based on an average fare of $38 per person (Praxis 2004), total revenues could be estimated at $4.2 million for 2000 and $7.5 million for 2004.

Marine Tourism Governance

Multiple government agencies are responsible for regulating marine tourism, with the relevant department depending on the type of activity undertaken.

Transport Canada regulates recreational boating.

Fisheries and Oceans Canada regulates recreational fishing and provides guidelines for whale watching.

Cruise ships are required to comply with a variety of regulations, including requirements of the **International Maritime Organization**, the **Canada Border Services Agency**, **Transport Canada** and **Environment Canada**.

Various departments are responsible for regulating development in the coastal zone, such as the infrastructure supporting coastal recreational tourism.

Visits to ocean beaches and parks continue to be an important aspect of the Nova Scotia tourism experience. Thirty-three percent of Nova Scotia visitors in 2004 visited an ocean beach to explore or beachcomb while 10 percent went to an ocean beach to swim or sunbathe (Corporate Research 2005).[5]

Marine Recreational Fishing: In 2005, 50 807 licensed anglers in Nova Scotia participated in recreational fishing (DFO 2007a). Of that, 48 674 were Nova Scotia residents and 2 133 were non-residents, mainly from other regions in Canada. There were approximately 18 000 saltwater anglers in Nova Scotia in 1995 and nearly 23 000 in 2000 (Gardner Pinfold 2005); figures are not available for 2005. Key marine anadromous species include smelt, mackerel and cod. In 2000, marine fishing effort constituted about 22% of total recreational fishing effort (days) in the province; in 2005, saltwater fishing was about 20% of the total recreational fishing effort (DFO 2005). In 2005, Canadian anglers were estimated to spend about $762/year per angler on fishing, an increase of more than $100 over the 2000 total (Gardner Pinfold 2005, DFO 2007a).[6] Total spending by Nova Scotia anglers – both marine and freshwater – was estimated to be $ 21.9 million (DFO 2007a). Spending on saltwater fishing is typically on boats, motors, transportation and camping and fishing equipment.

Economic Overview: Coastal tourism in the province was estimated to generate about $300 million in expenditures in 2006, down from about $363 million in 2002 (Gardner Pinfold 2009). Coastal tourism makes up the bulk of the expenditures; these were estimated to be about $319 million in 2002 but declined to $272 million in 2006. The cruise ship industry also experienced a decline in expenditures in the middle of the decade; however, recent figures from the industry show that the number of passengers visiting Halifax have largely recovered (Cruise Halifax 2011a). The Port of Halifax claims that passengers, crew and cruise lines have combined expenditures of $50 million in the local area (Cruise Halifax 2011b).

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[5] Those participating in the survey could pick multiple activities, thus may have picked both beachcombing and sunbathing.

[6] The total is based on figures available for Nova Scotia, not the Canadian average per angler.

2.3.4.6 Maritime Defence: Canada’s naval presence on the east coast is provided through Maritime Force Atlantic (MARLANT) and has its headquarters in Halifax. The MARLANT area of responsibility covers approximately 6 million km^2 and extends from the Canada-US boundary in the Gulf of Maine to Greenland and includes Canada’s eastern Arctic to approximately 95 degrees west. Canada’s maritime forces engage in a range of operations and activities including sovereignty patrols, maritime surveillance, naval training and combat readiness, search and rescue, humanitarian relief and aid to civil authorities, and operational support to other government departments, including fisheries and environmental protection. To carry out its missions, MARLANT uses a range of platforms, including patrol frigates, coastal defence vessels, destroyers, submarines, ship-borne helicopters and long-range patrol aircraft (MARLANT 2010).

Defence Fast Facts

- Maritime Command Operational Training occurs in the region every 2 years and can involve up to 40 vessels.
- MARLANT currently possesses 7 Halifax-class Frigates, 2 Iroquois-class destroyers, 1 Oberon-class conventional submarine, 1 Preserver-class Operational Support Ship, 6 Kingston-class Maritime Costal Defence vessels, 1 Minesweeping Auxiliary, 14 Aurora and 4 Arcturus long range Maritime Patrol Craft and 31 Sea King helicopters.

In addition to and during the various types of missions and patrols carried out by MARLANT, naval training activities may take place in designated exercise areas off Nova Scotia (Breeze and Horsman 2005).

Canadian Forces Base Halifax is Canada’s largest military base and home to Canada’s Atlantic naval establishment. It incorporates three main facilities. HMC Dockyard in Halifax is the base for the fleet of frigates, supply vessels, submarines and coastal defence vessels. 12 Wing Shearwater is home to the navy diving school and Sea King helicopter base. About 1000 personnel are employed here and it also provides a jetty for docking NATO submarines. DND’s contribution to ocean activity also includes operations at 14 Wing Greenwood, the base for the Aurora long-range surveillance aircraft patrolling Canada’s extensive Atlantic coast.

Economic Overview: As an ocean use sector, maritime defence activities comprise a significant portion of Nova Scotia’s ocean-related economy through direct and indirect contributions to the province’s GDP. In 2006, maritime defence contributed $869 million to the GDP and provided 10 700 jobs and $614 million in salaries (Gardner Pinfold 2009).

2.3.4.7 Submarine Cables: Nova Scotia has been a landfall for major transatlantic communication cables since the days of the telegraph. Canso hosted a major telegraph cable station from 1884 to 1962, and the first direct connection between Europe and mainland North America was at nearby Tor Bay in 1874. Nova Scotia continues to play an important role in international telecommunications, with cables crossing the Scotian Shelf and making landfall in Nova Scotia. As of March 2011, there were seven active international or interprovincial submarine cables crossing the Scotian Shelf that made landfall in Nova Scotia (APOCS 1C, APOCS 2, CANUS 1, CANTAT-3, Hibernia Atlantic Segment A, Hibernia Atlantic Segment D, Hibernia Atlantic Segment E). Other cables cross the Scotian Slope and link the east coast of the United States with Europe. All the existing interprovincial and international cables are for telecommunications, although a high voltage power cable to Newfoundland has been proposed (Office of the Premier 2010). There are also numerous inactive cables.

The international telecommunications cables that land in Nova Scotia are owned by two companies, Hibernia Atlantic and Tata Communications. They have connectivity agreements that allow them to connect to countries and locations where they may not have cables of their own.

As well, telecommunications companies in general may purchase long or short term capacity on another company's cable system.

In September 2010, Hibernia Atlantic announced a new subsea fibre optic cable system called Project Express (Hibernia Atlantic 2010). The company plans to lay a cable from the United Kingdom to the Halifax area, connecting with an existing cable that runs from Halifax to Boston. The project is scheduled to be completed by the summer of 2012. Ships that lay and repair cable are an important part of the industry. As of 2010, at least two cable ships were based in Halifax (ICPC 2010).

In addition to longer interprovincial and international cables, numerous submarine telecommunications and power cables link coastal islands to Nova Scotia's mainland (Breeze and Horsman 2005). There are also military surveillance cables on the Scotian Shelf.

Submarine Cable Governance

International conventions protect submarine cables and give the right to lay them on the seabed. The 1884 Convention for the Protection of Submarine Cables is intended to protect submarine cables from human-caused damages. The United Nations Convention on the Law of the Sea considers one of the freedoms of the high seas to be the freedom to lay submarine cables, subject to the rights of the coastal state on the continental shelf. In Canadian waters, proponents of cable laying projects must apply for an approval under the *Navigable Waters Protection Act*. They may also be subject to requirements under the *Canadian Environmental Assessment Act*, the *Fisheries Act*, and the *Canadian Environmental Protection Act*. Cables which start and end in Canada do not have any further licensing requirements. Proponents of international cables – those with a landfall outside Canada -- must apply for a permit from Industry Canada under the International Submarine Cable Regulations of the *Telecommunications Act* and are subject to environmental assessment requirements (Coffen-Smout and Herbert 2000).

2.3.4.8 Potential Future Uses: New activities that may be proposed for the Scotian Shelf include the development of wind, wave, or tidal energy and marine mining. The marine renewable energy sector has gained a heightened profile in Nova Scotia with the placement of an experimental tidal turbine in the Bay of Fundy. On the Scotian Shelf, there is some tidal energy potential off Cape Sable Island and Yarmouth, as well as in St Andrews Channel in the Bras d'Or Lakes (Triton Consultants 2006). Technologies to exploit energy from waves are in relatively early stages of development, with few commercial developments. However, Canada's Atlantic coast, including offshore areas, has been identified as having a high potential capacity for wave energy (NRCan 2011). Offshore wind farms have been put in place in many locations around the world. In Canada, wind energy potential has largely focused on land, although there is interest in developing wind farms in the Great Lakes and off the Pacific coast (NRCan 2008).

In the 1990s, there was increasing interest in the offshore as a source of non-fuel minerals. The Scotian Shelf has vast reserves of aggregate (sand and gravel) that is used by the construction industry (Fader and Miller 1994). An intergovernmental task force was created to investigate the development of an offshore minerals mining regime (Coffen-Smout et al. 2001). However, the task force did not complete its work and to date, no offshore mining regime has been developed.

2.4 OCEAN MANAGEMENT ISSUES

Human use of the Scotian Shelf ecosystem exerts many different pressures on the marine environment. These range from direct removal of fish and invertebrates from the system to increased noise and light in the water column. Some key pressures are listed below and they are described in more detail in the theme papers on each topic. In addition to individual environmental pressures, there are also concerns around cumulative impacts from all ocean activities and multiple use conflicts.

2.4.1 Direct Removal of Fauna

Fishing is the main activity that removes organisms from the Scotian Shelf environment. Impacts of fishing on target species have been widely documented, and may include impacts on the size of the population, the structure of the population, its success in reproduction, the area occupied by the species, the size spectrum on the species, as well as many others (see, e.g., Smith et al. 1993, Zwanenburg et al. 2006). Globally, historic fishing trends have shown fishing progressing from the most valuable and easiest to catch species, which tend to be large, fish-eating fish, to lower trophic levels, such as invertebrates and plankton-eating fish[7] (Pauly et al. 1998). The focus of the fishery has also moved from shallow coastal waters, to deeper offshore waters. Large scale removal of a particular species or multiple species may influence energy flow in the ecosystem as well as other ecosystem properties (see e.g., Zwanenburg et al. 2006). There is evidence that the trophic structure of the eastern Scotian Shelf has changed as a result of the decline of the cod population (Frank et al. 2005).

Fishing removes non-target species from the system, affecting their populations. If the bycatch is high enough, if may have similar effects on particular species as directed fishing.

2.4.2 Incidental Injury/Mortality

Many activities on the Scotian Shelf may result in accidental injury or death to the species. Shipping, fishing, aquaculture, and construction of offshore and coastal infrastructure may all result in incidental injury or mortality. Incidental catches of non-target species by fishing (bycatch) are noted above. Incidental impacts may result in a significant overall effect at the population level. For example, two of the key threats to the endangered North Atlantic right whale are incidental impacts: collisions with ships and entanglement in fishing gear.

2.4.3 Benthic Habitat Disturbance

Human activities on the Scotian Shelf may disturb or damage marine habitat, particularly benthic habitat. Fishing, construction of offshore and coastal infrastructure, discharges from oil and gas operations and disposal at sea may all impact marine benthic habitats. The impacts of different types of fishing gear on benthic habitat have been documented in a number of reports and include changes in habitat complexity, changes in seafloor structure (e.g., through movement of rocks and boulders or creation of furrows), as well as removal of structure-building organisms, such as corals and sponges (DFO 2006). Fishing may also impact the composition of benthic communities (DFO 2006).

2.4.4 Noise

Marine construction, seismic surveys carried out by the petroleum industry, various types of SONARs, and vessels used in various activities are the main contributors of noise in the marine environment of the offshore Scotian Shelf. Low-flying aircraft may also be major contributors in certain areas, such as near Sable Island (LGL Limited and Malme 2000). Marine mammals use sound to varying degrees for several purposes: communication; foraging;

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[7] This is a simplification of general trends: there have long been some invertebrates (e.g., lobster, scallops) and planktivorous fish (e.g., herring) that have been fished.

orientation in the water; and predator avoidance (Götz et al. 2009). Some fish species are known to use sound for communication and may also use it for orientation, although sound use in fish species has not been investigated very thoroughly (Götz et al. 2009). Other marine animals, including invertebrates, turtles and birds, may also be sensitive to sounds, depending on the type and frequency. Marine mammals produce sounds in a wide variety of frequencies and their hearing spans a similarly wide range (Götz et al. 2009). Thus, different sounds will have different impacts on marine species. More information can be found in a report of the OSPAR Commission (Götz et al. 2009), which carried out a review of the impacts of human produced sound in the marine environment. Marine mammals have traditionally been considered the most vulnerable to noise and an assessment of noise issues relevant to two species of whales, the sperm whale and the Northern bottlenose whale, was carried out for the Scotian Shelf in light of ongoing petroleum exploration activities in the area (LGL Limited and Malme 2000).

2.4.5 Pollution

Shipping, petroleum exploration and development, disposal at sea (e.g., of dredging material) and fishing activities all discharge wastes into the marine environment. However, the largest source of marine pollution comes from land-based activities, including agricultural runoff, wind-blown debris, industrial activity, and municipal waste-water (Environment Canada 2004). Stewart and White (2001) provide a general overview of contaminants on the Scotian Shelf. Some marine sources of pollution on the Scotian Shelf are briefly described here.

The offshore oil and gas industry discharges treated water into the marine environment. Oil and gas operators are expected to meet guidelines published by the CNSOPB (CNSOPB/CNLOPB 2010). Discharges from the shipping industry are regulated; however, there are incidental and accidental releases of fuel, chemicals, ship debris and cargoes (Stewart and White 2001) as well as occasional major events, such as the sinking of the oil tanker, Arrow, in Chedabucto Bay in 1970 (Environment Canada 2010). The major sources of pollution from the fishing industry are lost or abandoned fishing gear and garbage. Two studies carried out in the 1990s found that fishing was the most important source of marine litter in offshore areas of the Scotian Shelf (Lucas 1992; Dufault and Whitehead 1994). Since then, fishermen’s organizations have been active in developing programs to encourage fishermen to bring garbage back to shore. The federal government has also developed awareness brochures and other awareness tools (DFO 2007b).

2.4.6 Cumulative Effects

A cumulative effect may be defined as “a change to the environment caused by an action in combination with other past, present and future human actions” (Hegmann et al. 1999). Cumulative effects are important when the effects of an ocean use are persistent over time (i.e., difficult to reverse), such as pollution with heavy metals and some pesticides or large-scale destruction of habitat, or when activities are in close proximity in time and space. When environmental effects of activities are considered separately, they may all be below the threshold levels that cause impacts. Some effects, although thought to be transitory or of minor importance on the scale of a single source (e.g., a vessel discharge, an otter trawler, an oil well, or a seismic survey) may prove to be of more serious concern when combined. Cumulative effects need to be addressed at varying scales, from local/site-specific to broader regional ecosystems.

2.4.7 Multiple Use

Some portions of the Scotian Shelf experience relatively high or intensive levels of use, such as heavily fished areas, hydrocarbon production areas, and high vessel traffic areas. Parts of the outer shelf and shelf break, for example, have been subject to an increasing intensity of multiple uses, including oil and gas development and a variety of fisheries. Other areas remain little to moderately used. Current and anticipated expansion, however, of existing uses (e.g., deep water fisheries) coupled with the potential for new ocean uses, such as offshore minerals development or wind power generation, underscores the growing requirement for effective multiple use management practices.

2.5 OCEAN GOVERNANCE AND MANAGEMENT

Governance is the way by which society has instituted objectives, priorities and systems of cooperation (IUCN 2005), and establishes the framework for management. Governance is constituted by institutions, formal and informal agreements and behaviours, how resources are used, how the problems and chances are assessed, the actions permitted or prohibited; and the regulation and sanctions that are applied (OMRN 2003). The governance of any geographical area, including marine spaces, is actually the management of stakeholder relationships with regard to resource use in the pursuit of many sanctioned economic, social, political, and environmental objectives. Good governance is based on recognition of the interests of all stakeholders, and is collaborative, cooperative, and integrative.

International Legislation

The United Nations Convention on the Law of the Sea (UNCLOS), signed in 1982, is considered the international constitution of the oceans. UNCLOS incorporates both the codification of customary international law and negotiated treaty commitments relating to the world's oceans. It provides a comprehensive framework for the regulation of the oceans and deals with a range of activities such as access to the seas, navigation, protection and preservation of the marine environment, pollution prevention and control, exploitation of living and nonliving resources, conservation, scientific monitoring and research, and the outline of a dispute settlement mechanism. The Government of Canada ratified the 1982 UNCLOS in 2003. A significant proportion of UNCLOS provisions are reflected in Canadian legislation. There are also numerous other international instruments, processes and institutions dealing with the full range of ocean issues in which Canada is actively engaged to promote and support its interests and responsibilities. These rights and obligations under international conventions and agreements are fully recognized and respected in Canada's Oceans Strategy.

2.5.1 Ocean-Related Legislation and Policy

There are various federal and provincial acts and policies that are relevant for the management of ocean activities and the conservation and protection of ocean resources on the Scotian Shelf. Chao et al. (2004) provides a comprehensive *Overview of Federal, Provincial and International Ocean Regulatory and Policy Frameworks on the Scotian Shelf*. Canada's *Ocean Act* outlines the country's responsibilities for an integrated approach to coastal and ocean management. The Act identifies the Minister of Fisheries and Oceans Canada as the lead federal authority for oceans management. Three primary commitments outlined in the Act are: 1) develop a national strategy for managing Canada's oceans (Section 29); 2) establish a national network of Marine Protected Areas (Section 35); and 3) promote the integrated management of Canada's marine activities (Section 31) (Government of Canada 1996).

2.5.2 Integrated Costal and Ocean Management on the Scotian Shelf

In 2002, the *Canada's Ocean's Strategy* was released, which is the Government of Canada's policy statement for the management of estuarine, coastal and marine ecosystems (Government of Canada 2002a). *Canada's Oceans Strategy* sets out the policy for ocean management in Canada. At the heart of the strategy is an integrated approach to ocean governance. Integrated management requires collaboration between the federal and provincial governments, Aboriginal peoples, ocean industries, academia and the Canadian public. The strategy commits the Government of Canada to implement integrated management and planning. *Canada's Policy and Operational Framework for Integrated Management of Estuarine, Coastal and Marine Environments in Canada* (Government of Canada 2002b) outlines the process for integrated management in Canada.

An integrated management initiative for the Eastern Scotian Shelf was initiated in 1997. This initiative lead to the development of an integrated management plan and a governance structure that included all levels of government and stakeholders. Elements of the integrated management plan and the governance structure, such as the Regional Committee on Coastal and Ocean Management (RCCOM), have since expanded and now provide intergovernmental coordination for the entire Scotian Shelf. The RCCOM is the senior executive level forum for federal and provincial departments and agencies with ocean-related programs. The geographic focus for the RCCOM is Nova Scotia, New Brunswick and Prince Edward Island. Membership is comprised of senior federal (Regional Director-General) and provincial (Deputy-Minister) representatives of government departments and agencies. The RCCOM is co-chaired by alternately by the Regional Directors-General, DFO Maritimes Region and Gulf Region, and a Deputy-Minister of the Province of Nova Scotia, New Brunswick or Prince Edward Island, on a rotational basis. RCCOM meets on an annual basis, or as necessary. The RCCOM provides coordination at the intergovernmental and interdepartmental levels for: planning, management and regulatory matters related to integrated ocean and coastal management, internal oversight, monitoring and performance assessment of regional integrated management processes; and formal and executive level government involvement in the development and implementation of plans for regional integrated management processes.

Oceans Strategy Objectives

- Understanding and protecting the marine environment.
- Supporting sustainable economic development
- International leadership

2.5.3 Marine Protected Area Planning

Canada's Federal Marine Protected Areas Strategy (2005) sets the direction for building a national network of marine protected areas (MPAs). Further, the *Oceans Act* requires the establishment of MPAs by DFO to protect and conserve important fish and marine mammal species and their habitats, endangered marine species, unique features and areas of high biological productivity or biodiversity. Canada has committed to establishing a network of protected areas to help meet a range of conservation goals. There is currently one area designated as MPAs under the *Oceans Act*, on the Scotian Shelf, The Gully MPA. Two other federal agencies, Environment Canada (Canadian Wildlife Service) and Parks Canada Agency, are working in collaboration with DFO to establish and manage federal marine protected areas. In May 2010, Parks Canada selected Sable Island for future designation as a National Park. More recently, a draft *National Framework for Canada's Network of Marine Protected Areas* was created to provide guidance for the planning and implementation of MPA networks within 13 bioregions across Canada (DFO 2010g). The Scotian Shelf (including the Bay of Fundy) is one of these bioregions and DFO and its federal and provincial partners will be leading an MPA network planning process for the bioregion in the coming years.

2.6 CONCLUSION

The Scotian Shelf in Context gives a brief overview of the region by providing some baseline knowledge of the biophysical, social and economic environment of the Scotian Shelf. It is intended as a useful resource for a broad-based audience, as well as to provide context for the more in-depth discussion in the theme papers. Readers interested in finding out more about the issues facing the Scotian Shelf are encouraged to read the theme papers. The State of the Scotian Shelf Report can also be accessed at: http://coinatlantic.ca/index.php/state-of-the-scotian-shelf

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Biodiversity

3. MARINE HABITATS AND COMMUNITIES[8]

Christopher Burbidge, Marine Affairs Program, Dalhousie, Halifax, NS

3.1 ISSUE IN BRIEF

"Habitat" is loosely defined as any area that provides the conditions and resources that organisms need to survive. The offshore marine habitats of the Scotian Shelf fall into two broad categories: the water column and benthic habitats. Within these habitats live groups of organisms known as "communities" that interact with each other while sharing a similar environment. The structure and function of these communities have evolved in response to the natural conditions on the Scotian Shelf (e.g. temperature, salinity, light regime and depth), which in turn are influenced by the broader oceanography, geology, circulation and climate. The driving forces influencing marine habitats and communities of the Scotian Shelf include changes in the economic, human and natural environments (**Figure 3-1**). Anthropogenic pressures on marine habitats and communities include those from ocean activities such as commercial fisheries, offshore oil and gas activity, marine shipping and vessel traffic, and the laying of submarine cables. These activities can disturb and alter habitat, contaminate the marine environment, and change the structure (i.e. species diversity, productivity and food-web structure) of communities. Variability in the natural environment also places pressure on the habitats and communities of the Scotian Shelf by altering dominant oceanographic conditions and the physical and chemical properties of seawater. These changes can affect the distribution and extent of habitat and the distribution and structure of biological communities (see *Climate Change and its Effects on Ecosystems, Habitats and Biota*). As a result of the combined effects of human activities and changing environmental conditions, the Scotian Shelf ecosystem has undergone a major structural shift since the 1970s which has impacted all trophic levels and altered the structure of marine communities (Bundy 2005; DFO 2010a; see *Trophic Structure*). A variety of management actions have been implemented to protect the offshore habitats and communities of the Scotian Shelf including a variety of legislation and policies, and scientific research and monitoring programs.

Linkages

This theme paper also links to the following theme papers:
- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Fish Stock Status and Commercial Fisheries
- Incidental Mortality
- Ocean Acidification
- Ocean Noise
- Species at Risk
- Trophic Structure
- Water and Sediment Quality

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[8] Completed November 2011.

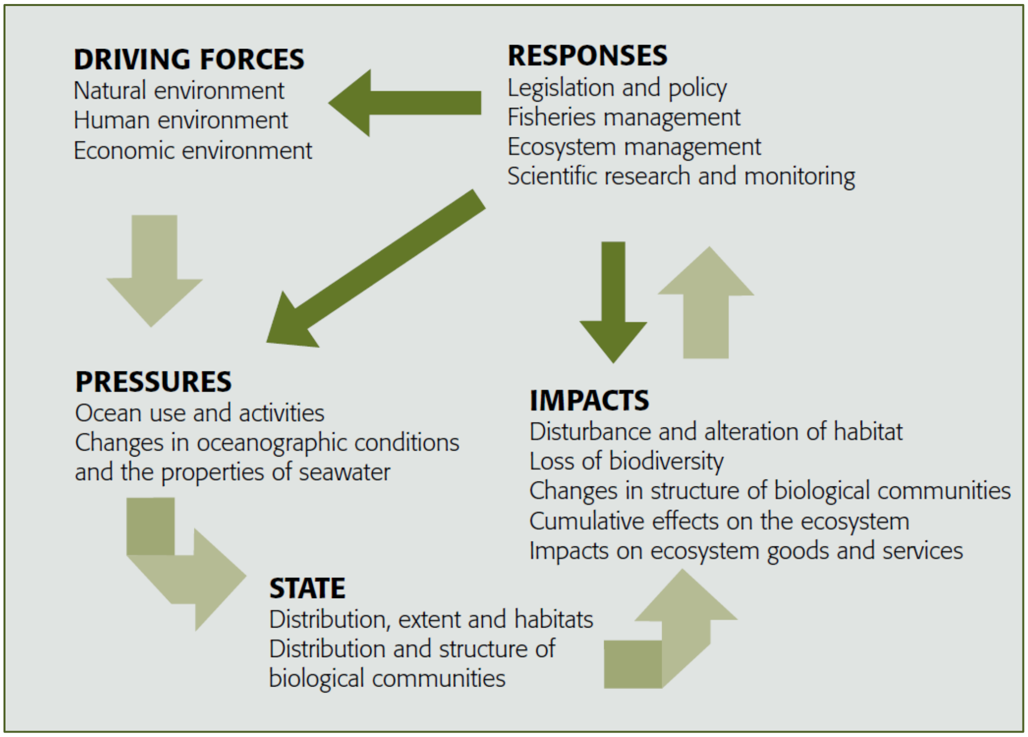

Figure 3-1: Driving forces, pressures, state, impacts and responses (DPSIR) for marine habitats and communities on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

3.2 DRIVING FORCES AND PRESSURES

Changes in the human and economic environment influence demand for ocean resources, such as seafood and offshore energy, and may lead to increased human activity on the Scotian Shelf. These ocean uses and activities are important pressures on marine habitats and communities. The natural conditions of the Scotian Shelf, such as variations in the physical and chemical properties of seawater, are another important driving force influencing marine habitats and communities (see *The Scotian Shelf in Context* and *Climate Change and its Effects on Ecosystems, Habitats and Biota*).

3.2.1 Natural Conditions

Natural conditions refer to the geomorphology, geology, climate and oceanographic conditions of the Scotian Shelf. These natural conditions are described in detail in *The Scotian Shelf in Context*. Physical features, such as the sediment and topography of the seabed, strongly influence habitat type and the distribution and abundance of marine organisms. Temperature, salinity and water circulation are also important factors influencing habitat quality and the distribution, growth and survival of marine organisms. Temperature and salinity are important because each organism has a particular range of temperature and salinity that is optimal for its success. Ocean currents are important because they transport food and oxygen, remove wastes and transport less active organisms from place to place.

Oceanographic conditions on the Scotian Shelf such as water temperature and salinity vary over time and space. Changes in oceanographic conditions over the past 30 years have been associated with expansion of range by some fish and invertebrate species, the occurrence of new species in the area, and decreases in the average size and condition of fish within some groundfish populations (Worcester and Parker 2010). For example, the cooling of waters in the Scotian Shelf in the late 1980s has been associated with the appearance and subsequent increases in abundance of capelin (a species of cold-water, pelagic fish) in the northeastern Scotian Shelf (Worcester and Parker 2010). Some recent studies have suggested that long-term changes in ocean temperature and circulation could affect marine organisms by changing species abundance and distribution (with respect to both latitude and depth) and the structure and dynamics of plankton and fish communities (Cheung et al. 2010; Engelhard et al. 2010; Lehodey et al. 2006; MacNeil et al. 2010; Rijnsdorp et al. 2009).

3.2.2 Oceans Uses and Activities

Numerous ocean-related industries and activities occur on the Scotian Shelf including commercial fisheries, offshore oil and gas, marine shipping, ocean tourism, and submarine cables (see *The Scotian Shelf in Context*). Combined with the effects of changing natural conditions, these activities can impact marine habitats and communities in a variety of different ways.

Commercial fishing is a major source of income and employment in Nova Scotia and is widespread on the Scotian Shelf. A diverse range of species is targeted in commercial fisheries on the Scotian Shelf including groundfish (e.g. cod, haddock, pollock, flatfishes), small pelagic fishes (e.g. herring, mackerel), large pelagic fishes (e.g. tuna, sharks, swordfish) and invertebrates (e.g. lobster, crab, shrimp, scallop) (Coffen-Smout et al. 2001). Different types of gears are used in fisheries on the Scotian Shelf including otter trawl, seine, longline, gillnet, handline, dredge, weir, traps and pots, and harpoon (DFO 2005a). **Figure 3-2** shows the total groundfish landings from 1999 to 2003 in the Scotia-Fundy Region and the proportion of landings by gear type. There are also many different types and sizes of fishing vessels, from small vessels used in coastal lobster fisheries to very large vessels used in offshore scallop and groundfish fisheries (DFO 2005a).

Fishing has direct and indirect effects on habitat and on the diversity, structure and productivity of benthic communities, and it is the main activity affecting marine habitats and communities in the region (Fuller et al. 2008; Jennings and Kaiser 1998). Some fishing gear types, such as trawls, dredges and other mobile, bottom-contacting gears can disturb and alter benthic habitat and communities (DFO 2006a; Fuller et al. 2008). They impact the physical features of the seafloor by damaging or reducing structural biota and complexity, altering the seafloor structure and large habitat features, and temporarily increasing sedimentation rates (DFO 2006a). These types of gear can also impact benthic communities by changing the relative abundance of species in a community, decreasing the abundance of some long-lived species, increasing the abundance of some short-lived species, increasing the abundance of scavenger species, and changing the rates of nutrient cycling within a community (DFO 2006a). Other types of fishing gear, such as demersal longlines and gillnets, pots and traps can also disturb and damage bottom habitat and have been found to cause entanglement and breakage of bottom features such as corals (Baer et al. 2010; Donaldson et al. 2010). Overexploitation of commercial species and/or the incidental capture of non-target species may alter biological communities by changing the productivity, species diversity and size structure of the community (DFO 2010b;

Jennings and Kaiser 1998; see *Fish Stock Status and Commercial Fisheries and Incidental Mortality*).

Oil and gas activity is one of the main non-fishing industrial activities taking place on the continental shelf and slope (Worcester and Parker 2010). As of 2004, over 300,000 km of seismic survey tracks had been recorded and 194 wells had been drilled, with the majority of wells concentrated on the eastern shelf near Sable Island (Coffen-Smout et al. 2001: Zwanenburg et al. 2006). To date, two petroleum production projects have operated on the Scotian Shelf near Sable Island including the Cohasset-Panuke Project (1992 - 1999) and the Sable Offshore Energy Project (1999 – present) (CNSOPB 2011). A third project, the Deep Panuke Offshore Gas Development Project is currently under development and is expected to start production in 2012 (CNSOPB 2011). Oil and gas activity can affect marine habitats and communities by generating noise, pollution and contamination, and disturbing the seabed (CNSOPB 2005; Hurley and Ellis 2004; Thomson et al. 2000; see *Ocean Noise and Water and Sediment Quality*).

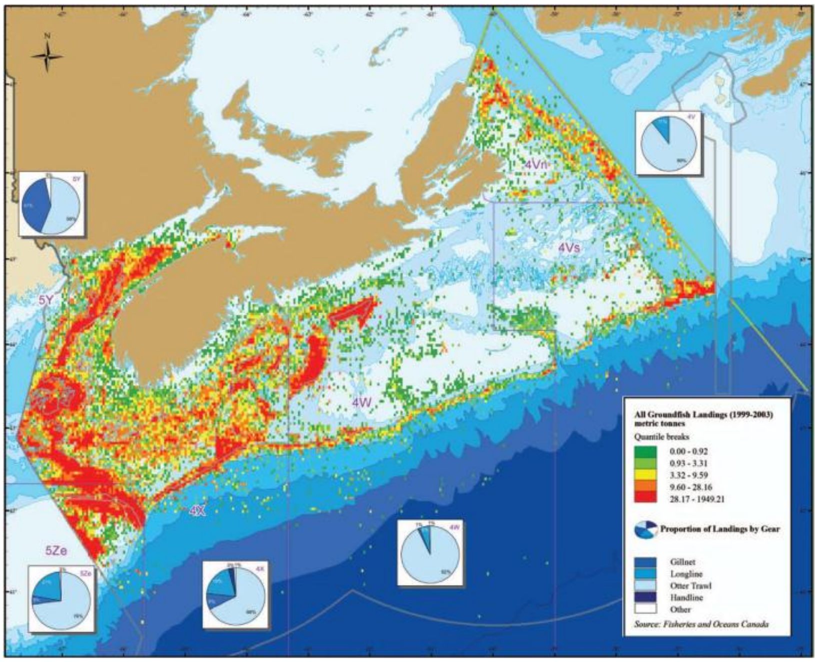

Figure 3-2: Total groundfish landings (1999-2003) in the Scotia-Fundy Region and the proportion of landings by gillnet, longline, otter trawl, handline and other gear types (DFO 2005a).

The strategic location of Nova Scotia on the Great Circle Route (i.e. shortest distance over the earth's surface) between eastern North America and Europe makes it important for international shipping (Coffen-Smout et al. 2001). Commercial shipping in this area is generally in the form of tankers, general bulk and containerized cargo carriers (Coffen-Smout et al. 2001). The area is also transited locally by a range of fishing vessels, cruise ships and various government vessels (Coffen-Smout et al. 2001). The primary commodities being moved in the region include crude oil and gas, minerals and chemicals, paper and forest products, coal and coke and various containerized goods (Coffen-Smout et al. 2001). Pressures on marine habitats and communities resulting from the high volume of shipping activity and vessel traffic in the Scotian Shelf include ship-source pollution, shipboard wastes, noise and collisions between vessels and marine life (see *Incidental Mortality*; *Ocean Noise*; and *Water and Sediment Quality*).

There are numerous active and inactive submarine cables on the Scotian Shelf and Slope, some of which are more than 100 years old (DFO 2005a). At present, no high voltage DC power cables cross the Scotian Shelf, although some have been proposed (DFO 2005a). Several active submarine telecommunications cables make landfall in Nova Scotia and cross the Scotian Shelf (DFO 2005a). Submarine cables are either installed on the surface of the seabed or buried in the seabed, and therefore have the potential to disturb and alter benthic habitats and communities in the vicinity (Carter et al. 2009; Worzyk 2009). A new telecommunications cable running from England to Halifax is proposed by Hibernia Atlantic for 2012.

3.3 STATUS AND TRENDS

3.3.1 Marine Habitats

The focus of this paper is on offshore marine habitats and communities of the Scotian Shelf, particularly the water column, which is home to pelagic species, and benthic habitats, which are home to bottom-dwelling organisms. For information on the status and trends associated with coastal and nearshore habitats in the region, the reader is directed to the 2009 State of Nova Scotia's Coast Report (CBCL Limited 2009; http://www.gov.ns.ca/coast/state-of-the-coast.htm).

3.3.1.1 The Water Column: The area between the seafloor and the sea surface, including all marine and estuarine waters, is referred to generically as the water column and represents the most widespread habitat in the Scotian Shelf. It is a dynamic environment consisting of distinct layers and water masses (see *Scotian Shelf in Context*). The physical and chemical properties of water masses (i.e. temperature, salinity, acidity) greatly influence their suitability as habitat for organisms (Davis and Browne 1996; Todd and Kostylev 2010; Zwanenburg et al. 2006), and variations in these properties affect the distribution and abundance of marine organisms.

- Between 1961 and 2003, global ocean temperature increased by 0.10°C from the surface to a depth of 700 m, with lesser temperature increases observed to a depth of 3000 m (IPCC 2007). Regional trends in water temperature are less clear as water temperatures on the Scotian Shelf are among the most variable in the North Atlantic, with noticeable warm (1979-1986; 1999-2000) and cool cycles (1987-1993; 2003-2004) (Worcester and Parker 2010). The greatest temperature anomaly in the 38-year time series for the Scotian Shelf was recorded in 2006 and it appears that variability in water temperature has been increasing over the past decade (Worcester and Parker 2010).
- Over several decades, changing patterns of precipitation, evaporation, river runoff and ice melt have led to changes in ocean salinity on gyre and basin scales, with a global trend towards freshening in subpolar latitudes (IPCC 2007). Salinity in the Scotian Shelf region is variable, decreasing from the mid-1970s to the mid-1990s, then increasing to 2002 before decreasing again (Worcester and Parker 2010).
- The pH of seawater on the Scotian Shelf decreased by 0.002 pH units per year over the period 1927 to 2009 (DFO 2009a; Worcester and Parker 2010).

3.3.1.2 Benthic Habitats: The physical attributes of the seabed are known to be important factors influencing habitat and the distribution of benthic organisms, including: topography (macro relief), roughness (micro relief), sediment type and distribution, grain size and shape, patchiness, rock composition and sediment thickness (Davis and Browne 1996; Fader et al. 1998;

Todd and Kostylev 2010). Oceanographic factors such as oxygen saturation, temperature variability, water stratification and chlorophyll-a concentration are also important for structuring benthic habitat and communities and are strongly related to water depth (Todd and Kostylev 2010).

The Scotian Shelf is host to a diverse range of benthic habitats due to its geological and topographical complexity (Davis and Browne 1996; Todd and Kostylev 2010). Substrate type and sediment grain size have a particularly strong influence on the benthic fauna that inhabit a particular area (Davis and Browne 1996; Kostylev et al. 2001; Todd and Kostylev 2010). Some areas of the Scotian Shelf are homogenous, with similar substrate type and grain size, but many areas are characterized by a variety of surface sediments, and tend to support greater biological diversity (Breeze et al. 2002; Todd and Kostylev 2010). The main characteristics of the various substrate types and sediment grain sizes found on the Scotian Shelf include:

Clay and Silt: Areas of the Scotian Shelf with muddy bottoms include the mouth of the Laurentian Channel, the Gully Fan, the Scotian Rise and the basins of the Middle Scotian Shelf (Breeze et al. 2002; WWF 2009). Muddy bottoms are usually comprised of varying proportions of silt and clay and provide habitat for a variety of infauna (i.e. organisms that live in sediment), epifauna (i.e. organisms that live on or above sediment) and bottom-feeding fish (Davis and Browne 1996). Some common species of infauna found in areas with muddy bottoms include sea anemones, sea pens, polychaete worms, bivalve molluscs, tusk shells, gastropods, sea cucumbers, brittlestars and starfish (Davis and Browne 1996; Kostylev et al. 2001). Common species of epifauna found on muddy bottoms include bryozoans, ascidians, crabs, shrimp, sea spiders, skates and groundfish (Davis and Browne 1996; Kostylev et al. 2001).

Sand and Gravel: Sand and gravel bottoms are widespread on the Scotian Shelf and are found throughout the Inner Shelf, on the tops of banks, the flanks of basins and channels, and on the floors of submarine canyons (Breeze et al. 2002; WWF 2009). Quahogs, sea scallops, and surf clams commonly occur on the sandy/ gravelly bottoms of the Inner Shelf and on offshore banks (Davis and Browne 1996; WWF 2009). The sand dollar, *Echinarachnius parma*, is strongly associated with fine sandy sediments and is commonly found in areas of the Scotian Shelf with fine and medium-grained sands (Breeze et al. 2002). Species typically occurring on sandy substrate include sand dollars, cumaceans, amphipods, polychaete worms, tanaidaceans, and sand lance (Davis and Browne 1996; WWF 2009). Horse mussels, brittle stars, lobsters and crabs are common in gravelly areas of the Shelf (WWF 2009). Structurally complex gravel habitats found on banks have been associated with a diverse range of fauna and abundant epifauna including sponges, brachiopods, tunicates, polychaetes and sea cucumbers (Kostylev et al. 2001). Gravel sediments on the Laurentian Fan are home to unique “cold seep” communities of clams, snails, crabs and feathery polychaete worms that derive energy from the available carbon and hydrogen sulphide seeping out of the sediment (WWF 2009).

Boulders and Bedrock: Rocky bottoms can be found on the banks of the Outer Scotian Shelf, the basins of the Middle Scotian Shelf, and in parts of the Northeast Channel (WWF 2009). Areas of the sea-bottom with bedrock and boulders are ideal for epifauna, but provide little habitat for infauna, except where sediment has accumulated in cracks and under rocks and boulders (Davis and Browne 1996). Horse mussels, brittle stars, starfish, lobsters, crabs, polychaete worms, sea urchins, sea cucumbers, corals, sponges, hydroid polyps, bryozoans and tunicates inhabit areas with rocky bottoms (Davis and Browne 1996; WWF 2009). Rocky bottoms also serve as important habitat for a range of fish species including sculpin, cunner, lumpfish, wolffish and pollock (Davis and Browne 1996). Most species of deep-sea corals and sponges found on the Scotian Shelf need the hard surfaces of boulders and bedrock on which to settle (Breeze et al. 2002). Sampling equipment is usually not suitable for representative sampling of hard rocky bottoms and fewer samples have been taken from these environments than others on the Shelf (Breeze et al. 2002).

Biogenic Habitats: Certain structure-forming animals that live on the seabed including ascidians, bryozoans, corals, hydroids, and sponges can create, modify and maintain habitat for other species by producing complex structures on top of sediments (Breeze et al. 2002; Fuller 2011). These habitats, known as biogenic habitats, may offer space for attachment, increased food supply, hiding places from predators, and shelter from harsh environmental conditions (see *Scotian Shelf in Context*). The distribution and extent of biogenic habitats can influence species richness and community structure in the surrounding ecosystem (Fuller 2011), and may be a limiting factor for populations of certain species (Breeze et al. 2002). On the Scotian Shelf, deepsea corals and sponges are common in certain areas and form complex structures that support increased biodiversity compared to most other benthic habitats (DFO 2010c). Corals provide shelter for numerous species and influence, both directly and indirectly, the local occurrence or abundance of fish and invertebrate species (DFO 2010c). They provide habitats at key life stages of many marine species as well as a food source for other invertebrates (DFO 2010c). Sponge reefs provide habitat for fish and high-complexity reefs are associated with higher species richness and abundance (DFO 2010c). Additional information on the status of coral and sponge communities on the Scotian Shelf is provided in Section 3.3.2 below.

3.3.2 Marine Communities

The term “community” describes a group of interacting organisms living near, on, or within one another and found in similar environments (Breeze et al. 2002). The structure (i.e. species diversity, productivity and *Trophic Structure*) of biological communities depends on a range of factors such as climate, competition, predator-prey relationships, disturbance, nutrient availability, and habitat type (Greenstreet 2003; Emery 1978). Traditionally, research on marine organisms of the Scotian Shelf has focused on population level studies of species targeted by commercial fisheries (DFO 2007a). As a result, there is a lack of information on the structure, distribution and dynamics of marine communities, making the identification of ecologically significant species and community properties difficult (DFO 2006b). Furthermore, reliable indicators for assessing the status of biological communities are not yet available (ICES 2005; Rochet and Trenkel 2003). In some cases, studies have been conducted on “assemblages.” Assemblages are subsets of species or taxonomic groupings (e.g. finfish assemblages) found in similar environments (Fauth et al. 1996). Usually, the ecological relationships among species in an assemblage are not well understood. Information about the individual populations and/or assemblages which comprise a biological community can help assess the status of the community when there is insufficient data or information at the community level (Rochet and Trenkel 2003).

The Scotian Shelf ecosystem has undergone a major structural shift since the 1970s, which has impacted all trophic levels and many biological communities (Bundy 2005; DFO 2010a; Frank et al. 2005; see *Trophic Structure*). This shift involved concurrent increases in seals, small pelagic fish, benthic macroinvertebrates, and phytoplankton; and decreases in groundfish and zooplankton (Bundy 2005; DFO 2010a; Frank et al. 2005; see *Trophic Structure*). However, in 2006 the ecosystem began showing signs of recovery towards its previous structure, including a declining abundance of forage fish and an increasing abundance of zooplankton and groundfish such as cod and haddock (Frank et al. 2011). The status of some of the main communities and assemblages found on the Scotian Shelf is summarized below.

Planktonic communities: On the Scotian Shelf, phytoplankton biomass is dominated by diatoms and dinoflagellates (Zwanenburg et al. 2006). Zooplankton include a range of organisms which feed on phytoplankton and other zooplankton including single-celled protozoa, copepods, euphausiids (krill), chaetognaths (arrow worms), salps and jellyfish (Zwanenburg et al. 2006). The patterns of abundance of phytoplankton are largely determined by variations in the physical oceanographic features of the ocean environment, and the complex nature of these features on the Scotian Shelf makes high spatial and temporal variability in phytoplankton biomass a common feature of the region (Zwanenburg et al. 2006). There is also a distinctive seasonal cycle of growth characterized by a conspicuous and widespread spring biomass peak (the spring "bloom") and a more diffuse fall bloom (Zwanenburg et al. 2006).

The composition of the phytoplankton community on the Scotian Shelf has remained relatively constant over time, with diatoms dominating in the winter/spring, and flagellates and dinoflagellates dominating the rest of the year (DFO 2009b). Compared with historical data records dating back to 1961, recent phytoplankton abundances on the Scotian Shelf have been at or above the long term average while zooplankton abundances have been at or below the norm (DFO 2009b). These changes in abundance have been linked to the increased abundance of forage fish on the Scotian Shelf (Bundy 2005; Frank et al. 2005; see *Trophic Structure*). In 2007, the magnitude of the spring phytoplankton bloom reached a record high, but was followed by a decrease to an average or below average level in 2008 (DFO 2009b). Chlorophyll levels outside of the spring bloom period have been declining since observations began in 1999 (DFO 2009b).

Finfish assemblages: There are 538 species of finfish known to occur in the Canadian Atlantic (Worcester and Parker 2010). The abundance and distribution of marine fishes on the Scotian Shelf is continually changing as a result of fishing and environmental factors (Shackell and Frank 2003). The distribution patterns of fish are linked to environmental factors such as water temperature and salinity, bottom type, and availability of food, and these patterns often differ at different life stages (Breeze et al. 2002). Horsman and Shackell (2009) identified areas of important habitat for a variety of ecologically significant fish species on the Scotian Shelf including forage species, influential predators, depleted and rare species, and other dominant species. The distribution maps are presented on a species-by-species basis and no analysis was performed at the assemblage or community level. Certain areas on the Scotian Shelf have been identified as having a high degree of finfish diversity including the Eastern Gully, the slopes, Western Bank and the northeastern shelf (Shackell and Frank 2003).

Types of Fishes

Fishes of the Scotian Shelf can be grouped into three categories: *demersal* fishes that spend most of their life near the ocean bottom (e.g. groundfish such as haddock and cod); *pelagic* fishes that live in the water column (e.g. herring, mackerel, tuna); and *diadromous* fish that spend part of their lives in freshwater and part in salt or brackish water (e.g. Atlantic salmon) (Breeze *et al.* 2002).

Studies of fish assemblages on the Scotian Shelf have focused on demersal species, as pelagic species are highly migratory and may not have strong associations with other fishes (Worcester and Parker 2010). Membership in the demersal fish assemblages is relatively constant, but also adaptable to different environmental conditions (Breeze et al. 2002; Mahon and Smith 1989). They may vary in location over time, and do not conform to accepted biogeographical boundaries (Breeze et al. 2002; Mahon and Smith 1989).

Overall, the composition of marine finfish on the Scotian Shelf has remained relatively constant, but the dominance structure has changed dramatically over the past 30 years (Shackell and Frank 2003; Worcester and Parker 2010). Notable changes include decreases in the abundance and distribution of groundfish, increases in the abundance of small pelagic fish, and the geographic expansion of species that are known to be important prey items of groundfish such as herring, sand lance and snake blenny (Shackell and Frank 2003; Worcester and Parker 2010). The collapse of benthic/demersal fish communities in the 1990s was a primary factor in the structural changes that have occurred in the Scotian Shelf ecosystem (Frank et al. 2005). Since 2006, the abundance of small pelagic fish has declined and the abundance of groundfish has increased, with Atlantic cod and redfish reaching levels of abundance not seen since the early 1990s and haddock reaching a unprecedented high (Frank et al. 2011). Changes in oceanographic conditions such as water temperature have been associated with the expansion of range by some fish species and the occurrence of new species to the Scotian Shelf (Shackell and Frank 2003; Worcester and Parker 2010). For more detailed information on the status of fish stocks and trophic structure see *Fish Stock Status and Commercial Fisheries* and *Trophic Structure*).

Benthic invertebrate communities: There is a lack of information on the abundance and distribution of non-commercial benthic fauna on the Scotian Shelf, and community trends over time are largely unknown (Hargrave et al. 2004; Worcester and Parker 2010). Currently, there is no comprehensive listing of marine invertebrates on the Scotian Shelf. However, there has been an increase in directed research on benthic habitats and communities in recent years, especially on coral and sponge communities (see the following section for more detail). General descriptions of the distribution of common bottom invertebrate species found on the Scotian Shelf are presented in Breeze et al. (2002), Davis and Browne (1996), Mobil Oil (1983); and Steele et al. (1979). Much more is known about the distribution and abundance of commercial invertebrate species.

Benthic habitats and species assemblages have been relatively well defined for some areas of the Scotian Shelf, but data tend to be both spatially and temporally limited (Breeze et al. 2002; Worcester and Parker 2010). For the purposes of mapping, benthic habitats were defined as areas where physical, chemical and biological characteristics combine to form recognizable ecological units (Kostylev et al. 2001; Todd and Kostylev 2010). Kostylev et al. (2001) identified six benthic habitat types and corresponding species associations for Browns Bank (**Figure 3-3** and **Table 3-1**). Habitat types were distinguished by sediment type, water depth, geomorphology, habitat complexity, and relative current strength (Kostylev et al. 2001). In general, the distribution of benthic mega-invertebrates showed a predominance of suspension-feeders (e.g. *Placopecten*, *Cucumaria*, Sabellidae) on the western, shallower part of the bank and an increase in abundance of deposit-feeders (e.g. Nothriidae) with increasing depth towards the east (Kostylev et al. 2001). Structurally complex gravel habitats on the central and eastern parts of the bank had the greatest species diversity and the greatest abundance of sessile epifauna including sponges, brachiopods and tunicates (Kostylev et al. 2001). No megafauna were observed on large sand formations (Kostylev et al. 2001).

Hargrave et al. (2004) identified seven benthic assemblages in The Gully that were associated with specific habitat types characterized by depth, substrate type, seasonal temperature variance and average annual salinity (**Table 3-2**). Eight visible epifauna and megafauna phyla (Echinodermata, Coelenterata, Annelida, Chordata, Mollusca, Porifera, Brachiopoda and Arthropoda in order of decreasing abundance) and 175 taxa were identified from photo and video observations (Hargrave et al. 2004). Their analysis showed that epifauna communities in The Gully are associated with different substrates and that the highest species richness occurred on hard glacial substrates, where there was a predominance of suspension-feeding species (Hargrave et al. 2004). Epifauna biomass was found to be highest where gravel cover was greater than 50% (Hargrave et al. 2004).

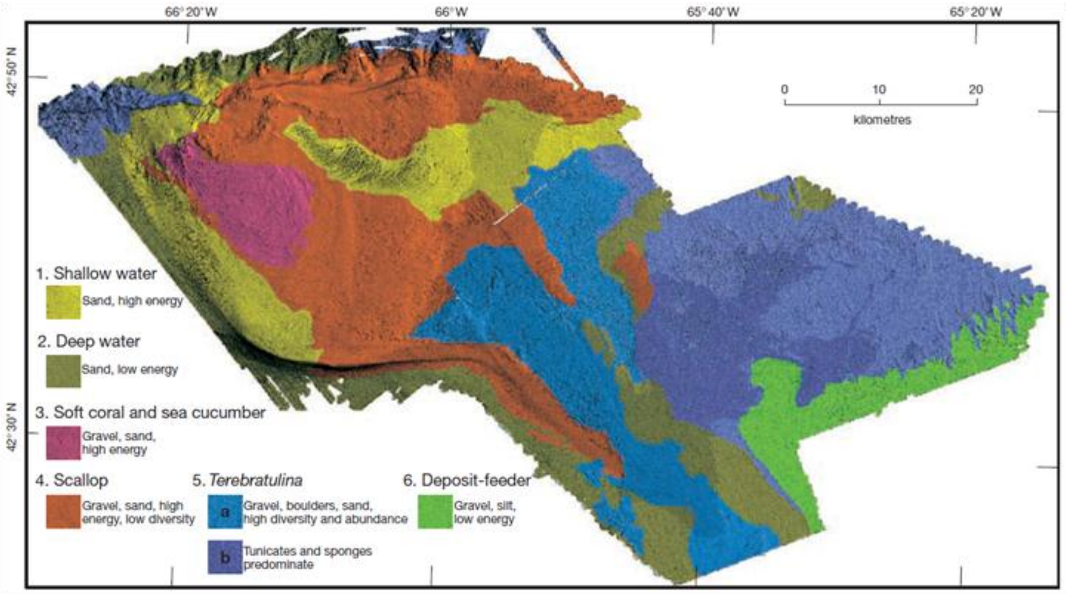

Figure 3-3: Benthic habitat map of Browns Bank showing six colour-coded benthic habitats (Kostylev et al. 2001).

Table 3-1: Benthic habitat types and corresponding species of megafauna on Browns Bank, Scotian Shelf (Compiled from Kostylev et al. 2001).

Habitat Type	**Description**	**Common Species**
1. Shallow water	Sand, high energy	Gilded wedge clams *(Mesodesma deauratum),* possibly surf clams *(Spisula solidissima)* and soft-shelled clams *(Mya truncata)*
2. Deep water	Sand, low energy	Gilded wedge clams, sand dollars, Stimpson's surf clams *(Spisula polynyma)*, barnacles, sea snails (*Neptunea sp*.), Iceland scallops *(Chlamys islandica),* solitary hydroids *(Corymorpha* sp.*)*
3. Soft coral and sea cucumber	Gravel, sand, high energy	Soft corals *(Alcyonium digitatum* and *Duva multiflora)*, sea cucumbers *(Cucumaria frondosa)*
4. Scallop	Gravel, sand, high energy, low diversity	Sea scallops *(Placopecten magellanicus)*, hydroidea especially *Sertularella* sp., whelks, hermit crabs
5. *Terebratulina*	a. Gravel, boulders, sand, high diversity and abundance b. Tunicates and sponges predominate	a. Brachiopods (*Terebratulina septentrionalis)*, Ascidians, serpulid polychaetes (commonly *Filograna implexa, Spirorbis* sp., and less often *Serpula vermicularis*), sea stars *(Henricia* sp.*),* bivalves *(Astarte* sp.*, Macoma calcarea,* and *Clinocardium ciliatum)* b. dominated by tunicates and sponges
6. Deposit-feeder	Gravel, silt, low energy	Polychaetes (possibly Nothriidae and Terebellidae), occasionally anemones, brachiopods and sponges, abundant infauna

Table 3-2: Epifauna assemblages identified by cluster analysis in areas within The Gully, Scotian Shelf, with common habitat characteristics for each group (Hargrave et al. 2004).

Benthic Assemblage	Major Taxa	Predominant Habitat Type
Cluster 1	Brittlestars (*Ophiomusium* sp.), banded corals (*Keratoisis ornata*), sea whips (likely *Balticina* sp.), hydroids, soft alcyonacean corals (*Anthomastus* sp.)	Deep-water, mouth of The Gully, on canyon walls, >600 m depth, ridges dominated by suspension feeders, depositional valleys dominated by deposit-feeders
Cluster 2	Infaunal brittlestars (*Ophiopholis* sp.), daisy-top anemones (*Stomphia* sp.), sponges, chitons, and crinoids	Deep-water, gravelly substrate, 250–650 m, relatively constant temperature and high salinity along edge of canyon
Cluster 3	Cerianthid anemones (*Cerianthus borealis*), shrimp (Pandalidae, Crangonidae spp.), burrowing anemones, polychaetes, krill, (*Meganyctiphanes norvegica*), deposit- feeding brittlestars (*Ophiura* sp.), sea urchins (*Strongylocentrotus pallidus*)	Upper Gully, 130–410 m, glaciomarine deposits, microhabitats in bedrock, outcrops in tributary channels, moderate salinity and varying temperature
Cluster 4	Sand dollars (*Echinarachnius parma*), brittlestars (*Ophiura sarsi*), tube-dwelling polychaetes (Northriidae), hermit crabs (*Pagurus* sp.) and spider crabs (*Hyas araneus*), burrowing anemones (*Edwardsia* sp.), gastropods (Trochidae), polar sea stars (*Leptasterias* sp.)	Shallow depth (50–300 m), sand (bank tops) with highly variable oceanographic conditions
Cluster 5	Protozoan (*Bathysyphon* sp.), burrowing brittlestar (*Amphioplus* sp.), anemones, sponges (*Polymastia* sp.), soft corals (Alcyonacea spp.), sea feathers (*Pennatula* sp.)	Variable sediments (in tributary canyons), 200–600 m in areas with steep slopes, substrates range from silty sand to till, soft sediment between cobbles and boulders
Cluster 6	Sponges (*Halichondria* sp., *Scypha ciliata*, and *Crella guernei*), encrusting and solitary tunicates (Molgulidae spp.), bryozoans (anascan and ascophoran), stalked hydrozoans (*Sertullaria* sp.), gastropods (*Buccinum* sp.), and terebellids	Winnowed gravel 100–500 m in areas affected by shelf water with lower salinity and moderately variable temperature
Cluster 7	Many taxa similar to Cluster 6 brachiopods (*Terebratulina septentrionalis*), white encrusting sponges, anemones (*Fragesia* sp.), serpullid worms (*Filograna implexa*), and (*Protula tubularia*), tube-building polychaetes (Nothriidae)	Poorly sorted gravel (glacial till), 100–500 m on top of deep banks with average salinity, moderately variable temperatures and strong currents

Todd and Kostylev (2010) studied the seabed geology and benthic habitats on German Bank. They used statistical analysis of biological data and oceanographic and geological variables to identify eight benthic habitat types and associated fauna on the Bank (**Figure 3-4 and Table 3-3**). Their analysis showed the distribution of benthic assemblages are scattered in a mosaic fashion and are associated with topographic or geological features.

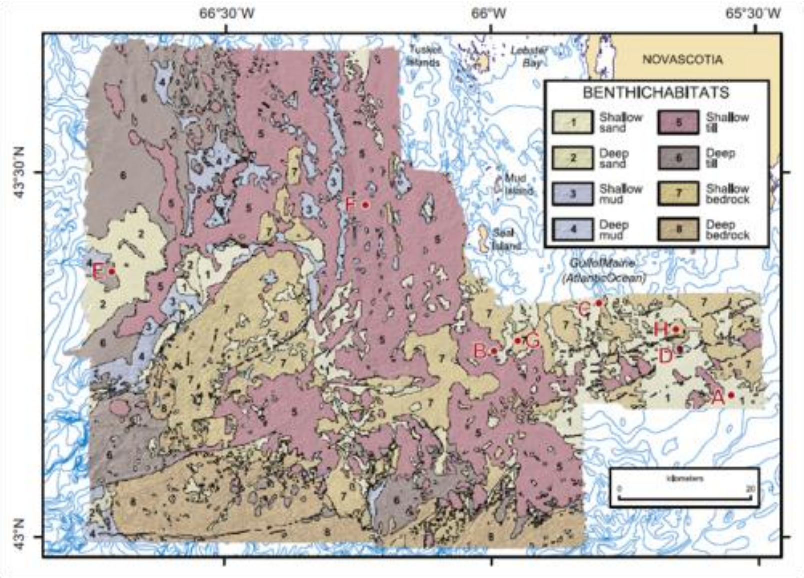

Figure 3-4: Benthic habitat map of German Bank showing eight colour-coded benthic habitat types (Todd and Kostylev 2010).

Corals and Sponges: Corals are mainly found below about 200 m along the edge of the continental slope, in canyons or in channels between fishing banks, but sponges and some soft corals are common in shallower waters on the continental shelf (Kenchington et al. 2010; Mortensen et al. 2006). The distribution of deep-water corals is patchy and largely influenced by substrate type, but temperature, salinity, currents, and topographic relief are important environmental factors as well (Bryan and Metaxas 2006; Mortensen et al. 2006; Watanabe et al. 2009). There are only two known concentrations of the stony, reef-building coral *Lophelia pertusa* in Atlantic Canada (Cogswell et al. 2009). One concentration is located in The Gully, and the other on southeast Banquereau Bank, and was heavily damaged by fishing prior to its discovery (Cogswell et al. 2009; Kenchington et al. 2010). The known distribution of corals on the Scotian Shelf is shown in **Figure 3-5**.

The Scotian Shelf hosts different sponge assemblages, but the overall biomass is relatively low (Kenchington et al. 2010). Typically, sponge grounds are composed of one or two species of large structure-forming sponges and many other smaller but abundant associated sponge species (Kenchington et al. 2010). Unique populations of the large, barrel-shaped glass sponge Vazella pourtalesi (also known as “Russian Hats”) exist in the vicinity of Emerald Basin and Sambro Bank as well as areas of the Northeast Channel (Fuller 2011; Kenchington et al. 2010; Metaxas and Davis 2005; WWF 2009). More detailed information on the distribution and abundance of corals and sponges on the Scotian Shelf can be found in Cogswell et al. (2009); Kenchington et al. (2010) and Mortensen et al. (2006).

Corals of the Scotian Shelf

Five major orders of coral are known to occur on the Scotian shelf including: *Alcyonacea* (soft corals), *Antipatharia* (black/thorny corals), *Gorgonacea* (branching corals), *Pennatulacea* (sea pens), and *Scleractinia* (stony corals, cup corals) (Cogswell *et al.* 2009).

Corals and sponges form complex structures that serve as important deep-sea habitat (see Section 3.3.1.2 above). Therefore, a variety of fish and invertebrate species are often associated with coral and sponge communities on the Scotian Shelf. Studies of benthic habitats and species assemblages on Browns Bank (Kostylev et al. 2001), in The Gully (Hargrave et al. 2004), and on

German Bank (Todd and Kostylev 2010) describe some organisms commonly associated with coral and sponge communities in these areas (see **Tables 3-2** to **3-3**). Buhl-Mortensen and Mortensen (2005) studied the associated fauna of the most abundant large gorgonian corals (*Primnoa resedaeformis* and *Paragorgia arborea*) on the continental shelf and slope off Atlantic Canada. They identified 114 associated species and 3,915 specimens. Crustaceans were the most abundant fauna associated with the corals, contributing 46% to the total number of individuals and 26% to the total number of species (Todd and Kostylev 2010.; see **Figure 3-6**).

Table 3-3: Seafloor habitats and species associations on German Bank, Scotian Shelf (Compiled from Todd and Kostylev 2010).

Seafloor/Habitat Description	Species Associations
• 100-140 m depth • Flat sea bed • Sediment varies from gravely sand to mud	• Amphipods and polychaete tubes, anemones (*Cerianthus borealis*), shrimp (*Pandalus* sp.), hake (*Urophycis* sp.), monkfish, flatfish, Jonah crabs (*Cancer* sp.), hermit crabs (*Pagurus* sp.) • Scarce benthic epifauna
• 50-100 m depth • Topographically complex and heterogeneous seabed • Seabed varies from exposed bedrock through cobbles and boulders to sandy gravel and shell hash beds	• **Hard substrates:** Sponges, sea stars (*Asterias* sp., *Crossaster papposus*, *Solaster endeca*, *Hippasteria phrygiana*), tunicates (*Boltenia ovifera*), brachiopods (*Terebratulina* sp.), soft corals (*Gersemia* sp.), mats of hydrozoans and bryozoans • **Complex rock habitat:** fish • **Poorly sorted sediments:** Polychaete tubes, sponges • **Sandy gravel, gravely sand, and shell beds:** Sea stars (*Asterias* sp., *Crossaster* sp., *Hippasteria* sp.) • **Sand and sandy mud patches among till and bedrock:** scarce fauna, infrequent occurrence of flatfish, Great spider crabs (*Hyas aranaeus*), sea urchins (*Strongylocentrotus* sp.) • Shell beds containing populations of horse mussels (*Modiolus modiolus*)
• 50-100 m depth • Dominated by moraines • Seabed varies from gravelly mud to complex cobble and boulder bottom	• **Hard substrates:** Abundant epifauna with low diversity • **Gravely sand in troughs between drumlins:** Groundfish, Jonah crabs (*Cancer* sp.), scallops (*Placopecten magellanicus*) • **Drumlins:** Anemones, sea stars (*Asterias* sp.), sponges (*Halichondria panicea*)
• 30-70 m depth • Sand deposits	• **Deep waters (70 m):** Brittlestars (*Ophiura sarsi*), sea urchins (*Strongylocentrotus* sp.), rigid cushion stars (*Hippasteria phygiana*), hermit crabs (*Pagurus* sp.), whelk (*Colus* sp.; *Buccinum* sp.), gastropods (*Neptunea* sp.), hydrozoans, bryozoans, anemones • **Shallow waters (30-40 m):** Scarce fauna including scallops (*P. magellanicus*), horse mussels (*M. modiolus*), anemones, sponges (*Polymastia* sp.)
• 20-40 m depth • Seabed dominated by bedrock and boulders with a few patches of sand	• Coralline algae (*Lithothamnium* sp.) on boulders • Frilled anemones (*Metridium senile*) and stalked tunicates (*B. ovifera*) are very abundant • Horse mussels (*M. modiolus*), sponges (*Haliclona oculata*), mound-shaped sponges, echinoderms (*Asterias* sp., *Henricia* sp., *Strongylocentrotus* sp.)

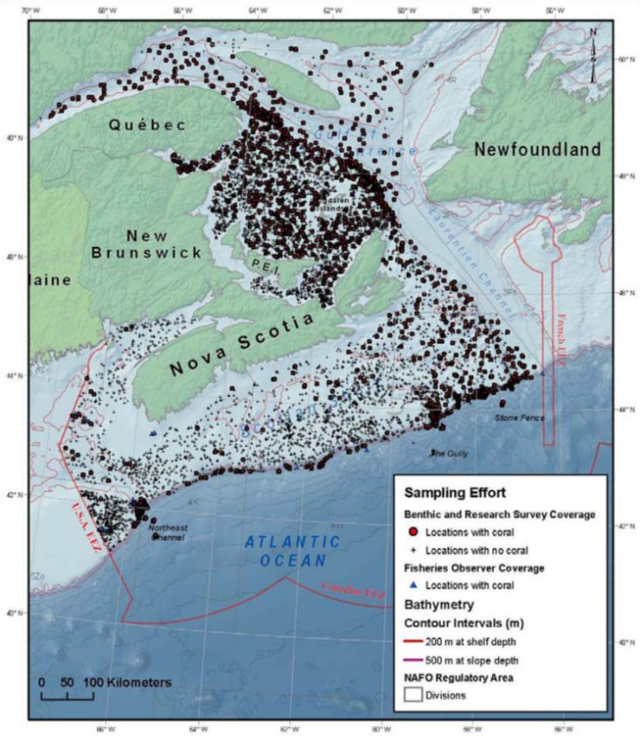

Figure 3-5: Distribution of cold-water corals on the Scotian Shelf and the Gulf of St. Lawrence (Campbell and Simms 2009).

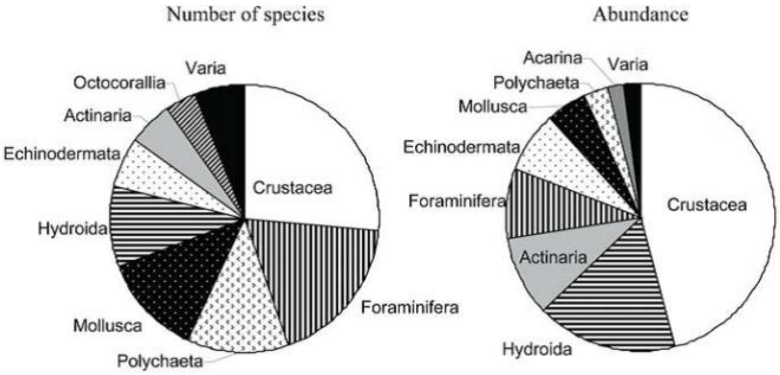

Figure 3-6: The relative species richness and abundance of different taxonomic groups associated with *Primnoa resedaeformis* and *Paragorgia arborea* from off Atlantic Canada (Buhl-Mortensen and Mortensen 2005).

Mortensen and Buhl-Mortensen (2005) examined the diversity of benthic megafauna in The Gully. A total of 95 megafauna taxa were observed, with the most species rich groups being fish (Teleostei, 19 taxa) and octocorals (18 taxa). The most common fish species observed were redfish (*Sebastes* sp.) followed by long-finned hake (*Urophycis chesteri*). Metaxas and Davis (2005) studied the distribution and abundance of benthic megafauna in areas of Northeast Channel associated with known gorgonian coral assemblages using a remotely operated vehicle (ROV). The most abundant epibenthic taxa they observed included gorgonian corals (*Primnoa resedaeformis* and *Paragorgia arborea*), suspension feeders (*Actinauge verrilli* and *Bolocera* *tudiae*), an unidentified anemone, encrusting sponges (*Ophiacantha abyssicola*), and basket star (*Gorgonocephalus arcticus*). In the canyons of Georges Bank, shrimp are commonly associated with the large gorgonian corals *P. arborea*, *P. resedaeformis*, and *Paramuricea grandis* and the alcynocean coral *Eunepthya florida* (Breeze et al. 2002). In the same area, the brittle star *Asteronyx loveni* is associated with colonies of *P. grandis* (Breeze et al. 2002).

Organisms commonly associated with sponges and sponge grounds in Atlantic Canada include species of marine worms, bryozoans, fish, crabs, shrimp, prawns, and other euphausiids (Campbell and Simms 2009; DFO 2010c). Fuller (2011) describes benthic megafauna associated with *V. pourtalesi* sponges in Emerald Basin. The ocean pout (*Zoarces americanus*) was the most frequently observed fish species, followed by redfish (*Sebastes* spp.), hake (*Merluccius merluccius*), flatfishes and gadoids. Shrimp (*Pandalus borealis*) were the most frequently observed invertebrates associated with *V. pourtalesi*. Other invertebrate species observed included various other sponges, rock crabs (*Cancer borealis*), cerianthid anemones and sea stars (*Henricia* sp.).

Corals and sponges are vulnerable to anthropogenic disturbance because of their slow growth and sensitivity to physical and chemical changes (Fuller 2011; Watanabe et al. 2009). Evidence of fishing impacts to corals such as broken live corals, tilted corals, scattered skeletons, tracks made by fishing gear and lost longlines entangled in corals have been observed in a variety of locations on the Scotian Shelf, including the Northeast Channel and the Stone Fence (Cogswell et al. 2009; Mortensen et al. 2006).

3.4 IMPACTS

Pressures from changing environmental conditions and ocean activities such as commercial fisheries, offshore oil and gas activity, marine shipping and vessel traffic, and the laying of submarine cables result in a number of important biophysical and socio economic impacts (**Table 3-4)**.

3.4.1 Biophysical Impacts

Ocean uses and activities have the potential to impact marine habitats and communities in variety of ways (**Table 3-4**). The overexploitation of commercial species and/or the incidental capture of non-target species in fisheries can alter biological communities by changing the productivity, species diversity and size structure of the community (DFO 2010b; Jennings and Kaiser 1998; see also *Fish Stock Status* and *Commercial Fisheries* and *Incidental Mortality*). Marine pollution and ocean noise from commercial shipping, vessel traffic and oil and gas activity can reduce the quality of marine habitat (DFO 2004a; Hurley and Ellis 2004; Southall 2005; Thomson et al. 2000; see also *Water and Sediment Quality* and *Ocean Noise*).The greatest impact of ocean activities on benthic habitats and communities is physical disturbance and alteration of the seabed, especially from mobile, bottom-contacting fishing gear (DFO 2006a; Fuller et al. 2008). DFO has recently reviewed a framework for the classification and characterization of benthic habitats in the Scotian Shelf and Bay of Fundy which helps to identify benthic habitats that are sensitive to physical disturbance from human activities (DFO 2005b; Kostylev and Hannah 2007). This framework classifies benthic habitats as a function of disturbance and scope for growth. Disturbance is defined as a natural, mechanical force determined by the action of currents and waves on the seabed (DFO 2005b). Scope for growth is related to the energy available for organisms to spend on reproduction and growth after meeting basic metabolic needs and can be described by some combination of food availability to the benthos, annual bottom temperature, seasonal and interannual temperature variability, and oxygen saturation (DFO 2005b). Using these parameters, the framework characterizes the potential sensitivity and predicted response of benthic communities to physical disturbances resulting from human activities (**Figure 3-7**). In this model, sensitivity is defined as a function of the recoverability and the vulnerability of some biological component, such as a community, species, or population. Vulnerability is the likelihood that a biological component will be exposed to some impacting factor and recoverability is the rate at which the component is able to return to some previous state after being impacted. Therefore, the most sensitive benthic communities are those with high vulnerability and low recovery rate such as deep-sea coral communities. At the other end of the spectrum, the least sensitive benthic communities are those with a low vulnerability and high recovery rate, such as communities dominated by scavengers and mobile species.

Table 3-4: Potential biophysical and socio-economic impacts of pressures on marine habitats and communities on the Scotian Shelf.

Element	Potential Impacts
Biophysical	
Habitat	• Physical disturbance or alteration of the seabed from bottom-contacting fishing gear (DFO 2006a; Fuller et al. 2008a; Fuller 2011; Jennings and Kaiser 1998), oil and gas activity (Hurley and Ellis 2004; Thomson et al. 2000), and submarine cables (Carter et al. 2009; Worzyk 2009) may affect the distribution and extent of benthic habitats as well as the distribution and structure of associated biological communities. • Short-term and long-term changes in seawater properties (i.e. temperature, salinity, acidity) and oceanographic conditions may affect the distribution and extent of some marine habitats (see *Climate Change and its Effects on Ecosystems, Habitats and Biota* and *Ocean Acidification*). • Changes in the distribution and extent of marine habitats resulting from ocean activities and changing natural conditions may affect the distribution and structure of associated biological communities and biodiversity in the Scotian Shelf region (Cheung et al. 2009; DFO 2006a; Fuller 2011; Fuller et al. 2008; Jennings and Kaiser 1998; Rijnsdorp et al. 2009). • Pollution and noise from marine shipping, vessel traffic, and oil and gas activity may affect the quality of marine habitats (see *Water and Sediment Quality* and *Ocean Noise*).
Community Structure	• Removal of organisms from the ecosystem through fishing and incidental mortality may affect the distribution and structure of biological communities (Baer et al. 2010; Bundy 2005; DFO 2006a; Donaldson et al. 2010; see *Incidental Mortality*).
Ecosystem Structure and Function	• Changes in the structure of biological communities resulting from ocean activities and changing natural conditions may affect the Scotian Shelf ecosystem by altering trophic structure and biodiversity (Bundy 2005; Frank et al. 2005; see also *Trophic Structure*).
Socio-Economic	
Ecosystem Goods and Services	• Loss of benefits and services to humans derived from ecosystem functioning (e.g. disturbance regulation, biological control and the regulation of populations, food production, genetic resources, etc.) (Costanza et al. 1997).
Economy and Livelihoods	• Changes in the distribution and extent of marine habitats and the distribution and structure of biological communities could impact commercial fisheries (Bundy 2005; Charles et al. 2009; Frank *et al.* 2005; Gien 2000; see also *Trophic Structure*).

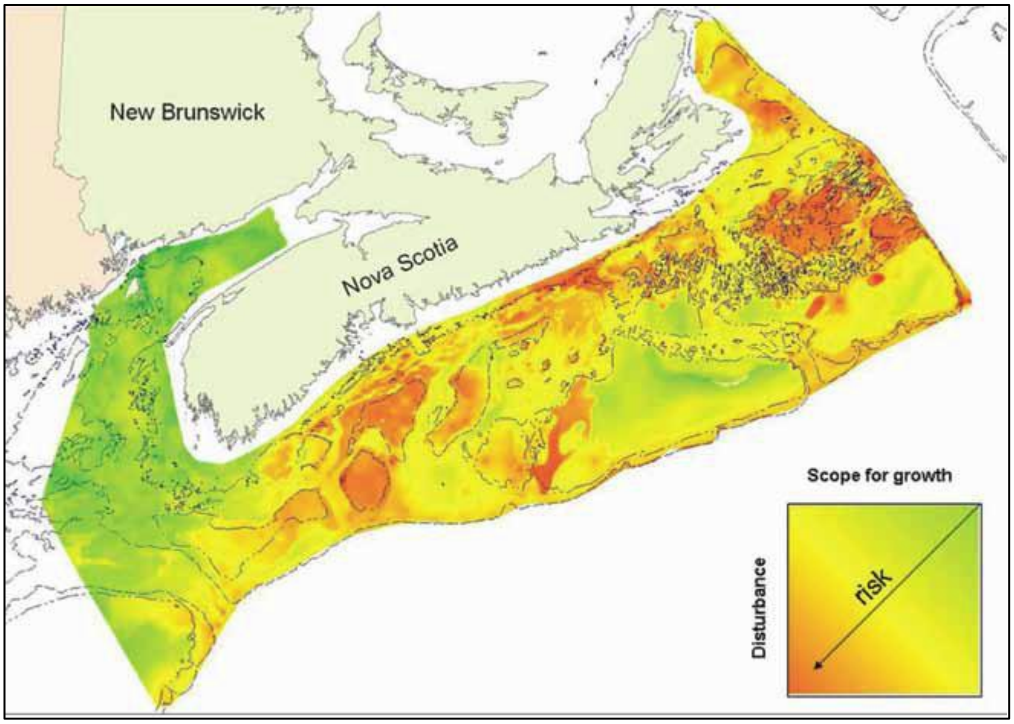

Figure 3-7: Potential sensitivity and predicted response of benthic communities to physical disturbances resulting from human activities (DFO 2006d).

3.4.2 Socioeconomic Impacts

The marine habitats and communities of the Scotian Shelf are associated with a number of important economic, social, and cultural values. Nova Scotia's fishing industry is a major source of direct and indirect employment and income and is the province's leading source of export earnings (see *Scotian Shelf in Context*). The productivity and health of commercially valuable fish and invertebrate populations is strongly influenced by the status of their habitat and the community and ecosystem that they are a part of. Therefore, biophysical impacts on marine habitats and communities can affect the status of commercial fish and invertebrate populations and result in socioeconomic impacts on those who rely on the fishery. Marine habitats and communities also provide many important functions and services that contribute both directly and indirectly to human welfare such as climate regulation, disturbance regulation, biological control and the regulation of populations, food production, genetic resources, and opportunities for recreation and other non-commercial uses (Costanza et al. 1997). Changes in marine habitats and communities can alter these functions and services, having a range of potential socioeconomic impacts.

3.5 ACTIONS AND RESPONSES

Management actions and responses to impacts on marine habitats and communities include legislation and policy, and scientific research and monitoring.

3.5.1 Legislation and Policy

There are various pieces of legislation that contribute to the conservation and protection of marine habitats and communities. Key legislation includes Canada's *Oceans Act*, *Fisheries Act* and *Species at Risk Act*.

Fisheries Management: DFO regulates the use of fishery resources and restricts certain fishing activities to protect and conserve fishery resources and to limit as much as possible, the destruction of sensitive marine habitat and species (DFO 2009c). The most common fisheries management measures used are area or time closures, gear restrictions, and requirements for gear modification (DFO 2009c). Although fisheries closures may not be put in place to protect marine habitats and communities, many spatial/time closures provide indirect protection. Under the Fisheries Renewal Initiative (http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/index-eng.htm), DFO has committed to implementing an ecosystem approach to fisheries. DFO is currently developing an Ecosystem Approach to Management (EAM) Framework (DFO 2010e). The ecosystem approach requires that fisheries management decisions consider the impact of the fishery not only on the target species, but also on non-target species, seafloor habitats, and the ecosystems of which these species are a part (DFO 2009d). The EAM framework for fisheries is currently being implemented through Integrated Fisheries Management Plans (IFMPs) for fisheries that occur on the Scotian Shelf. In 2010, DFO released the *Sustainable Fisheries Framework*. The Framework comprises two main elements: (1) conservation and sustainable use policies, and (2) planning and monitoring tools (DFO 2009e; see http://www.dfo-mpo.gc.ca/fm-gp/pechesfisheries/fish-ren-peche/sff-cpd/overviewcadre-eng.htm). The Framework includes a new *Policy for Managing Impacts of Fishing on Sensitive Benthic Areas*.

In addition to fisheries management regulations, the fishing industry has also implemented voluntary conservation measures. Atlantic Canada's offshore groundfish fishing companies recently announced a voluntarily fishing closure in a 332 km2 area of the Emerald Basin to protect a concentration of the rare glass sponge *Vazella pourtalesi*
(The Sou'Wester 2010).

Ecosystem Management: DFO's framework for the classification and characterization of benthic habitats on the Scotian Shelf will facilitate improved ocean planning and management by identifying benthic habitats that are sensitive to physical disturbance from human activities (DFO 2005b). DFO has established criteria for identifying Ecologically and Biologically Significant Areas (EBSAs) and Ecologically Significant Species and Community Properties. The identification of EBSAs and Ecologically Significant Species and Community Properties is a tool for facilitating a greater degree of risk aversion in the management of human activities that may affect such areas, species or community properties (DFO 2006b; DFO 2004b). EBSAs of the Scotian Shelf have been identified in Doherty and Horsman (2007). Scotian Shelf EBSAs have been considered during oil and gas planning and conservation planning.

Several major spatial conservation measures including Marine Protected Areas (MPAs) and coral conservation areas have been established on the Scotian Shelf to protect habitat, ecologically significant species and species at risk (**Table 3-5**). Three federal departments and agencies including DFO, Environment Canada, and Parks Canada Agency have specific mandates to establish and manage MPAs. Canada's Federal *Marine Protected Areas Strategy* aims to establish and manage a network of MPAs that contributes to the health of Canada's oceans and marine environment (Government of Canada 2005). More recently, a *National Framework for Canada's Network of Marine Protected Areas* was created to provide guidance for the planning and implementation of MPA networks within 13 bioregions across Canada (DFO 2010f). The Scotian Shelf (along with the Bay of Fundy) is one of these bioregions and DFO will be leading an MPA network planning process for this bioregion in the coming years. The federal MPA network is comprised of three core programs: Oceans Act MPAs; National

Wildlife Areas (NWAs); and National Marine Conservation Areas (NMCAs). Currently, there is one Oceans Act MPA on the Scotian Shelf (The Gully, see **Table 3-5**). In 2010, DFO completed consultations to identify an Area of Interest (AOI) for designation as the next *Oceans Act* MPA in the eastern Scotian Shelf region (DFO 2009f). DFO has also implemented conservation measures to protect cold-water corals including the establishment of the Northeast Channel Coral Conservation Area and the Lophelia Coral Conservation Area which restrict bottom fishing year-round (Campbell and Simms 2009; Cogswell et al. 2009; DFO 2002; see **Table 3-5**). DFO has also developed a *Coral Conservation Plan* which aims to document what has been done to conserve corals, put forward a more comprehensive approach on coral conservation, identify issues where more work is needed, and build collaboration among a variety of groups to address coral conservation (DFO 2006c).

Canada's *Species at Risk Act* (*SARA*) provides for the legal protection of wildlife species at risk and contains prohibitions against the damage or destruction of their residences (Government of Canada 2009). Once an area is identified as Critical Habitat in a Recovery Strategy or Action Plan, provisions of *SARA* prevent activities that would destroy any part of the species' Critical Habitat, including issuance of a Protection Statement or a Protection Order (DFO 2007b). For more information on *SARA*, see *At Risk Species*.

Table 3-5: Major spatial conservation measures protecting marine habitats on the Scotian Shelf.

Location	Restricted Activities	Closure Period	Reason for Protection	Sources
***Oceans Act* MPAs**				
The Gully: a 2,364 km^2 area near Sable Island	General prohibitions against disturbance, damage, destruction or removal of any living marine organism or any part of its habitat within the MPA apply to the entire water column and include the seabed to a depth of 15 m	Closed year-round since 2004	Protects a rich diversity of marine habitats and species; Endangered northern bottlenose whales; and deep-sea corals including one of only two known areas in Atlantic Canada with the reef-building *Lophelia pertusa*	DFO (2004c)
Coral Conservation Areas				
Northeast Channel Coral Conservation Area: a 424 km^2 portion of the Northeast Channel	90% of the area is restricted to all bottom fisheries;10% is open only to longline fishing gear	Closed year-round since 2002	Protects high densities of intact octocorals, mainly bubblegum (*Paragorgia arborea*) and seacorn coral (*Primnoa resedaeformis*)	Campbell and Simms (2009); DFO (2002)
Lophelia Coral Conservation Area: a 15 km^2 zone located at the mouth of the Laurentian Channel	All bottom fishing activities	Closed year-round since 2004	Protects one of only two areas of the reef-building *Lophelia pertusa* in Atlantic Canada	Campbell and Simms (2009); Cogswell *et al.* (2009)
Voluntary Closures				
Emerald Basin Closure: a 332 km^2 portion of Emerald Basin	Voluntary closure of all groundfish fisheries	Closed year-round since 2010	Protects a concentration of the rare glass sponge *Vazella pourtalesi*	The Sou'Wester (2010)

Habitat Management Program and Environmental Assessments*[9]*: Subsection 35(1) of the *Fisheries Act* prohibits the harmful alteration, disruption or destruction (HADD) of fish habitat without an authorization from the Minister or by regulation. This applies to works or undertakings in the offshore which could result in a HADD (e.g. exploratory wells, pipelines), but it does not apply to commercial fishing activities. Development proposals in the offshore are subject to the regulations outlined in the *Canadian Environmental Assessment Act* (*CEAA*) and generally require an environmental assessment. The CNSOPB is responsible for conducting environmental assessments on all proposed oil and gas activities in the offshore, while DFO's Habitat Management Program is responsible for assessing all other proposed activities which could result in a HADD. For oil and gas activities that occur on the Scotian Shelf, environmental assessments have been conducted and take into account habitats and communities that DFO identifies as vulnerable to the activity, particularly MPAs, conservation areas and EBSAs.

Pollution and Ocean Noise: Canada has many laws, regulations, policies and guidelines related to the management of marine pollution and ocean noise. For a detailed description of the actions and responses to the impacts of pollution and noise on the Scotian Shelf ecosystem, the reader is directed to *Water and Sediment Quality* and *Ocean Noise*.

3.5.2 Scientific Research and Monitoring

The data and information generated from research and monitoring programs improves our understanding of the Scotian Shelf ecosystem and is used to develop more effective strategies for managing ocean activities and protecting marine habitats and communities. A wide range of government agencies, universities and research institutions are involved in research and monitoring of the Scotian Shelf ecosystem. Some of the main research organizations and institutions in the region include DFO's Science Branch (DFO-Science), Natural Resources Canada (NRCan), Environment Canada, the Canadian Hydrographic Service (CHS), Dalhousie University, the Huntsman Marine Science Centre and the Bedford Institute of Oceanography (BIO). As the primary ocean research agency of the federal government, DFO-Science conducts research on a broad range of ocean issues including the sustainable use of ocean resources, conservation and environmental protection, and integrated oceans management. DFO-Science has recently committed to an ecosystem science approach and has developed *A New Ecosystem Science Framework in Support of Integrated Management* in order to implement this approach (DFO 2007a). An ecosystem science approach supports integrated oceans management and science-based decision-making by improving our understanding about how human activities interact with one another and how they affect marine ecosystems (DFO 2007a).

Some of the key ongoing research and monitoring activities and programs related to marine habitat and communities that are carried out on the Scotian Shelf include:

Atlantic Zone Monitoring Program (AZMP): The AZMP collects and analyzes biological, chemical, and physical field data on Atlantic Canada`s marine environment. There are several sampling transects on the Scotian Shelf: the Cabot Strait line across the Cabot Strait, the Louisbourg line across Misaine and Banquereau banks, the Halifax line across Emerald Basin and Emerald Bank, and the Browns Bank line across Browns Bank (DFO 2005a). For more information visit: http://www.medssdmm.dfo-mpo.gc.ca/isdm-gdsi/azmp-pmza/index-eng.html.

Continuous Plankton Recorder (CPR) Survey: The CPR Survey program is run by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the United Kingdom. SAHFOS has been using vessels of opportunity to collect plankton samples from the northwest Atlantic

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[9] Note that the Habitat Management Program and Environment Assessment section is out of date (August 2013).

since 1959, including a limited number of samples from the Scotian Shelf (DFO 2005a). For more information visit: http://www.sahfos.ac.uk/about-us/cpr-survey/the-cpr-survey.aspx.

DFO's Coral Research Program: In 1998, DFO began collaborating with university, NGO and industry partners to collect information on corals in the Scotian Shelf region. DFO initiated a full coral research program in 2000 (DFO 2011). The DFO coral research program conducted four dedicated research surveys in several areas of the Scotian Shelf and Slope between 2000 and 2003 in order to document the distribution, abundance and condition of corals as well as their preferred habitats and associated species (DFO 2011). For more information visit: http://www.mar.dfo-mpo.gc.ca/e0010591.

Geoscience for Oceans Management (GOM) Program and the Geology of the Eastern Scotian Shelf Project: The GOM program is based on a systematic approach to seafloor mapping for integrated ocean management, including the development of maps of the bathymetry, geology, and distribution of benthic habitat and organisms of Canada's offshore areas (NRCan 2008). For more information visit: http://ess.nrcan.gc.ca/2002_2006/gom/index_e.php.

Marine Fish Research and Monitoring: Researchers at DFO have conducted annual bottom trawl surveys on the Scotian Shelf since 1970. These surveys are one of the most important sources of information on marine fish and invertebrate populations (DFO 2005a). Other research surveys conducted on the Scotian Shelf include cooperative surveys with industry, such as the sentinel surveys for groundfish, the skate survey, the Scotian Shelf and Grand Banks halibut survey, and surveys for invertebrates such as shrimp, scallops and snow crab (DFO 2005a).

University Research Programs: A number of universities in the region are collaborating with other research institutions to study the marine habitats and communities of the Scotian Shelf. For example, researchers at Dalhousie University in Halifax have studied the distribution and ecology of benthic invertebrates and associated communities on the Scotian Shelf (e.g. Fuller 2011; Metaxas and Davis 2005; Watanabe et al. 2009). Some studies have used fishermen's knowledge to help determine the distribution and ecosystem function of coldwater corals and sponges on the Scotian Shelf (Breeze 1997; Fuller 2011; Gass and Willison 2005).

3.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR	Assessment	Trend
Sea Surface Temperature	Temperature influences habitat quality and the distribution, growth and survival of marine organisms	Pressure	Good	/
Average salinity	Salinity influences habitat quality and the distribution, growth and survival of marine organisms	Pressure	Fair	-
Disturbance from human activities (fishing, oil and gas, cables)	Direct and indirect effects on benthic habitat communities by disturbing and altering the seabed	Pressure	Fair	/
Abundance and distribution of structure-forming organisms (e.g. corals and sponges)	Structure-forming organisms create, modify and maintain habitat for other species by producing complex structures on top of sediments	State	Good	/
Community structure	Changes in species diversity, the abundance of ecologically significant species, trophic balance, size-based properties, and productivity within a community can affect its structure and function	State	?	?
Total area of habitat protected by conservation and management measures (e.g. MPAs, fisheries closures, gear restrictions, etc.)	Conservation and management measures can protect marine habitat from harmful human activities	Response	Fair	+
Total number of ecologically significant species protected by conservation and management measures (e.g. catch limits, size restrictions, gear modifications, etc.)	Conservation and management measures can protect ecologically significant species and the communities they are a part of from harmful human activities	Response	?	?

Key:
Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?

Data Confidence:

- Water temperature, salinity and pH are monitored regularly
- Recent advances in benthic mapping and research have improved the state of knowledge regarding the abundance and distribution of structure-forming organisms and associated communities
- Species diversity is monitored infrequently and information is available for only a small number of species assemblages (e.g. finfish; plankton; site-specific benthic assemblages)
- Changes in the trophic structure of the Scotian Shelf ecosystem have been studied
- Fishing effort of vessels using bottom-contact fishing gear is monitored regularly
- Data on the location and quantity of drilling wells and submarine cables is available
- Data on the total area of habitat protected by conservation measures is available

Data Gaps:

- Data on benthic and pelagic community trends
- Overall ecological footprint of human activities on the Scotian Shelf
- High degree of uncertainty regarding the ecological significance of many species

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4. AT RISK SPECIES[10]

Dan Walmsley, Walmsley Environmental Consultants, Dartmouth, NS

4.1 ISSUE IN BRIEF

Marine ecosystems are experiencing accelerating loss of populations and species, and their recovery potential is decreasing with declining diversity (Millennium Ecosystem Assessment 2005a). Marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations (Worm et al. 2006). The Scotian Shelf is being subjected to numerous anthropogenic activities that have potentially damaging, and cumulative, impacts on the diversity of resident and migratory marine organisms (Zwanenburg et al. 2006; see **Figure 4-1**). Long-term changes in climate may also have implications for the distribution of species on the Scotian Shelf. The Shelf currently has at least 28 resident or migratory species of marine mammals, fish and reptiles that have received designation from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as being either, extirpated, endangered, threatened, or of special concern. The designations are based mainly on the degree of observed decline in population size. Anthropogenic activity on the Scotian Shelf is most often cited as the main reason why the populations of each of these species have declined, and an ongoing process of assessment continues to designate additional species (COSEWIC 2009). Further designation of species by COSEWIC, and continued loss of individuals of classified endangered species, has significant potential political, social, economic, legal, and ecological implications. There are numerous international and national legal instruments that currently contribute to the protection of species on the Scotian Shelf, and these have led to the establishment of numerous governance structures, and associated programs focusing on each of the designated species. In particular, the promulgation and implementation of the Canadian (*Species at Risk Act SARA)* has led to mandatory recovery strategies and recovery plans for Schedule 1 species at risk on the Scotian Shelf. There are eleven Scotian Shelf species that have received Schedule 1 designation, thus requiring mandatory recovery planning under *SARA*.

Linkages

This theme paper also links to the following theme papers:

- Marine Habitats and Communities
- Incidental Mortality
- Invasive Species
- Trophic Structure
- Commercial Fisheries
- Ocean Noise
- Climate Change and its Impacts on Ecosystems, Habitats and Biota

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[10] Completed June 2011.

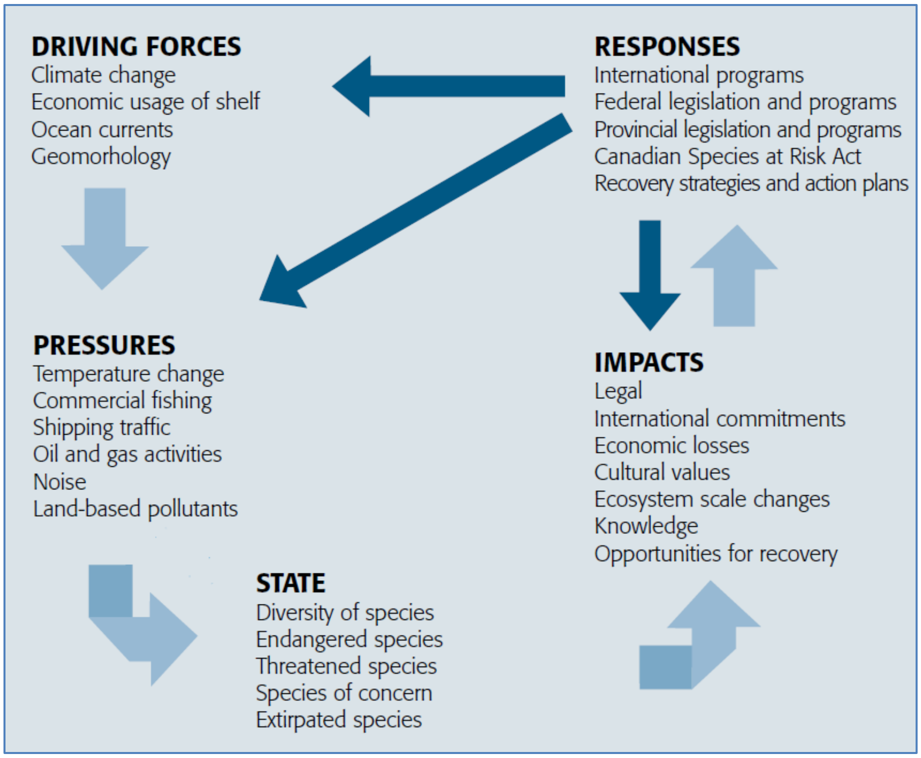

Figure 4-1: Driving forces, pressures, state, impacts and responses (DPSIR) for at risk species on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

4.2 DRIVING FORCES AND PRESSURES

4.2.1 Natural Conditions

The variety of natural physical and chemical factors that influence the biological productivity, range of habitats and variety of species on the Scotian Shelf has been well described (Davis and Browne 1996; Breeze et al. 2002; Zwanenburg et al. 2006; see also *Offshore Habitats and Communities*). The Shelf is relatively wide, extending from 125-230 km off the coast of Nova Scotia, and has an area of approximately 96 000 km2. It can be divided into four main zones: an inner, middle, outer and a continental slope (Davis and Browne 1996). Within these zones there are basins more than 200 m in depth and shallow banks less than 50 m deep. There are also several steep-sided submarine canyons indenting the shelf slope, of which the largest is the Gully with a depth greater than 2000 m. These features provide for a wide range of habitat, and trophic environments for pelagic, demersal and benthic species, as well as an area which attracts many migratory species.

The temporal and spatial (vertical and horizontal) distribution of most species, resident and migratory, on the Scotian Shelf is highly related to temperature, salinity and ocean currents, which display both a seasonal and long-term variation (Zwanenburg et al. 2002; Pickrill and Kostylev 2007). The Labrador Current and the Gulf of St Lawrence outflow converge and flow in a southerly direction to form the Nova Scotian Current, which carries relatively cold water over the Shelf. This southerly flow is influenced on its periphery by the warmer Gulf Stream that allows warm water to penetrate the southern part of the Shelf over the continental slope (**Figure 4-2**). Temporal and spatial variations in water temperature contribute to stratification of the water column and a fairly wide variation in winter (0-4°C) and summer surface water temperatures (0 -17°C; Breeze et al. 2002).

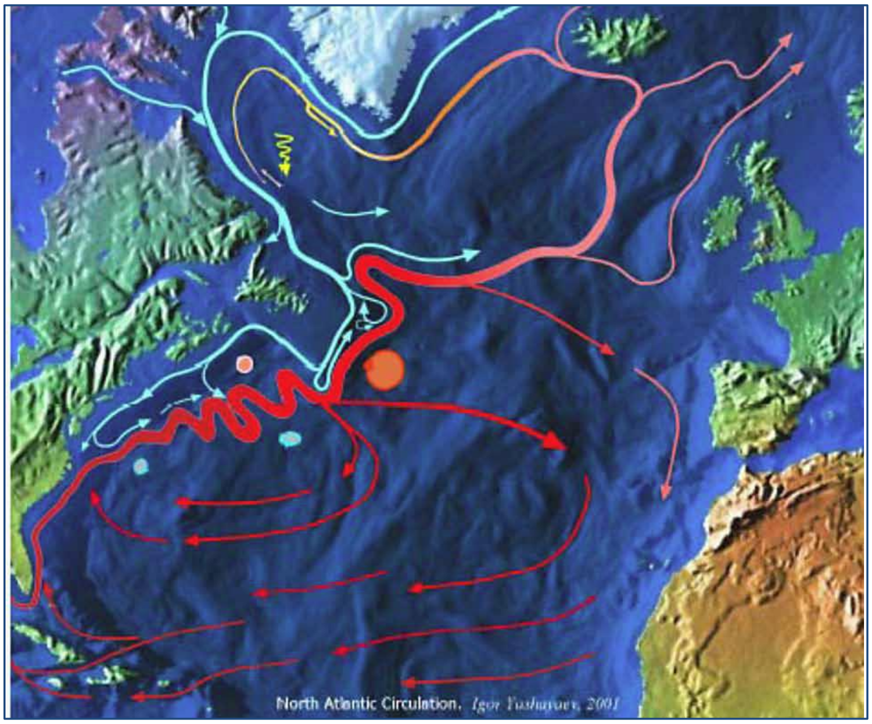

Figure 4-2: Surface circulation of the North Atlantic. The red arrows indicate warmer, more saline waters and the blue arrows indicate cooler, fresher waters (from Breeze et al. 2002).

Global climate change is a long-term factor that has implications for biological diversity of the Scotian Shelf (see *Climate Change and its Effect on Ecosystems, Habitats and Biota*). Sea surface temperature data along the Halifax line from the last 70 years indicate warming and cooling cycles (see *Trophic Structure*). However, Aquarone and Adams (2009) present evidence of a warming trend for waters of the Scotian Shelf of about 2°C over the last 40 years, and conclude that it is one of the world's fastest warming large marine ecosystems. This warming of the ocean is projected to lead to a progressive northward shift in distribution of many species (Lemmen et al. 2009).

4.2.2 Anthropogenic Activities

There are numerous economic sectors and trading partners that are dependent on the natural resources of the Scotian Shelf (Gardner Pinfold 2009). It is an economically active area with various sectors making use of its resources (fisheries, oil and gas, communications, shipping etc.; DFO 2007a). As a consequence there are numerous human influences that have an impact on biota and habitats of the Scotian Shelf (Zwanenburg et al. 2006). These impacts have a cumulative effect on habitat, trophic interactions, populations and the status of individual species.

Commercial fishing is extensive over the Shelf with a variety of species (benthic, demersal and pelagic) being landed using different technologies and methodologies (hydraulic clam dredges, otter trawls, scallop dredges, longlines, gillnets and pots - e.g. **Figure 4-3**). As well as impacting commercial fish species through overexploitation, fishing activity affects many non-commercial species through incidental capture and/or entanglement (Vanderlaan and Taggart 2009). Parker and Worcester (2010) indicate that catches during trawl fisheries can include between 50 to 400 bycatch species. A high proportion of species such as the right whale (almost 75%) have been observed to have scars indicative of an entanglement at some time in their lives (Knowlton et al. 2005).

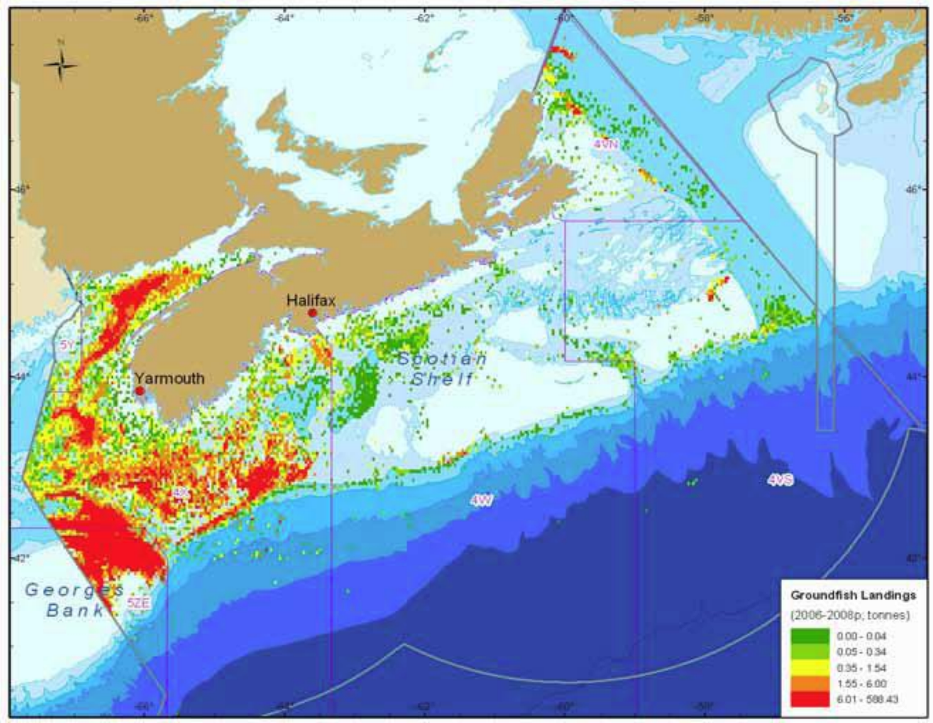

Figure 4-3: Groundfish landings (2006-2008) (DFO 2010).

Several areas on the Scotian Shelf have been licenced for oil and gas exploration and development over the past three decades. These activities have involved seismic exploration, test drilling and site development (particularly in the Sable Island area). There are many potential impacts which have been identified such as: influences of drilling wastes and produced water; accidental spills of hydrocarbons and drilling fluids, and the influence of seabed structures such as platforms and pipes (Zwanenburg et al. 2006).

The Scotian Shelf is subject to significant levels of marine traffic between Canada, the US and Europe (**Figure 4-4**). The probability and risk of shipping strikes on large marine animals is fairly high (Vanderlaan and Taggart 2009). Estimates show that there have been 21 ship strike mortalities of the North Atlantic right whale over the period 1991 to 2007 and that this represents 50% of all observed mortalities for this period (Brown et al. 2009).

There is also concern that sources of chemical contaminants (land-based and industry based), which ultimately end up in the sediments and then various levels of the food chain, might also have a longer term influence in the general biodiversity of the Scotian Shelf ecosystem (Stewart and White 2001). Noise from shipping and seismic exploration is also considered to be a factor which vitiates the marine environment, particularly for species that use sound for echolocation (Breeze et al. 2002; see *Ocean Noise*).

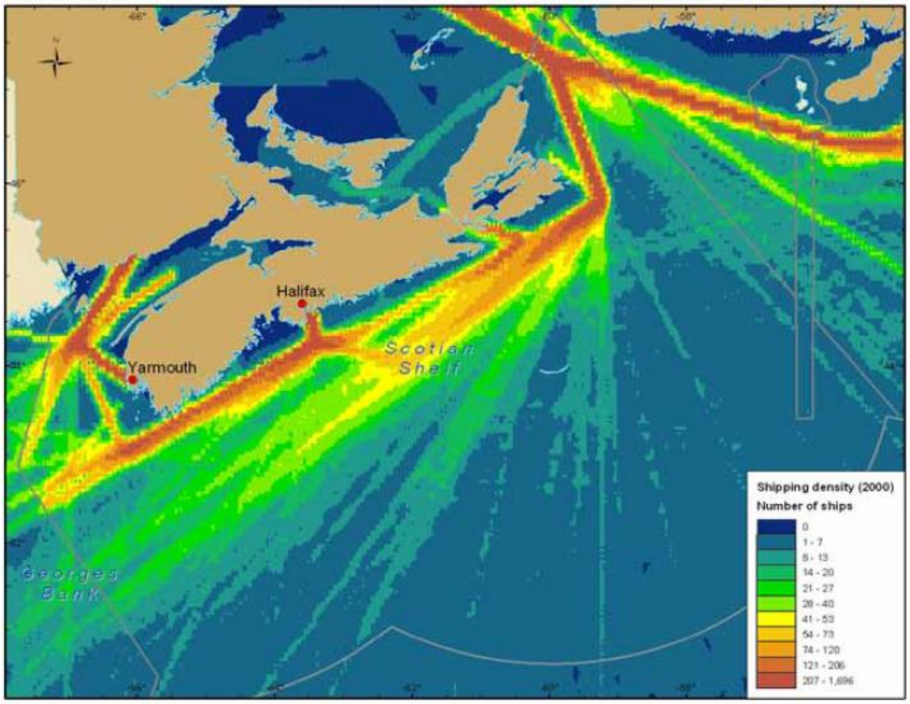

Figure 4-4: Map showing the density of inbound marine traffic over the Scotian Shelf for 2000 (DFO 2005).

4.3 STATUS AND TRENDS

From an international perspective, the International Union for Conservation of Nature (IUCN 2001) and the United Nations Convention on International Trade of Endangered Species (CITES, http://www.cites.org/eng/resources/species.html) provide information and lists of endangered and threatened species which are of concern for respective areas and regions of the world. Some of these species, especially those that are migratory (e.g., the leatherback sea turtle and the North Atlantic right whale) are also found on the Scotian Shelf (IUCN 2001). In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), under its mandate from the *Species at Risk Act (SARA)*, provides the main mechanism by which species at risk are assessed and designated according to their degree of endangerment. Under *SARA*, using specific criteria and scientific information on populations and habitat, COSEWIC evaluates the status of the country's wildlife and assigns risk categories to species (http://www.cosewic.gc.ca/eng/sct3/index_e.cfm -see also section 4.5 which deals with responses). The Canadian Species at Risk Public Registry (http://www.sararegistry.gc.ca) provides an ongoing summary of the status of species at risk in Canadian marine waters. Based on the Canadian approach, there are several categories of "at risk" species that have been designated for attention.

COSEWIC Marine Candidate List for the Atlantic Area (September 2010)

High priority
Ocean pout

Medium priority
Alewife
Capelin
American shad
Haddock
Spinytail skate
Spiny eel
Pollock
Cuvier's beaked whale

Low priority
Hooded seal
Harp seal
Sperm whale
Kemp Ridley sea turtle

Extinct - a species that no longer exists.

Extirpated - a species no longer existing in the wild in Canada, but occurs elsewhere.

Endangered - a species facing imminent extirpation or extinction.

Threatened - a species likely to become endangered if limiting factors are not reversed.

Special concern - a species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.

Examination of the Canadian Species at Risk Public Registry yields the following information for the Atlantic Canada region, which incorporates the geographic area of the open water Scotian Shelf (**Table 4-1**):

- There are 32 species that have COSEWIC status (20 species of fish, 2 reptiles and 10 mammals). There are no molluscs, arthropods or birds listed for the Atlantic region. The Scotian Shelf does have marine birds associated with it (Breeze et al. 2002), and these are listed in the Public Registry under Nova Scotia. Their critical habitat is more associated with land-based areas (mainland Nova Scotia and islands) than the open water offshore area of the Scotian Shelf and, consequently have not been included in this analysis.
- Of the 32 species, none are extinct, two are extirpated, eleven are endangered, seven are threatened and twelve are of special concern.
- Many species in Canada have not yet been assessed by COSEWIC, but are suspected of being at some risk of extinction or extirpation. These species, referred to as candidate wildlife species, are listed in terms of their priority for assessment (see box above). Assessment of species is an ongoing process and the Public Registry list is continually being updated as more species are brought to the attention of COSEWIC.
- Of the 32 species, only 14 have been scheduled under *SARA* (i.e., ~44%).

Species that have Schedule 1 Status (September 2010) include:

Atlantic salmon (inner Bay of Fundy populations) spawn in rivers of Nova Scotia and New Brunswick that drain into the Minas Basin and Chignecto Bay. It is not known where they spend the winter or whether their marine distribution extends on to the Scotian Shelf. Population estimates indicate an adult decline from as high as 40 000 in the mid-1980s to less than 250 in 1999. Reasons for the decline point to as yet unidentified factors (DFO 2010).

Atlantic walrus originally numbered in the tens of thousands, but the Northwest Atlantic population was heavily harvested in the 17th and 18th centuries and hunted to extirpation by the late 18th century. Recovery of this species is considered neither technically nor biologically feasible but this situation will continue to be assessed (DFO 2007b).

Grey whales are understood to have become extirpated from the western North Atlantic before the end of the 1800s as a consequence of commercial whaling activity (DFO 2007c). Recovery of the Atlantic population is considered neither technically nor biologically feasible, but this situation will continue to be assessed.

Table 4-1: Status of species that have been assessed by COSEWIC for the Atlantic region, and are associated with the Scotian Shelf. List accessed from http://www.sararegistry.gc.ca/sar/index/default_e.cfm in September 2010. It should be noted that the list is continually being updated as new species are added, and progress is made on COSEWIC assessments.

Common name	Scientific Name	Taxon	COSEWIC Status	Schedule	SARA Status
Acadian Redfish	*Sebastes fasciatus*	Fishes	Threatened	No schedule	No Status
American Eel	*Anguilla rostrata*	Fishes	Special Concern	No schedule	No Status
American Plaice	*Hippoglossoides platessoides*	Fishes	Threatened	No schedule	No Status
Atlantic Cod (southern population; Laurentian South)	*Gadus morhua*	Fishes	Endangered	No schedule	No Status
Atlantic Salmon (Inner Bay of Fundy)	*Salmo salar*	Fishes	Endangered	Schedule 1	Endangered
Atlantic Wolffish	*Anarhichas lupus*	Fishes	Special Concern	Schedule 1	Special Concern
Basking Shark	*Cetorhinus maximus*	Fishes	Special Concern	No schedule	No Status
Blue Shark	*Prionace glauca*	Fishes	Special Concern	No schedule	No Status
Cusk	*Brosme brosme*	Fishes	Threatened	No schedule	No Status
Deepwater Redfish	*Sebastes mentella*	Fishes	Endangered	No schedule	No Status
Northern Wolffish	*Anarhichas denticulatus*	Fishes	Threatened	Schedule 1	Threatened
Porbeagle Shark	*Lamna nasus*	Fishes	Endangered	No schedule	No Status
Roughhead Grenadier	*Macrourus berglax*	Fishes	Special Concern	No schedule	No Status
Roundnose Grenadier	*Coryphaenoides rupestris*	Fishes	Endangered	No schedule	No Status
Shortfin Mako Shark	*Isurus oxyrinchus*	Fishes	Threatened	No schedule	No Status
Spiny Dogfish	*Squalus acanthius*	Fishes	Special Concern	No schedule	No Status
Spotted Wolffish	*Anarhichas minor*	Fishes	Threatened	Schedule 1	Threatened
White Shark	*Carcharodon carcharias*	Fishes	Endangered	No schedule	No Status
Winter Skate (Eastern)	*Leucoraja ocellata*	Fishes	Threatened	No schedule	No Status
Winter Skate (Western)	*Leucoraja ocellata*	Fishes	Special Concern	No schedule	No Status
Atlantic Walrus	*Odobenus rosmarus rosmarus*	Mammals	Non-active	Schedule 1	Extirpated
Blue Whale	*Balaenoptera musculus*	Mammals	Endangered	Schedule 1	Endangered
Fin Whale	*Balaenoptera physalus*	Mammals	Special Concern	Schedule 1	Special Concern
Grey Whale	*Eschrichtius robustus*	Mammals	Extirpated	Schedule 1	Extirpated
Harbour Porpoise	*Phocoena phocoena*	Mammals	Special Concern	Schedule 2	Threatened
Humpback Whale	*Megaptera novaeangliae*	Mammals	Not at Risk	Schedule 3	Special Concern
Killer Whale	*Orcinus orca*	Mammals	Special Concern	No schedule	No Status
North Atlantic Right Whale	*Eubalaena glacialis*	Mammals	Endangered	Schedule 1	Endangered
Northern Bottlenose Whale	*Hyperoodon ampullatus*	Mammals	Endangered	Schedule 1	Endangered
Sowerby's Beaked Whale	*Mesoplodon bidens*	Mammals	Special Concern	Schedule 3	Special Concern
Loggerhead Sea Turtle	*Caretta caretta*	Reptiles	Endangered	No schedule	No Status
Leatherback Sea Turtle	*Dermochelys coriacea*	Reptiles	Endangered	Schedule 1	Endangered

Leatherback turtle, designated endangered, is migratory, and breeds in tropical or subtropical waters with migration to the Scotian Shelf, which is considered to be critical habitat for species prey, chiefly jellyfish (James et al. 2006; Sherill-Mix et al. 2007). It is estimated that the Atlantic population contains approximately 15 000 females. Because of a lack of offshore aerial survey data and fishery bycatch data on leatherbacks in Atlantic Canada, leatherback population size and trends in this area have yet to be determined (Atlantic Leatherback Turtle Recovery Team 2006). Entanglement in fishing gear throughout the species' range is considered to be a threat factor on the Scotian Shelf.

North Atlantic right whale is a migratory species that frequents coastal waters along the east coast of the United States and Canada. In Canadian waters, individuals are known to congregate in the summer and fall in the lower Bay of Fundy, mainly east of Grand Manan Island, and in the vicinity of the Roseway Basin. A database maintained by the North Atlantic Right Whale Consortium contains record of 438 known individuals, of which 402 (92%) have been seen in Canadian waters at least once (Brown et al. 2009). Movement and distribution of right whales overlaps many fishing and shipping areas (**Figure 4-5**). Analyses of documented right whale deaths between 1986 and 2005 show that 38% of mortalities were a result of vessel strikes, 12% were due to entanglement in fishing gear and the remaining 50% were attributed to unknown causes or neonatal mortality (Kraus and Rolland 2007). Based on scarring from fishing gear it is estimated that at least 72% of the right whale population have been involved in an entanglement event at some point in their lives, and that 10-30% of the population is entangled each year (Clapham 2005). Risk and probability of entanglement is high (Vanderlaan and Taggart 2009).

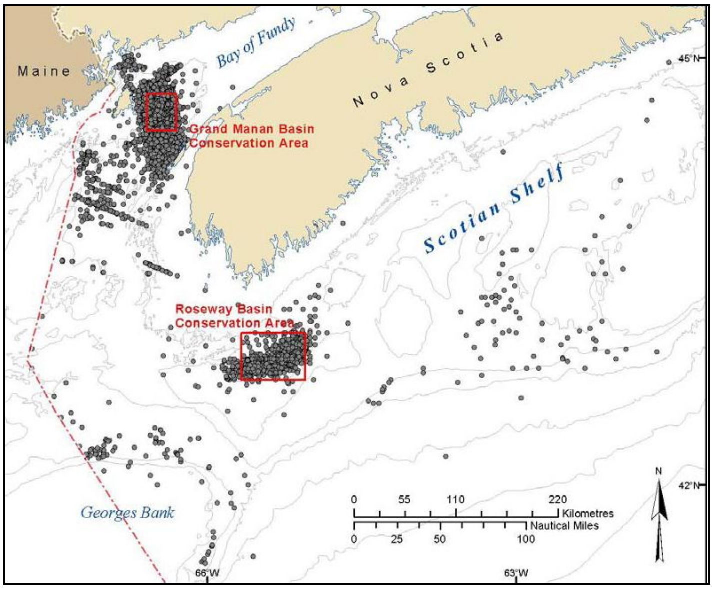

Figure 4-5: Canadian range and observed sightings of the North Atlantic right whale: 1951-2005 (from Brown et al. 2009)

Blue whales frequent waters off the Gulf of St. Lawrence and eastern Nova Scotia. Currently, the size of the Northwest Atlantic population is unknown, but it is unlikely that the number of mature animals exceeds 250 individuals according to experts' estimates (Beauchamp et al. 2009). At least 11 000 blue whales were harvested in the North Atlantic before 1960. Approximately 1 500 of these were harvested in eastern Canadian waters from 1898 to 1951.

Since the end of commercial whaling, the high-risk anthropogenic threats have been cited as noise and the increased harvesting of krill. Collisions with ships, disturbance from increasing whale-watching activity, entanglement in fishing gear, and pollution (especially oil pollution) are considered to be medium risk (Beauchamp et al. 2009).

Northern bottlenose whale (Scotian Shelf population) is found mainly in and around the Gully, which is the southernmost area where the northern bottlenose whale is routinely found. Whaling was a factor in reducing global populations of the northern bottlenose whale with over 80 000 whales caught over the entire whaling period. The current Scotian Shelf population is estimated to be approximately 163 individuals (DFO 2009a). Three canyons along the edge of Scotian Shelf appear to contain critical habitat for northern bottlenose whales (The Gully, Haldimand Canyon, and Shortland Canyon). Commercial shipping, fishing activity, and petrochemical exploration and exploitation, threaten this population as these activities result in acoustic and chemical pollution, entanglement in fishing gear, floating debris, and interactions between whales and vessels.

Fin whale is widely distributed along the east coast the US and Canada and makes up 46% of all large whale sightings and 24% of all cetacean sightings in the Scotian Shelf (COSEWIC 2005). Population estimates made in 1999 give an Atlantic population of 2 814 in the area between Georges Bank and the mouth of the Gulf of St. Lawrence. The main reason behind their population decline has been commercial whaling as pre-commercial population estimates for the Atlantic were 30 000- 50 000. At least 13 337 fin whales were taken in Atlantic Canada between 1903 and 1945, the vast majority (11 815) of which were from Newfoundland-Labrador. The Nova Scotia stock was whaled only from 1964 to 1971. The population appears to be fairly mobile with a general seasonal population migration between US (summer) and Canadian waters (winter). Current threats include fishing entanglement, ship strikes, noise, and chemical pollution.

Spotted wolffish, Northern wolffish and Atlantic wolffish are bottom living species whose populations have been shown to have declined markedly over the last 30 years (Kulka et al. 2007). Although the Wolffish are not targeted by the fishing industry, they are taken as by-catch by offshore trawlers. Bottom trawling for fish and dredging for scallops and clams also damages spawning habitat by disturbing rocks and boulders used for shelter and nesting. In addition, the bottom sediments are re-suspended, smothering spawning areas and damaging gills. Although commonly found on the Grand Banks, spotted wolffish are also found on the Scotian Shelf. Northern wolfish, however are rare on the Scotian Shelf (Kulka et al. 2007). For the Atlantic wolffish, which has a wider southerly distribution the number of locations where the species occurs has declined and the range where the species is abundant may be shrinking. Available data indicate that the number of Atlantic wolfish in Canadian waters also declined by 87% from the late 1970s to the mid-1990s.

4.4 IMPACTS

Loss of species, or a reduction in the populations of existing endangered species, may have numerous political social, legal, economic and ecological ramifications (**Table 4-2**), all of which require management attention.

Table 4-2: Some potential impacts associated with loss of diversity and/or protection of species on the Scotian Shelf (derived from Millennium Assessment Report 2005b and Zwanenburg et al. 2006).

Aspect	Possible Impact
Political	• An increase in criticism from the international community for failure to meet international obligations to which Canada is signatory.
Legal	• An increase in litigation from parties involved in utilizing natural resources, as well as parties opposed to use of natural resources.
Social	• Increasing conflict between sectors that make use of resources on the Scotian Shelf. • Increased need for negotiation on natural resource utilization.
Ecological	• Loss of species might be linked to changes in ecosystem structure, which extends beyond just the loss of a single species. • Loss of species existence value.
Economic	• Increased costs of implementing recovery plans for specific species. • Increased cost of resources from the area. • Loss of livelihoods. • Increases in cases for subsidy and/or compensation.
Technological	• Changes to technologies and methods used in natural resource utilization e.g. fishing gear, methods, timing, areas, speed and routes of ships.
Knowledge and information	• Increase in resources for monitoring and research on species. • Increase in the need to educate and inform parties about species and their significance.

4.5 ACTIONS AND RESPONSES

Canada has initiated, and participated, in numerous response activities that relate to the management and conservation of marine resources, of which diversity and species at risk are a key consideration. Much of this relates to international conventions and legislation that ensure the protection of resources, habitats and individual species (**Table 4-3**). This has involved the development and implementation of international, federal, provincial legislation, and associated supportive programs. Because many species at risk are migratory and continuously moving out the country's provincial and national boundaries, it necessitates considerable interaction between parties.

The Species at Risk Act is the main instrument by which Canada assesses and manages species' that are at risk. Promulgated in 2002, the Act has put in place a system of governance, and a process by which identified species are assessed and managed. Accordingly, the key governance structures that are in place include:

- COSEWIC, acting under the auspices of the Canadian Endangered Species Conservation Council, is mandated to continually monitor and review information on species that are potentially under threat (COSEWIC 2009; see also Section 4.3 and **Table 4-1**).
- Fisheries and Oceans Canada (DFO), as the lead federal government department, is responsible for managing aquatic species (marine and freshwater). DFO is involved in: further assessing species listed by COSEWIC, making recommendations on which species should be listed as Schedule 1 under SARA; and managing recovery programs (strategies and action plans) for species that are designated as Schedule 1 under SARA. DFO has a Species at Risk Maritimes Division, which deals with species relevant to the Scotian Shelf (http://www.dfompo.gc.ca/speciesespeces/regions/Maritimes/maritimes-indexeng.htm).
- Federal cabinet decision-making, through the Governor in Council, which makes the decision as to whether a species should be listed as Schedule 1 under SARA, thereby giving such species legal protection, with associated mandatory recovery programs.

Table 4-3: Key legislation applicable to managing species at risk on the Scotian Shelf.

Legislative Instrument	Purpose	Comments
International		
The United Nations Law of the Sea, 1982 (UNCLOS)	Defines the rights and responsibilities of nations in their use of the world's oceans, provides guidelines for businesses, the environment, and the management of marine natural resources.	Canada ratified UNCLOS in 2003. http://dsp-psd.pwgsc.gc.ca/Collection-R/LoPBdP/BP/bp322-e.htm
The United Nations Convention on Biological Diversity, 1992 (CBD)	Deals with international conservation of biological diversity, sustainable use of its components; and fair and equitable sharing of benefits arising from genetic resources.	There is a Canadian Biodiversity Convention Office in Environment Canada that oversees the implementation of a national biodiversity strategy. http://www.cbin.ec.gc.ca/index.cfm?lang=e#
The United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1975 (CITES)	Ensuring that international trade in specimens of wild animals and plants does not threaten their survival. CITES provides guidelines and lists of endangered species to which signatory countries are obligated to respond.	Lead agency in Canada is Environment Canada http://www.cites.ec.gc.ca/eng/sct5/index_e.cfm
International Convention for the Regulation of Whaling, 1946 (ICRW)	Provides for the conservation of whale stocks and the orderly development of the whaling industry.	Managed through the International Whaling Commission. Canada is not a participant. http://www.iwcoffice.org/commission/iwcmain.htm
International Convention for the Safety of Life at Sea, 1974	Protects the safety of marine ships in international waters particularly spills of chemicals and oil	Managed through the International Maritime Organization. Canada has been a member since 1948. http://www.imo.org
Federal		
Fisheries Act , 1985	Provides fishing regulations for management of commercial species and also habitat protection.	Managed by Fisheries and Oceans Canada. http://laws.justice.gc.ca/en/F-14/index.html
Species at Risk Act , 2002	Provides for the recovery and protection of species that are endangered or at risk.	Coordinated by Environment Canada in collaboration with Fisheries and Oceans Canada, and Parks Canada. Activities include a Species at Risk Public Registry and Habitat Stewardship Program. DFO is responsible for aquatic species. http://www.dfo-mpo.gc.ca/species-especes/index-eng.htm
Oceans Act , 1996	Provides for the management and conservation of marine areas including the establishment of marine protected areas.	Managed by Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/oceans/oceans-eng.htm
Canada National Marine Conservation Areas Act, 2002	Allows for the establishment of marine conservation areas within the exclusive economic zone	Managed by Parks Canada http://www.pc.gc.ca/eng/progs/amnc-nmca/pr-sp/index.aspx
Coastal Fisheries Protection Act, 1985	Protects coastal fisheries and migratory fish stocks in Canadian ocean waters.	Managed by Fisheries and Oceans Canada http://laws.justice.gc.ca/eng/C-33/page-1.html
Fisheries Development Act, 1985	Provides for the efficient exploitation of fishery resources and for the exploration for and development of new fishery resources and technology.	Managed by Fisheries and Oceans Canada http://www.dfo-mpo.gc.ca/reports-rapports/fda/fda2001-eng.htm
Provincial		
Nova Scotia Endangered Species Act, 1998	The Act applies to *all* species at risk in the province of Nova Scotia.	Managed by the Wildlife Division of the NS Department of Natural Resources. There is considerable interaction between province and federal programs on species at risk, including marine species. http://www.speciesatrisk.ca/municipalities/sar_ns.htm

For each species, a project cycle approach is being taken (**Figure 4-6**), with publicly-available documentation on the SARA Public Registry that provides an indication of progress being made for each species. (http://www.sararegistry.gc.ca/sar/index/default_e.cfm)

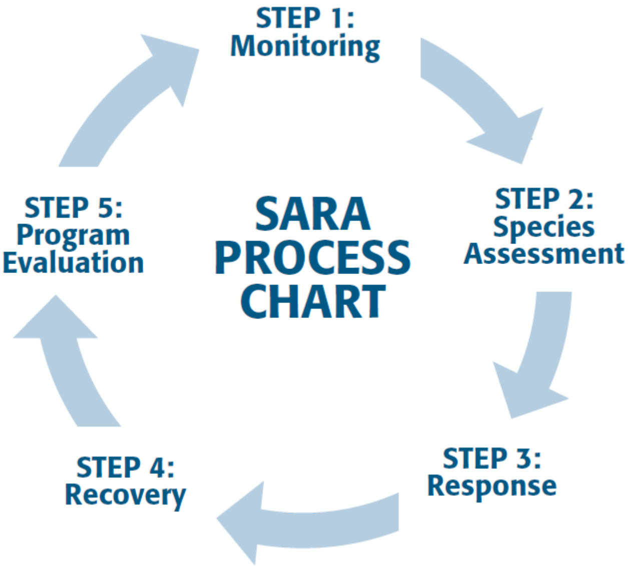

Figure 4-6: The *SARA* program cycle.

Of the 28 species that have been identified by COSEWIC for the offshore marine environment in Atlantic Canada (see **Table 4-1**), 11 species have been listed as Schedule 1, one species as Schedule 2, two species are Schedule 3, and 14 species have no designated schedule. Schedules 2 and 3 are categories that require re-assessment by COSEWIC. The *SARA* program is an extremely dynamic one with a continually changing status on the progress for each species, and these statistics provide a snapshot of the information provided by the Public Registry on March 10th 2010.

There are also a numerous supportive activities all aimed at conserving biodiversity of species on the Scotian Shelf. Amongst others, some of these include:

- The development, and implementation, of an integrated management plan for the Scotian Shelf which includes numerous ecological, social and economic objectives, and involves the inputs of multiple stakeholders from government, industry and non-government partners (DFO 2007).
- An Atlantic Zone Monitoring Program, which provides baseline information on the ecological conditions and general biodiversity of the Scotian Shelf (http://www.bioiob.gc.ca/monitoring-monitorage/azmp-pmza/indexeng.htm).
- The involvement of NGOs, academics and focus groups in networks to provide resources that can be mobilized to contribute to monitoring and management specific species. Such networks organize conferences, recovery groups, webpages, databases, publications and information transfer.
- The development of a network of marine protected and conservation areas on the Scotian Shelf. Areas that already receive some form of protection include: Roseway Basin (Area to be Avoided), Sable Island (Migratory Bird Sanctuary/ future National Park), The Gully (*Oceans Act* MPA), and Northeast Channel and Lophelia Coral Conservation Areas. A public consultation process was recently completed for the identification of the next Area

of Interest on the Scotian Shelf for MPA designation under the *Oceans Act* and a longer term process to plan and establish a network of MPAs in the Scotian Shelf-Bay of Fundy region will begin in the next year or so (DFO 2009b).

- Numerous research activities all of which contribute to a growing understanding of the large marine ecosystem and the species which inhabit it (DFO Maritimes Region and Natural Resources Canada 2008).
- The establishment of the Habitat Stewardship Program (HSP) for Species at Risk. Which allocates funding for projects that conserve and protect species at risk and their habitats (http://www.cws-scf.ec.gc.ca/hsppih/default.asp?lang=En&n=2D1DA0C5-1).

4.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR	Assessment	Trend
Temperature change	Climate change	Pressure	Fair	/
Commercial Fishing	Pressure from anthropogenic activities	Pressure	Fair	/
Shipping	Pressure from anthropogenic activities	Pressure	Poor	/
COSEWIC list of at-risk species	Evaluation of current status	State	Poor	-
COSEWIC listed species that have SARA status	Evaluation of regional response - only 44% have SARA status	Response	Poor	/
Recovery strategies	Resource management	Response	Poor	/

Key:

Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data:?

Data Confidence

- Species registry provides up- to-date information on the current status of all listed species
- Databases are available on anthropogenic activities, species population studies

Data Gaps

- Knowledge on total diversity of the Scotian Shelf is incomplete.
- Scientific knowledge and understanding of each species is incomplete.
- Accurate population estimates of most Schedule 1 species are incomplete.
- Quantification of threat factors (singly and cumulatively), and interaction with anthropogenic activities is incomplete.

4.7 REFERENCES

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5. INCIDENTAL MORTALITY[11]

Jana Aker and Sarah Deller, Fisheries and Oceans Canada, Dartmouth, NS

5.1 ISSUE IN BRIEF

Human activities that occur in the marine environment often result in the unintentional mortality of marine organisms. Incidental mortality is a consequence of human activities. While incidental mortality is something that can be avoided, it is often not economically feasible to do so because it would require the cessation of whichever human activity (e.g. fishing) that was causing the mortality. The focus of this paper is on the direct causes of incidental mortality, including fisheries, transportation, oil and gas activities and marine waste and debris.

Linkages

This theme paper links to the following theme papers in the State of the Scotian Shelf Report:

- Fish Stock Status and Commercial Fisheries
- Marine Waste and Debris
- Ocean Noise
- At Risk Species
- Marine Habitats and Communities

There have been and will continue to be a number of human activities occurring within or affecting the marine environment. With the knowledge that these activities will continue, it becomes important to identify the source and scale of incidental mortality in order to consider appropriate management measures and other responses. The identification of causes of incidental mortality can directly lead to improved management of human activities in the marine environment (**Figure 5-1**). In some cases, reductions in incidental mortality, e.g., through fishing gear modification, have allowed activities to expand.

5.2 DRIVING FORCES AND PRESSURES

International trade, economic development and the human activities involved are some of the main driving forces that are leading to the pressures causing incidental mortality in the marine environment of the Scotian Shelf.

5.2.1 Fishing

Commercial fishing on the Scotian Shelf has occurred for centuries. In 1700, cod, mackerel and herring were the primary species caught for export from Nova Scotia and these species continued to be important for centuries. After peaking in the 1970s and 1980s, it became apparent that landings for groundfish stocks, particularly cod and haddock, were beginning to decline. This resulted in some fisheries closures in the early 1990s that remain in place today. Limited fishing for some groundfish has continued, but shellfish fisheries have taken over as the dominant activity occurring on the Scotian Shelf. Shellfish fisheries include lobster, scallop, shrimp, crab, and surf clam. Additionally, large pelagic species such as swordfish, tuna and shark support fisheries throughout the Scotian Shelf (See *Fish Stock Status and Commercial Fisheries*).

With the many different fisheries occurring throughout the Scotian Shelf, there are also differences in the type of gear used. Fishing gear can be either active (i.e., mobile and physically dragged by the vessel) or passive or fixed (typically lowered to the seafloor or suspended in the water column for some period and retrieved). Both of these methods can cause injury or mortality of non-target marine species. The specific ways in which fishing causes mortality and the species most affected are listed below.

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[11] Completed January 2013.

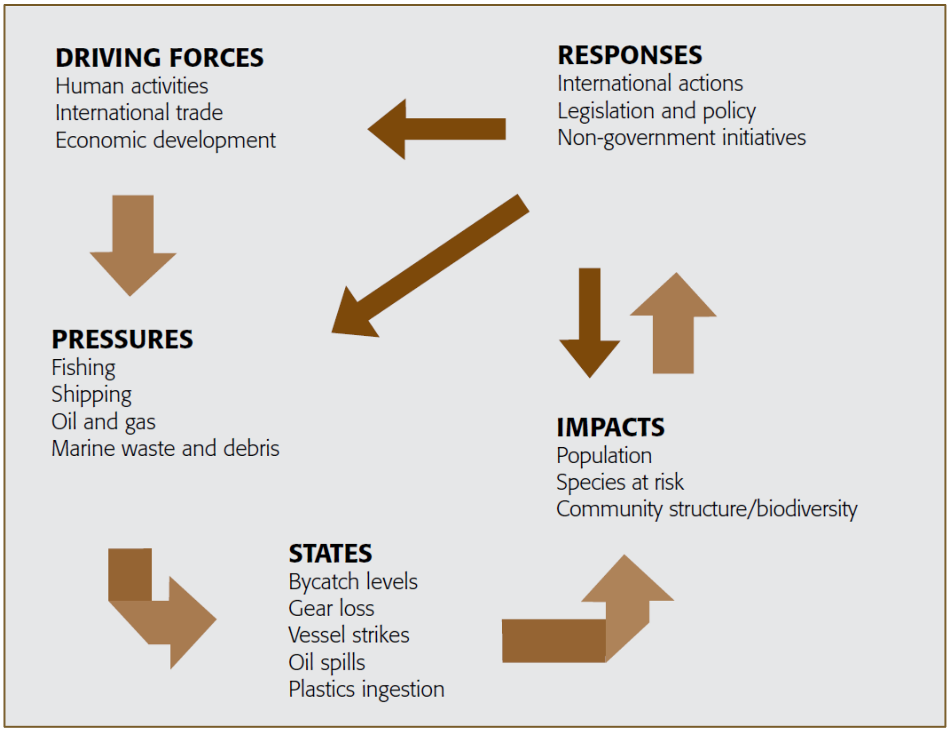

Figure 5-1: Driving forces, pressures, state, impacts and responses (DPSIR) to incidental mortality of marine organisms on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all other elements.

Bycatch: Bycatch is a term often used to describe non-targeted species caught through fisheries. It can also apply when undersized or juvenile forms of the targeted species are caught. Bycatch is a complex issue and rules surrounding what is discarded and what is retained vary from fishery to fishery. In general, most non-commercial species are returned to the water. Whether or not a commercial species is retained varies, and this can depend on the life history stage and other characteristics of the species, and the nature of the fishery. Bycatch that is retained is monitored as fisheries landings, whereas bycatch that is not kept is not always recorded. While discarded species may survive post-release, actual survival rates are difficult to measure. There are a number of fisheries management measures intended to reduce the incidence of bycatch; these are outlined in law, regulations, fisheries management plans, and licence conditions.

Precatch Losses: Precatch loss is another type of incidental mortality caused by fishing. Examples of precatch losses include the incidental crushing or smothering of marine organisms that may occur from laying traps or pots or trawling. There have also been examples where a predator has eaten a fish caught on a longline (Iversen 1995). This can be considered a precatch loss because the animal may not have been consumed by the predator if fishing had not been occurring in the area (Iversen 1995).

Ghost Fishing: Ghost fishing can occur as a result of derelict fishing gear, which is gear that has either been discarded or lost from a fishery. Gear can be lost as a result of storms or rough waters, chafing or cutting of ropes, bottom snags, faulty gear, vandalism, human error or gear being moved unintentionally by other vessel traffic (Newman et al. 2011). It most commonly occurs as a result of gear lost from passive fishing activities such as use of nets, ropes, pots or traps. Since the materials used to construct this gear often do not degrade, the gear may continue to catch marine species despite no longer being used by a fishery[12]. It is estimated that 52 metric tonnes of fishing gear accumulate annually (UNEP 2011). Nets can catch fish species within the water column, but can also form into a ball, at times weighing up to a tonne, and roll along the ocean floor, crushing benthic species and habitats (DFO 2010) (See *Marine Waste and Debris*).

Entanglement: Large pelagic marine organisms have the potential to get entangled in fishing gear and nets, and more than 200 species are susceptible to entanglement worldwide (UNEP 2011). In the region, the main concern of entanglement is with the endangered North Atlantic right whale (*Eubalaena glacialis*), herein after referred to as the right whale. Photographs taken in surveys in the Gulf of Maine have shown that 75% of right whales showed signs of entanglement, with lobster gear the primary source of entanglement (Myers et al. 2007). Entanglement is also a risk for endangered leatherback turtles in the region (James et al. 2005). Entanglement can lead to suffocation, starvation, drowning, restricted movement, vulnerability to predators, or other injury such as wounds from tightening material (UNEP 2011).

5.2.2 Marine Vessel Traffic

The commercial shipping industry is continually growing as the global demand for goods is increasing. The marine transportation industry is responsible for over 90% of international trade (IMO 2012a) with cargo vessels and oil tankers making up the majority of the global fleet (UNCTAD 2011). As of 2006, the marine shipping sector in the Maritime Provinces contributed $0.5 billion to Canada’s Gross Domestic Product (GDP) and employed approximately 10 000 people (CPCS Transcom Limited 2012). The Scotian Shelf is an area that is frequently transited by commercial shipping vessels moving between ports in Europe, the Eastern Seaboard of North America and the St. Lawrence Seaway (**Figure 5-2**).

Aside from commercial shipping vessels, there are also many passenger vessels, including ferries and cruise ships, recreational vessels, including pleasure craft, research, whale watching, and fishing vessels on the Scotian Shelf. Most of the recreational vessels occur in regions that are closer to the coast. Marine Atlantic Ferries run year round between North Sydney, Cape Breton and Port aux Basques, Newfoundland and from June to September between North Sydney and Argentia, Newfoundland (Marine Atlantic 2012). The Scotian Shelf is also a popular destination for cruise ships. In 2010, the Port of Halifax alone was the port of call for over 120 cruise vessels (Cruise Halifax 2011).

Vessel traffic in the marine environment has the potential to contribute to incidental mortality through vessel strikes (to large, pelagic organisms), pollution and noise. Vessel-source pollution— including sewage, oily substances (from operational discharges or spills from accidents or leaks), garbage and hazardous and noxious substances— may result in direct mortality of marine life or have long-term health impacts. Commercial vessel traffic has raised

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[12] Some of the materials used in manufacturing fishing gear is now biodegradable and may eventually wear down, resulting in less mortality. However, this gear is still expected to last for at least a fishing season meaning that some mortality will still occur.

natural ambient noise levels in some parts of the world's oceans by approximately 180 Hz (Tyack 2008). This can cause behavioural changes in marine mammals, but it is not clear if it has a direct link to incidental mortality (see also *Ocean Noise*).

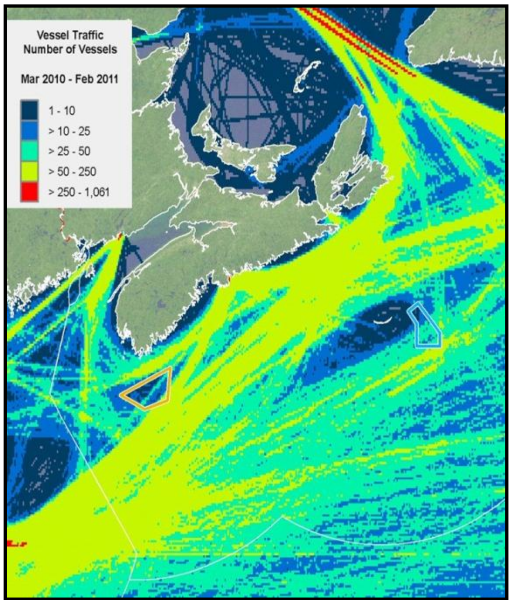

Figure 5-2: Composite image of vessel track counts for the Maritimes based on Long Range Identification and Tracking (LRI T) data with the Roseway Basin area to be avoided (orange polygon) and the Gully Marine Protected Area (MPA) (blue polygon) highlighted (from Koropatnick et al. 2012). Note that LRI T data only contains information for vessels of 300 gross tonnage or more on international voyages and therefore do not entirely represent the vessel activity on the Scotian Shelf.

5.2.3 Offshore Oil and Gas

The increasing need for oil and gas products has led to oil and gas exploration and drilling in the marine environment and the Scotian Shelf is thought to have large reserves of petroleum products (Breeze and Horsman 2005). There are currently two production projects in the offshore, the Sable Offshore Energy Project and the Deep Panuke project, both mainly focused on natural gas extraction (Nova Scotia Department of Energy 2012). There have also been multiple exploratory wells and areas licensed for exploration (**Figure 5-3**). In November of 2012, BP and Shell Canada Ltd. received exploratory licences for a total of eight offshore parcels and they will be conducting exploratory drilling in these areas (CNSOPB 2012a). This will most likely result in an increase in oil and gas exploration and extraction on the Scotian Shelf in coming years. Several aspects of oil and gas exploration and development activities can lead to incidental mortality:

Blowouts/Spills: Blowouts that result in oil being spilled in the marine environment have a low probability of occurrence, but have serious consequences if they do occur (Lee et al. 2011). If gas was released, it would most likely dissipate into the atmosphere; however, the release of oil products can create slicks on the surface of the ocean and cause the most serious environmental effects. If a spill occurs when there are larval or juvenile stages of marine life in the water column, it could cause impacts on recruitment and development of those species (Lee et al. 2011). Other marine species, such as sea birds and turtles, are also at risk from large spills. When seabirds come in contact with oil on the water's surface, it gets absorbed into the feathers of the bird and decreases their ability to thermoregulate and reduces waterproofing and buoyancy. This can result in hypothermia or starvation, leading to death (Wiese and Ryan 2003). Turtles have been found to consume oil, which can remain within their systems and the toxins get absorbed into their tissues (NOAA 2010). Oil may also cause turtles to become disoriented; it can influence the olfactory senses of the turtles and they rely heavily on these senses for navigation and orientation (NOAA 2010).

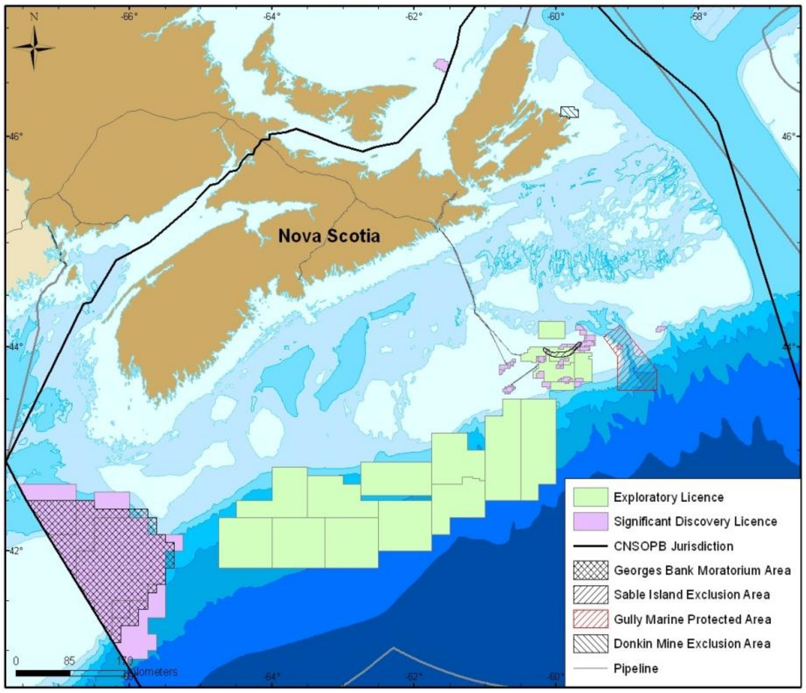

Figure 5-3: Nova Scotia offshore rights for petroleum exploration and development as of December 2012 (data courtesy of the Canada-Nova Scotia Offshore Petroleum Board).

Artificial Light: Seabirds are attracted to the lights and flares on oil platforms. Some are known to fly directly into light and flares, resulting in mortality and others have been reported to circle the light until they die of starvation (Wiese et al. 2001).

Construction / Demolition: Construction of offshore oil and gas platforms, pipelines and associated structures leads to the mortality of some species (e.g., benthic invertebrates) via machinery or dredging operations and the decommission of rigs often involves the use of explosives, which could also result in incidental mortality (Lee et al. 2011). While the potential for incidental mortality to occur exists within construction and demolition procedures, the number of mortalities has not been recorded and the exact impacts remain uncertain.

Seismic Testing: Seismic testing involves releasing sound waves into the marine environment in order to produce an image of the subsurface geology of an area (Hurley 2009). High levels of seismic noise can cause mortality, development abnormalities or injuries in the early life stages of fish and invertebrates, i.e., eggs and larvae, with most problems occurring within 5 metres of the air gun (Lee et al. 2011). While studies have found evidence that seismic noise can cause egg and larval fish mortality, the exact impacts in the natural environment remain unknown (DFO 2004).

5.2.4 Marine Debris

Marine waste or debris can be defined as any manufactured or processed solid material that enters the ocean either through direct or indirect means (UNEP 2011; USEPA 2011; NOAA 2011). Marine waste and debris includes almost all types of litter present in the ocean, ranging in size from micromillimetres (e.g., microplastics) to hundreds of metres (e.g., fishing gear). It can cause deaths of marine organisms directly through ingestion and entanglement as well as indirectly, such as through the transportation of invasive species that may outcompete indigenous species (see the *Marine Waste and Debris*). Seabirds and sea turtles are particularly vulnerable to ingestion of plastic materials such as bags or rope. Leatherback turtles mistake plastic bags for their prey, jellyfish. Plastic can cause suffocation, digestive tract blockage or starvation of seabirds and sea turtles.

5.3 STATUS AND TRENDS

The status and trends related to various sources of incidental mortality are difficult to determine because for most causes of incidental mortality, there is no baseline information for the Scotian Shelf. Available information is provided below and can provide a baseline for future work.

5.3.1 Fisheries Bycatch

Most fisheries occurring on the Scotian Shelf have some form of bycatch and there have been targeted measures to reduce incidental mortality in most of those fisheries, including groundfish, scallop, shrimp, herring purse seine, and pelagic longline. Even where there have been efforts to document bycatch, it is difficult to be sure how much mortality actually occurs (See Section 5.4 on Impacts for more information). Some recent studies, discussed below, have examined bycatch in particular commercial fisheries in an attempt to measure impacts and provide a better understanding of the status and trends of bycatch. Readers should be aware that information is not available for all fisheries and that the availability of information does not necessarily mean that bycatch is a greater problem in that fishery than in others for which information is not available. See Section 5.5 for Actions and Responses to some of the trends discussed below.

Scallop Fishery: The sea scallop (*Placopecten magellanicus*) fishery is one of the more economically important shellfish fisheries in Nova Scotia. In 2009, the total value of the offshore scallop fishery was $85 million and the majority of the catch was exported to the United States and European markets (DFO 2011a). On the Scotian Shelf, the fishery mainly occurs on Browns, Sable Island and Western banks. The gear used to fish scallops is a large dredge or rake, ranging in width from 3.96 to 5.18 metres and trailed by a large chain net that drags along the bottom and a mesh net on top that collects the catch (Walsh 2008). There are no overall bycatch estimates for the Scotian Shelf; however, yellowtail flounder (*Limanda ferruginea*), cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), skates (*Raja* spp.), monkfish (*Lophius americanus*), other species of flounder, and miscellaneous fish and invertebrates are caught as bycatch in the nearby Georges Bank fishery (see e.g., Gavaris et al. 2007; Walsh 2008). A recent assessment of fisheries observer data found that approximately 94% of organisms caught in the fishery on Georges Bank are scallops with the majority (by weight) of the remaining organisms caught being fish (Caddy et al. 2010). Between 2001 and 2007 the most abundant bycatch species (by weight) in scallop fishing area 29 west were Jonah crab (*Cancer borealis*), Atlantic rock crab (*Cancer irroratus*), hermit crabs (*Paguroidea*), longhorn sculpin (*Myoxocephalus* *octodecimspinosus*) and the thorny skate (*Amblyraja radiata*) (Smith et al. 2009). Many other species of skates, benthic invertebrates and groundfish have also been caught as bycatch in this area.

Swordfish and Tuna Longline Fishery: Swordfish is caught by pelagic longline and harpoon gear. The harpoon fleet is allocated 10% (up to 150 t) of the Canadian swordfish quota, while the longline fishery accounts for 90%. The offshore tuna fishery and the exploratory porbeagle shark fisheries also use pelagic longline gear. The pelagic longline gear used by Canadian fishermen consists of a backline that may be up to 64 kilometres long. Styrofoam floats ensure that the line is supported in the water column and there may be as many as 2000 baited hooks attached to the line (Stone and Dixon 2001). Since the gear does not allow for targeting of a specific species, bycatch occurs. Species with the most concerning incidences of bycatch are sharks (blue, porbeagle, and shortfin mako) and sea turtles (loggerhead and leatherback) (Gilman et al. 2006; Gavaris et al. 2010; Carruthers et al. 2011; **Table 5-1**).

Table 5-1: catch species (including alive, dead and unable to determine) by number and weight from the Eastern Canadian pelagic longline fishery from 2004-2009, based on observer data and including both retained and discarded animals. Most bycatch is discarded. Adapted from Devitt et al. 2012.

		Year					
Bycatch Species	**Number/ Weight**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**
Fish							
Cutlass Fishes	Number					7	
	Weight (kg)					16	
Sea Lamprey	Number		14				
	Weight (kg)		14				
Longnose Lancetfish	Number	9	8	11	26	10	4
	Weight (kg)	46	19	46	100	60	19
Monkfish	Number		4		1		
	Weight (kg)		13		3		
Oilfish	Number			1	4		
	Weight (kg)			5	114		
Opah	Number				7		
	Weight (kg)				116		
Atlantic Manta Ray	Number	3			1		
	Weight (kg)	455			500		
Manta Ray	Number		1				
	Weight (kg)		200				
Remora	Number	2	9				
	Weight(kg)	5	9				
Blue Shark	Number	2398	2367	1267	1692	836	1138
	Weight (kg)	112764	78661	30759	67267	35208	44145
Hammerhead Shark	Number	1					
	Weight (kg)	15					
Sand Shark	Number					1	
	Weight (kg)					75	
Thresher Shark	Number	1	2	4	2	3	1
	Weight (kg)	90	350	266	682	195	200

Table 5-1 (continued)

Bycatch Species	Number/ Weight	2009	2008	2007	2006	2005	2004
Fish							
Tiger Shark	Number	5	7	2	2	7	1
	Weight (kg)	576	2080	130	450	356	100
Pelagic Stingray	Number	54	17	148	98	113	4
	Weight (kg)	296	41	437	266	306	8
Ocean Sunfish	Number	2		3	3	1	1
	Weight (kg)	260		1120	495	200	80
Blackfin Tuna	Number					1	
	Weight (kg)					20	
Striped Bonito/Skipjack Tuna	Number	1		1			
	Weight (kg)	8		5			
Birds							
Great Black-Backed Gull	Number	1					2
	Weight (kg)	2					4
Greater Shearwater	Number	3	1				2
	Weight (kg)	4	1				2
Turtles							
Leatherback Turtle	Number	8	1	4	10	11	9
	Weight (kg)	1569	91	779	2884	2392	1350
Green Turtle	Number					22	1
	Weight (kg)					870	20
Kemp’s Ridley Turtle	Number					1	2
	Weight (kg)					100	60
Loggerhead Turtle	Number	16	31	37	77	90	5
	Weight (kg)	482	958	1476	3127	2803	270
Hardshelled Turtles (unsp.)	Number	12				2	1
	Weight (kg)	494				58	30
Marine Mammals							
Seal (unsp.)	Number						1
	Weight (kg)						135

Groundfish Fishery: Groundfish fisheries across the Scotian Shelf include pollock, halibut and other flatfish (such as American plaice and yellowtail flounder), silver hake, and redfish. As well, there are cod and haddock fisheries that occur on the western Scotian Shelf (DFO 2011b). The groundfish fishery is managed as a multi-species fishery, which means one or more species are caught using the same gear and contribute toward landings. In some ways, the simultaneous targeting of species reduces incidences of bycatch since most of the catch is in fact targeted. A groundfish licence holder must adhere to licence conditions which identify certain groundfish species as targeted. This condition makes the fishery different from other fisheries, where discards may be permitted, since incidental catch of other groundfish species must be retained. Most groundfish are caught using mobile gear such as otter or other types of trawlers, but longline, gillnet, seine and handlines are also used (Breeze and Horsman 2005). The catch in the haddock- directed fishery on the western Scotian Shelf and Bay of Fundy was documented by Cox and others (2010) and includes both targeted commercial species and non-targeted, non-commercial species (**Tables 5-2 and 5-3**). It is likely that the catch mix on the eastern shelf would be different. The Northwest Atlantic is divided into divisions and subdivisions set by the

Northwest Atlantic Fisheries Organization (NAFO). These divisions are used to manage most groundfish fisheries in the Northwest Atlantic (**Figure 5-4**).

Tables 5-4 to 5-7 show the various species that are caught by type of groundfish fishery for fisheries divisions in the Scotian Shelf and the Bay of Fundy. The tables are divided by fishing zone as well as by those species that are discarded but licensed, and those that are discarded but are of potential concern. The data are based on observations of discards by fisheries observers and the shaded cells are determined based on amount, consistency and reliability of the estimates (Gavaris et al. 2010)[13].

Table 5-2: Average annual retained catch in the haddock-directed fishery, by gear, on the western Scotian Shelf and Bay of Fundy (4X5Y), 2002-2008, from logbook data. Fish harvesters were considered to be directing for haddock when it made up more than 50 percent of the catch. Percentage is percentage of total catch (adapted from Cox et al. 2010).

	Bottom Otter Trawl		**Bottom Longline**	
Retained Species	**Weight (t)**	**Percentage**	**Weight (t)**	**Percentage**
Haddock	3063	82.2	400	63.3
Pollock	130	3.5	2	0.3
Redfish	66	1.8	1	0.2
Cod	263	7.1	126	19.9
Monkfish	49	1.3	3	0.5
Silver hake	0	0	0	0
Winter flounder	49	1.3	0	0
Dogfish	0	0	0	0
Cusk	5	0.1	32	5.1
Halibut	0	0	9	1.4
White hake	40	1.1	54	8.5
Yellowtail flounder	1	0	0	0
Others	60	1.6	5	0.8

Table 5-3: Total discarded catch in the haddock-directed fishery, by gear, on the western Scotian Shelf and Bay of Fundy (4X5Y), 2004-2008, as estimated from observer data. Fish harvesters were considered to be directing for haddock when it made up more than 50 percent of the catch. Percentage is percentage of total catch. Invertebrates (other than commercial species) were not included (adapted from Cox et al. 2010).

	Otter Trawl		**Longline**	
Discarded Species	**Weight (t)**	**Percentage**	**Weight (t)**	**Percentage**
Dogfish	5035	6.4	2129	7.3
Skates (unsp.)	1256	1.6	1145	3.9
Lobster	1138	1.2	-	-
Sharks	583	0.7	-	-
Halibut	208	0.3	104	0.4
Sculpin	87	0.1	-	-
Cusk	-	-	368	1.3
Haddock	-	-	33	0.1
Wolffish	-	-	27	0.1
Others	190	0.2	49	0.2

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[13] The findings from the Gavaris et al. (2010) study are coarse and the authors acknowledge more investigation is needed to perform a detailed analysis. The purpose of the study was to identify gaps in monitoring and consider the estimates of discards as the first stage in a triage to prioritize potential conservation risks that may be associated with higher discard amounts.

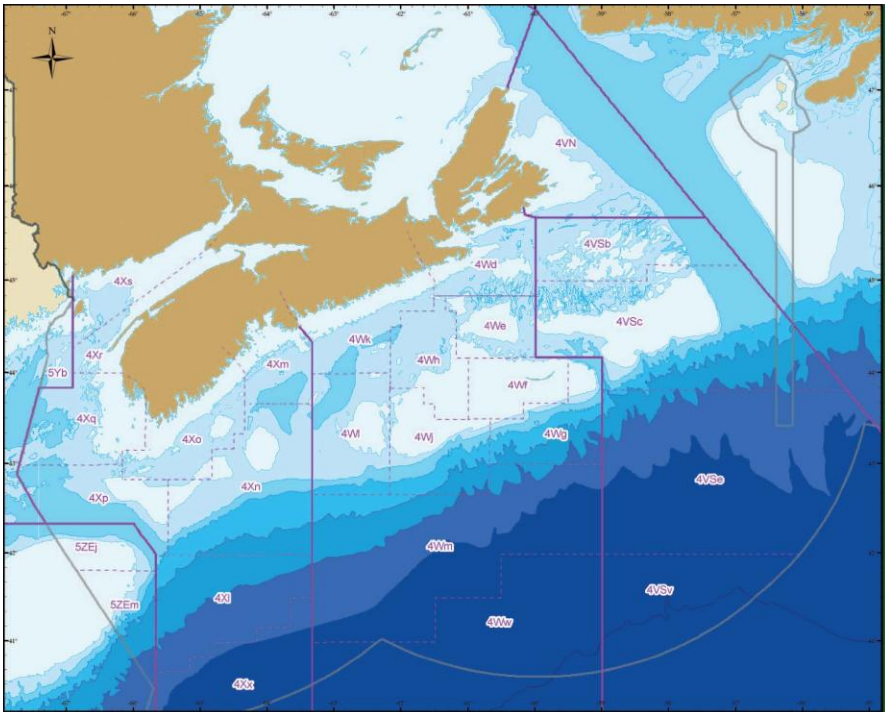

Figure 5-4: Fisheries management areas for the Maritimes Region (DFO 2011b).

Table 5-4: Summary of discards of licensed species in 4VW fishing region (Eastern Scotian Shelf). Lighter coloured cells indicate lower amounts of discards, while dark blue indicates high amounts. White cells indicate that there is no contribution to discards by that particular fishery (adapted from Gavaris et al. 2010).

Fishing Area: 4VW	Groundfish longline	Groundfish bottom trawl	Groundfish bottom trawl offshore	Silver hake bottom trawl	Redfish bottom trawl	Redfish bottom trawl offshore
Snow crab	░	░	░			
Halibut	▒	░	░	░	░	░
Swordfish				░		
Jonah crab	░			░		
Blue shark	░					
Other sharks	▓	░				
Herring		░	▒	▓		
Winter skate	▒	▒	▒	▒		
Other flounders		░		░		

Table 5-5: Summary of discards of species of potential concern in 4VW (Eastern Scotian Shelf). Lighter coloured cells indicate lower amounts of discards, while dark blue indicates high amounts. White cells indicate that there is no contribution to discards by that particular fishery (adapted from Gavaris et al. 2010).

Fishing area: 4VW	Groundfish longline	Groundfish bottom trawl	Groundfish bottom trawl offshore	Groundfish midwater trawl	Silver hake bottom trawl	Redfish bottom trawl	Redfish bottom trawl offshore
Northern wolffish	▒			░	░		░
Thorny skate	▒	▒	░		░	▒	░
Porbeagle			░				
Spiny dogfish	░	░	▒	░	▒	▒	░
Basking shark	░				▒		

Table 5-6: Summary of discards of licensed species in 4X5Y (Western Scotian Shelf and Bay of Fundy). Lighter coloured cells indicate lower amounts of discards, while dark blue indicates high amounts. White cells indicate that there is no contribution to discards by that particular fishery (adapted from Gavaris et al. 2010).

Fishing area: 4X5Y	Groundfish gillnet	Groundfish longline	Groundfish bottom trawl	Groundfish bottom trawl offshore	Silver hake bottom trawl	Redfish bottom trawl	Redfish bottom trawl offshore	Sculpin bottom trawl
Herring	░		▒	░	░	░	░	░
Scallop	░		░		░	░		░
American lobster	█	░	█	▒	░	█	▒	░
Jonah crab	▒	░	▒	░	░	▒		▒
Snow crab					░	░		
Halibut	░	█	█	░	░	░	░	░
Spiny dogfish	█	█	█	█	█	█	█	
Sea cucumbers								░
Atlantic rock crab	░	░	░		░	░		░
Sculpin	░	░	█	░	░	░	░	░
Blue shark		▒						
Sea urchins			░					░
Clam								░
Other flounders	░		░	░	░	▒	░	░

Table 5-7: Summary of discards of species of potential concern in 4X5Y (Western Scotian Shelf and Bay of Fundy). Lighter coloured cells indicate lower amounts of discards, while dark blue indicates high amounts. White cells indicate that there is no contribution to discards by that particular fishery (adapted from Gavaris et al. 2010).

Fishing area: 4X5Y	Groundfish gillnet	Groundfish longline	Groundfish bottom trawl	Groundfish bottom trawl offshore	Silver hake bottom trawl	Redfish bottom trawl	Redfish bottom trawl offshore	Sculpin bottom trawl
Thorny skate	░	█	█	▓	░	▓	░	░
Barndoor skate	░	█	▓	░	░	▓	░	
Winter skate		█	█	░	░	░	░	░
Smooth skate	░	▓	▓	░	░	░	░	
White hake	▓	░	░	░	░	░		░
Porbeagle	▓	░	▓	░				
Shortfin mako	▓			░				
Cusk		░	░	░				
Basking shark					▓	░	▓	

Shrimp Fishery: There are two managed shrimp fishing areas (SFA) on the Scotian Shelf, SFA 13-15 and SFA 16 (DFO 2011c); most shrimp is caught on the eastern Scotian Shelf. The shrimp trawl fishery was historically known for the amount of groundfish bycatch associated with it. Between the 1970s and the 1990s, shrimp stocks in the region were underutilized. The gear used in the fishery resulted in a high amount of bycatch and the bycatch was counted toward the total allowable catch for the fishery. However, the fishery is active today because there have been gear modifications that have significantly reduced the amount of bycatch associated with this fishery (**Figure 5-5**). Koeller et al. (2009) show that total bycatch is from about 50 to 400 t per year, a relatively small proportion of total catches; however, there is a lot of variability (**Figure 5-6**). Parsons and others (2011) documented bycatch in the northern shrimp fishery on the Scotian Shelf (**Table 5-8**). Only shrimp may be retained in this fishery, all non-target species are discarded.

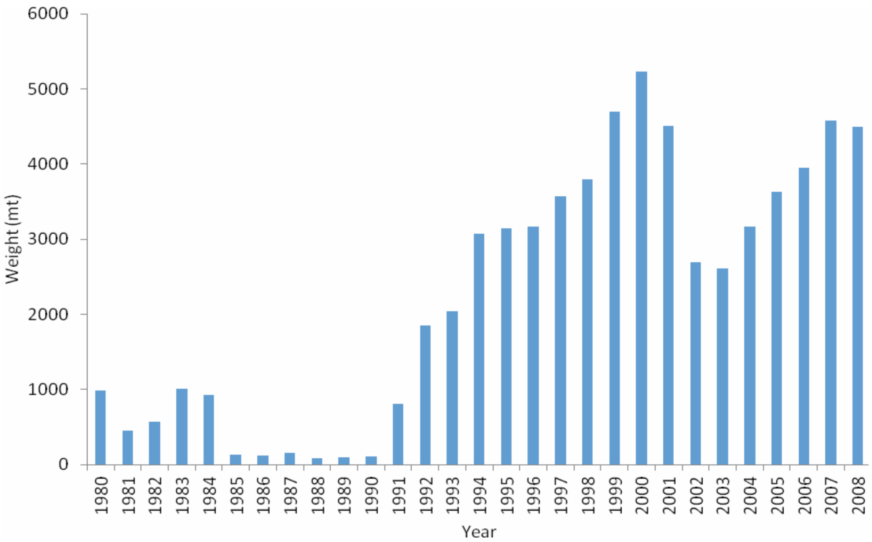

Figure 5-5: The total catches of shrimp on the eastern Scotian Shelf (SFAs 13 to 15) from 1980 through 2008 (adapted from Koeller et al. 2009).

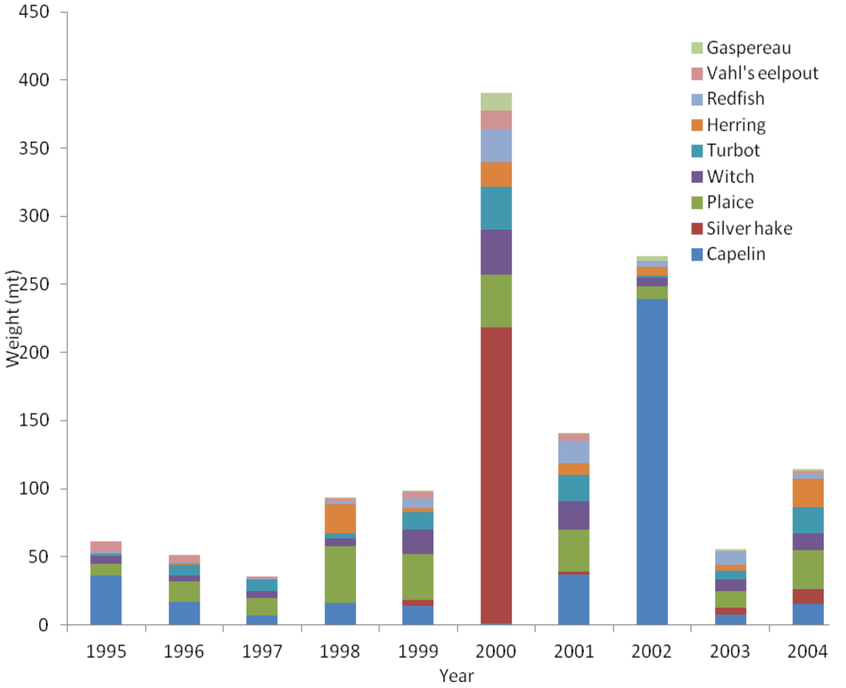

Figure 5-6: The estimated weight (mt) of bycatch (by species) from the Eastern Scotian Shelf shrimp fishery from 1995 through 2004 (adapted from Koeller et al. 2006).

Table 5-8: Discards as a percentage of total catch for the years 2002, 2004, 2005, 2006, 2008, 2009 in the northern shrimp (*Pandalus borealis*) trawl fishery on the eastern Scotian Shelf, from observed trips (adapted from Parsons et al. 2011).

Common Name	Percentage of catch
Northern shrimp	0.19
Redfish	0.33
Silver hake	0.31
Witch flounder	0.23
Greenland halibut	0.20
American plaice	0.12
Capelin	0.10
Atlantic herring	0.08
Winter flounder	0.05
Snake-blenny	0.04
Short-fin squid	0.02
Ocean pout	0.02
Eelpout (unsp.)	0.01
Thorny skate	0.01
American eel	0.01
Alligator fish	0.01
Alewife	0.01
Longfin hake	0.01
Red hake	0.01
Atlantic sea poacher	0.01
Short-tailed (Vahl's) eelpout	0.01
Snow crab	0.01
Striped wolfish	0.01
TOTAL	**1.72**

5.3.2 Fisheries Precatch Loses and Ghost Fishing

Information on precatch losses and ghost fishing on the Scotian Shelf is limited, but some studies have been done on the Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery. This was the first snow crab fishery to be established in Eastern Canada when it began in the mid-1960s (Gardner Pinfold 2006). A study by Hébert et al. (2001) designed to understand the effects of ghost fishing from the Gulf of St Lawrence snow crab fishery predicted that 1000 lost conical traps would kill 84 194 snow crabs per year. With a snow crab fishery now occurring on the Scotian Shelf, it could be assumed that some snow crab fatalities are occurring through ghost fishing in this region as well. Numbers are likely not as high as suggested by Hébert et al. (2001) because changes have been made to the conical traps (including the use of galvanic time releases and biodegradable twine) that may reduce mortalities caused by ghost fishing, but further studies are needed to verify. While the focus of this study was primarily on snow crab mortalities, there were also findings of toad crabs being caught and other studies have suggested that fish can get caught in the traps, starve, die and create bait for crustaceans resulting in a cyclical pattern (FAO 2012a).

5.3.3 Vessel Strikes – All Sectors

The species that are most commonly killed by vessel strikes include fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter catodon*), grey whales (*Eschrichtius robustus*) and right whales (*Eubalaena* spp.) (Laist et al. 2001). Though whales are more commonly struck, marine turtles are also at risk of vessel strikes in their summer feeding areas, which include the Scotian Shelf. Not all vessel strikes of marine mammals and turtles are reported on the Scotian Shelf—in some cases, the captain may not be aware that an animal has been hit. However, causes of right whale deaths are monitored and approximately 20% of the right whale mortalities from vessel strikes have occurred in Canadian waters (Brown et al. 2010). Of the known whale-vessel collisions off North America, most have occurred off the U.S. east coast (about 50%), followed by the U.S. west coast (about 20%) and then eastern Canada (about 10%), with the remainder occurring along the Alaskan and Hawaiian coasts and in the Gulf of Mexico (Jensen and Silber 2004).

5.3.4 Oil Spills and Discharges

Vessel-source Oil Spills and Discharges: Accidental or deliberate releases of petroleum from vessels can be a serious cause of seabird mortality in the offshore. Transport Canada's National Aerial Surveillance Program (NASP) is the main method of oil pollution detection in the region's marine environment (**Figure 5-7**). NASP plans and conducts surveillance flights daily, weather and equipment permitting, and it can detect anomalies using on-board remote sensing equipment. Pollution incidents can also be detected by satellite (e.g. through Environment Canada's Integrated Tracking of Pollution program), other vessels at sea, and concerned citizens in port areas.

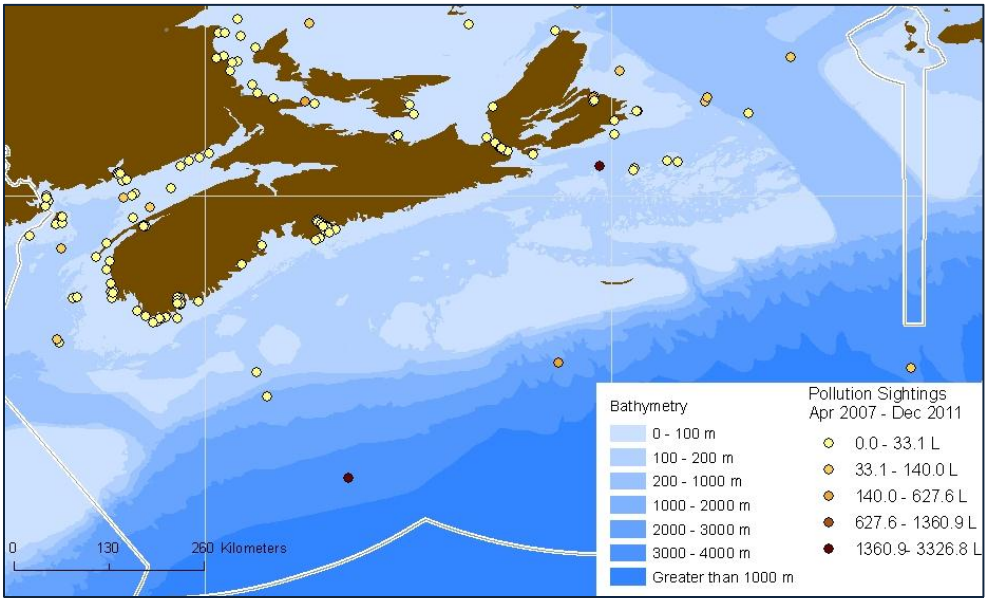

Figure 5-7: Locations and estimated volume (litres) of spills detected by Transport Canada's National Aerial Surveillance Program in the Bay of Fundy and Scotian Shelf from April 2007 to December 2011.

Petroleum Industry Oil Spills and Blowouts: The offshore oil and gas sector is in a growth phase on the Scotian Shelf and the Province of Nova Scotia is encouraging developers to take advantage of the resources that lie beneath the Scotian Shelf (Government of Nova Scotia 2012). To date there have been no major incidents involving blowouts or spills. However, the Canada-Nova Scotia Offshore Petroleum Board tracks the release of petroleum products into the marine environment from offshore oil and gas development and there have been 51 spills ranging in size from less than 1 litre to greater than 150 litres (**Table 5-9**).

Table 5-9: The number of spills from offshore oil and gas activity by approximate volume and product type from April 2006 to March 2012 (adapted from CNSOPB 2012b).

Substance	Less than 1L	1-10L	11-150L	Greater than 150L	Total number of spills
Hydraulic oil	8	5	6	1	20
Diesel	6	1			7
Chemicals		1	1	3	5
Condensate	2	1	2		5
Light oil	1				1
Water based mud				1	1
Oil (unclassified)	5	2			7
Lubricating oil	3				3
Mineral oil		2			2
Total	25	12	9	5	51

5.3.5 Plastic Ingestion

There is little data specific to the Scotian Shelf on plastics at sea and their ingestion by marine life. One study looked at plastics collected in plankton net tows from 1986 to 2008 in the North Atlantic, including parts of the Scotian Shelf (Law et al. 2010). It found that that the highest concentrations of plastic debris were found in a subtropical region surrounding Bermuda, with concentrations diminishing at higher and lower latitudes (**Figure 5-8**); data from latitudes equivalent to the Scotian Shelf show the lowest concentrations. Between the 1960s and the 1980s, a global study found that 37% of studied leatherbacks had plastic in their stomachs (Mrosovsky et al. 2009). A study focusing specifically on the Scotian Shelf has not yet been completed.

5.4 IMPACTS

Many occurrences of incidental mortality can go unreported and therefore can be difficult to measure. It is even more difficult to then understand the impacts of incidental mortality on the marine ecosystem. Though the impacts are difficult to understand, information about the impacts on populations from incidental mortality caused by the fishing industry is starting to be gathered. In many cases bycatch and entanglement etc. are reported and can be measured and therefore this section is heavily concentrated on fishing impacts.

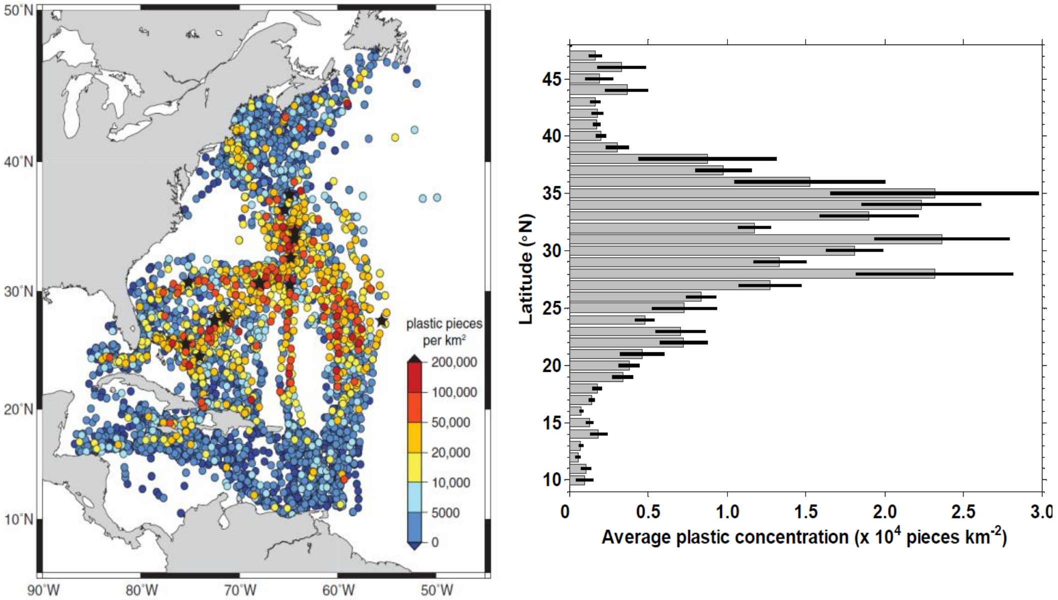

Figure 5-8: Left: Distribution of plastic marine debris collected in 6136 surface plankton net tows in the western North Atlantic. Black stars indicate tows with measured concentrations greater than 200 000 pieces/km^2 and symbols are layered from low to high concentration. Right: Average plastic concentration as a function of latitude. Averages were calculated by one-degree latitude groupings; black lines indicate standard error. The highest plastic concentrations were observed in subtropical latitudes (22-38°N). The Scotian Shelf and Slope are found at approximately 41 to 46°N (Law et al. 2010).

5.4.1 Population

Globally, fisheries bycatch has been identified as one of the leading factors for population declines, particularly of sea turtles, seabirds and cetaceans (Lewison et al. 2004). Studies have demonstrated that impacts of bycatch on seabirds on the Scotian Shelf are not a concern, however, sea turtles and cetaceans are being impacted, though more research is needed to confirm numbers specific to the Scotian Shelf (Anderson et al. 2011; Wallace et al. 2008; Moore and van der Hoop 2012). A concern related to such population declines is that they tend to go undetected before significant declines occur (Lewison et al. 2004). This becomes an issue, particularly with megafauna because they have long life spans and low reproductive output, meaning that their populations take a longer time to recover from depletion. If populations of these high order species decline, there will likely be consequences on other species populations that interact with the megafauna. For example, it is surmised that on average a leatherback turtle consumes between 65-260 kilograms of jellyfish per day (Mrosovsky et al. 2009) and thus, a decline in leatherback turtle populations may increase jellyfish populations. Similarly, it is believed that declines in shark populations result in increased seal populations, thus having a further trickle-down effect impacting herring and pollock populations (Heithaus et al. 2008).

The amount of incidental mortality and impacts of bycatch on these populations are difficult to calculate but analysis of data collected by at sea observers and research is helping to provide a clearer picture and to help guide management measures that may be required to reduce these impacts.

Sharks and Skates: Populations of sharks and skates have declined due to directed fisheries as well as incidental catches. Blue sharks are the most frequently caught shark species in longline fishing gear and have declined in abundance by 5-6% annually between 1995 and

2005 (Campana et al. 2006; Campana et al. 2011), and were assessed as a species of special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2006 (COSEWIC 2011). Blue sharks are highly migratory across the Atlantic and therefore, the decline in abundance cannot be attributed primarily to fisheries in Canada's Atlantic waters; however, they do contribute to the overall reduction (Campana et al. 2006). Using satellite pop up tags, post-release mortality for blue sharks has been measured at around 19% (Campana et al. 2011). Extrapolating these results to the entire Canadian fishery by using observer reports, Campana and others (2011) estimated that 500 t of discarded blue shark can be expected to die annually from activities associated with commercial fishing. The same study found that 30 t of discarded porbeagle and 10 t of discarded mako would also be expected to die. **Figure 5-9** provides a summary of total catch mortality by source for blue sharks caught in Atlantic Canadian waters.

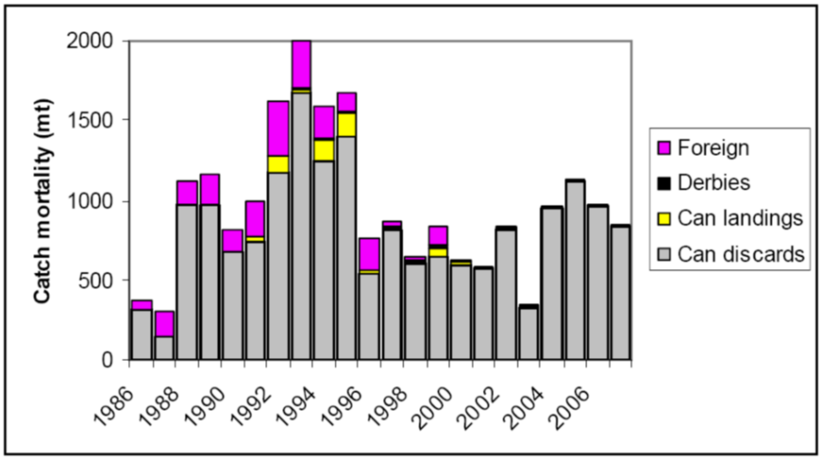

Figure 5-9: Total catch mortality by source for blue sharks caught in Atlantic Canadian waters (Fowler and Campana 2008).

Cetaceans and Other Marine Mammals: The Scotian Shelf provides habitat for a number of marine mammals, many of which are threatened or endangered. These include the right whale, blue whale (*Balaenoptera musculus*), northern bottlenose whale (*Hyperoodon ampullatus*), minke whale (*Balaenoptera acutorostrata*), fin whale (*Balaenoptera physalus*), dolphins (*Delphinus* spp., *Lagenorhynchus* spp.), and the grey seal (*Halichoerus grypus*). Both fixed and mobile gear can have impacts on these species. Whales, in particular, are of concern with respect to impacts caused by fishing gear. While the exact mortality rates and impacts are difficult to measure, examples of mortality caused by drowning, emaciation, increased drag, infections from tissue damage, and other impacts of entanglement have been observed in populations of many whale species (Moore and van der Hoop 2012). Through photographic surveys, Knowlton et al. (2012) estimated that the average rate of entanglement of right whales was 19% in 2009. Vessel strikes have had the greatest impact on the right whale. Overfishing of this species in the early 1900's had reduced the population greatly and vessel strikes are hindering the ability for the population to grow. Between 1970 and 2007, vessel strikes accounted for 37% of the known right whale mortalities (Brown et al. 2009).

Sea Turtles: The two sea turtle species known to inhabit Scotian Shelf waters are the leatherback (*Dermochelys coriacea*) and the loggerhead (*Caretta caretta*), although there are also a small number of reports of green turtle (*Chelonia mydas*) sightings (James et al. 2004). For sea turtles, the fishing gears that pose the largest threat are gillnet, longline and trawl (Wallace et al. 2010). On the Scotian Shelf, sea turtle bycatch has been observed mainly in the swordfish longline fishery. While it is possible that sea turtles may be released live resulting in some survival, generally it is believed that loggerheads have a post-release mortality rate between 17 and 42% (Wallace et al. 2008). **Figure 5-10** shows bycatch estimates for loggerhead turtles in the entire eastern Canadian pelagic longline fishery. There is some variability in the number of turtles caught each year which could suggest a gap in data collection or reflect changing numbers of vessels in the longline fishery.

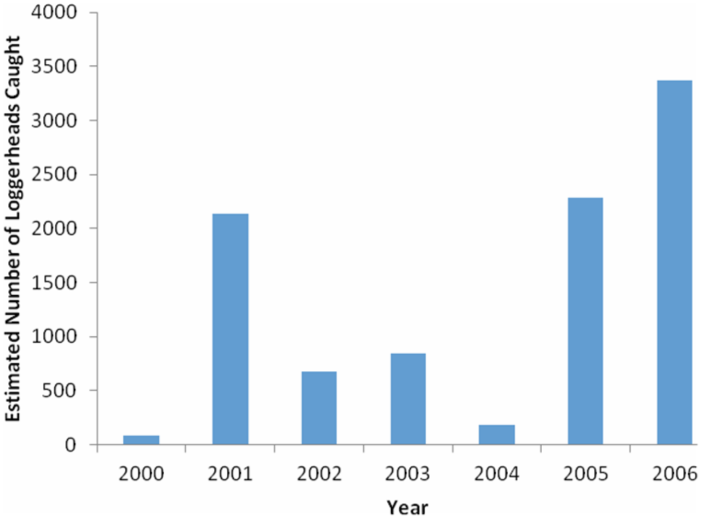

Figure 5-10: Estimated number of loggerheads captured through the eastern Canadian pelagic longline fishery, which includes an area beyond the Scotian Shelf (adapted from Brazner and McMillan 2008).

Corals and Sponges: There are several areas on the Scotian Shelf that have been identified as areas of high density and distribution of cold-water corals and sponges. The Northeast Channel and Lophelia Coral Conservation Areas and the Gully Marine Protected Area were designated to protect cold water corals. However, the locations of corals are not well understood and certain species are more sensitive than others to bycatch and precatch loss. Trawling is considered most damaging as it can clear entire coral colonies in one drag, but some passive gear can result in smothering or partial breakages (Freiwald et al. 2004; Hall-Spencer et al. 2002). In the waters off Nova Scotia's coast, trawling, bottom-set gillnet, bottom-set longline, and pot and trap fisheries pose the greatest threat to coral populations.

Seabirds: The threats that fishing activities, particularly longlining, pose to seabird populations have been deemed to be a large problem throughout the world's oceans. The Scotian Shelf hosts seasonally important habitats for global populations of thick-billed murres (*Uria lomvia*), common murres (*Uria aalge*), dovekies (*Alle alle*), shearwaters (*Puffinus* spp.) and storm-petrels (*Oceanodroma* spp.) (Hedd et al. 2011). Some studies have been done to better understand the impact that pelagic longline fisheries are having on global bird populations. The seabirds are attracted to the baited longline hooks and discharged offal (Tuck et al. 2011). Seabirds can die as a result of swallowing hooks and drowning. However, seabird mortalities can be avoided if the baited hooks are sunk before they are visible to birds or if the hooks are deployed in such a way that seabirds are unable to access the hooks (Bull 2007). While some seabird mortality does occur on the Scotian Shelf as a result of pelagic longline fisheries, the impact on bird populations is relatively minimal when compared to other countries (Anderson et al. 2011).

Estimates of seabird mortality as a result of vessel-source discharges in Atlantic Canada are as high as 300 000 birds per year (Weise 2002). A long term study on Sable Island conducted 93 surveys for bird carcasses from April of 1996 to May of 2005 (**Figure 5-11**). The majority of the alcids (e.g., murres and puffins) were found between December and April and the majority of the shearwaters were found between June and August. The artificial light produced by oil platforms has the greatest impact on seabird populations during migration periods. While it is known that artificial lights on the platforms does cause incidental mortality, the actual number of birds that are killed has not yet been investigated (Weise et al. 2001).

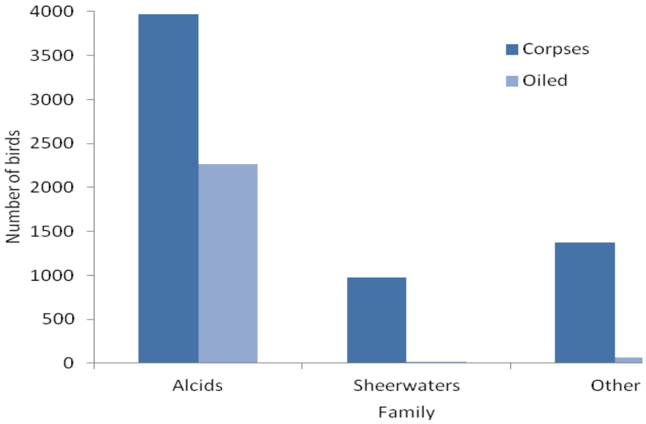

Figure 5-11: The number of bird carcasses found on Sable Island and the number of those carcasses that were oiled from April 1996 to May 2005 (adapted from Lucas and MacGregor 2006). The "other" category included gulls, loons, gannets, and other bird species.

5.4.2 Species at Risk

Incidental mortality is considered a key threat to the recovery of some species listed under the *Species at Risk Act* (*SARA*), as well as others that are considered "at risk" by COSEWIC. Incidental mortality is considered a threat to the recovery of several species found on the Scotian Shelf, such as the right whale (vessel strikes, entanglement in fishing gear), blue whales (vessel strikes, entanglement in fishing gear), and wolffish (bycatch). Leatherback turtles are a summer resident on the Scotian Shelf and are listed as endangered under the *SARA*. While the main threat to endangered leatherback turtles is damage to their tropical beach nesting sites, they are susceptible to entanglement in fishing gear (ALTRT 2006), vessel strikes and often ingest plastic bags.

Several species of sharks and skates found on the Scotian Shelf have been assessed as species at risk by COSEWIC, including the basking shark, blue shark, porbeagle shark, six-gill shark, smooth skate, spiny dogfish, spinytail skate, white shark, and winter skate (DFO 2007a) (see *At Risk Species*). All these species are or have the potential to be caught as bycatch in fisheries. Other fish species considered to be depleted are discussed in the population section (5.4.1) above.

5.4.3 Community Structure and Biodiversity

When a specific species is targeted, either directly or indirectly, through human activities, there can be significant impacts to the specific species population if the activities are not managed, but there can also be impacts on the community structure and environment with which that species may interact. While such impacts are difficult to measure, research on the issue is resulting in a better understanding of the changes that may occur. For example, the incidental mortality of leatherback turtles on the Scotian Shelf could result in a decrease in the population that feeds in the summer months. If the number of turtles feeding on jellyfish is reduced, it is possible that the jellyfish populations could increase and out-compete other pelagic species.

Ecosystems may also be impacted from habitat alteration, disturbance or destruction that can be caused by bottom-contacting fishing gear, oil and gas activity and submarine cables. Habitat loss can lead to indirect mortality of species that were reliant on that habitat (see *Marine Habitats and Communities*). For example, a direct impact of incidental mortality is the loss of coral from fishing efforts. Coral is bycatch in many fisheries, but also provides habitat for many species and again, loss of habitat can lead to mortality or reduced productivity of species that were reliant on that habitat.

5.5 ACTIONS AND RESPONSES

International organizations, the federal government, industry groups and other organizations have worked to reduce levels of incidental mortality in various marine activities. The following provides an overview of some of the responses to incidental mortality that are occurring at an international, national and local or non-governmental level.

5.5.1 International Commitments

Bycatch: Within the past decade or so, the international community has begun to address incidental mortality due to fisheries bycatch. The Food and Agriculture Organization of the United Nations (FAO) has developed International Guidelines on Bycatch Management and Reduction of Discards (FAO 2011) but generally, responses to this issue tend to be species specific. For example, as the global populations of sharks has declined, the FAO developed the International Plan of Action for the Conservation and Management of Sharks (IPOA – Sharks) which was implemented in 1999 (Techera and Klein 2011; FAO 2012b). The IPOA-Sharks is a voluntary strategy whereby countries who sign on commit to developing national plans to reduce levels of shark bycatch (FAO 2012b). In response to the FAO's initiative, Canada developed a National Plan of Action for the Conservation and Management of Sharks in 2007 (DFO 2007a). Along with providing an overview of shark and skate populations and status in Canadian Atlantic, Pacific and Arctic waters, the Plan identifies ways in which efforts will be made to reduce shark and skate bycatch levels including improving regulatory frameworks and enhancing reporting measures (DFO 2007a). In addition to the IPOA – Sharks, the FAO has also developed an International Plan of Action for Seabirds (IPOA – Seabirds) (FAO 2012c). Canada has joined this initiative as well through the development of the National Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (DFO 2007b). International regulatory frameworks, even if they are voluntary, can be effective in encouraging the development of management plans on a national scale.

In addition to the FAO, regional fishery management organizations (RFMOs) have taken steps toward developing guidelines to reduce incidences of bycatch. For example, international tuna fisheries have been identified as one of the main sources of bycatch for seabirds, sea turtles, sharks, marine mammals and young or undersized targeted fish (Gilman 2011). As a result, several RFMOs including the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Western and Central Pacific Fisheries Commission (WCPFC) have identified and encouraged the use of best practices through gear modification and changes in fishing methods (Gilman 2011). While these are important changes, some researchers have suggested that these methods only prevent bycatch of particular species but do not reduce bycatch of others (Gilman 2011), suggesting there is still much work to be done through RFMO regulatory measures.

Precatch Losses and Ghost Fishing: The exact effects and extent of precatch losses and ghost fishing are yet to be understood. Due to this lack of information, international measures directly addressing precatch losses and ghost fishing are somewhat limited. FAO's International Guidelines on Bycatch Management and Reduction of Discards (FAO 2011) recommend that nations and/or RFMOs should adopt measures for reducing precatch losses and ghost fishing through the development of technologies, adoption of gear modifications and improved retrieval procedures (FAO 2011). The FAO acknowledges that much more information and research is needed to understand the full effect of these activities and encourages nations to complete such research.

Entanglement: There have been some initiatives to help reduce entanglement in the region. The World Wildlife Fund (WWF) works with fishermen and other non-governmental organizations (NGOs) in Atlantic Canada to raise awareness about the impacts of fishing gear on the right whale and has held workshops with fishermen to help develop methods of setting gear that are likely to have the lowest impact on right whales (WWF 2010). Additionally, the Canadian Sea Turtle Network has developed a partnership with fishermen throughout Nova Scotia to help raise awareness about leatherback turtles and provide instruction on how to free a leatherback from gear safely.

Vessel Strikes: The International Maritime Organization (IMO) is the main regulatory body for international marine transportation. The IMO has the capacity to facilitate and implement changes to vessel traffic to reduce the risk of vessel strikes on whales in response to applications put forward by member governments. Canada is a member government of the IMO and has had successful applications through the IMO to designate North Atlantic right whale habitat in the Roseway Basin on the Scotian Shelf as an Area to be Avoided by vessels (Vanderlaan and Taggart 2009). The IMO has also produced a document that provides guidance to mariners on how to reduce the risk of vessel strikes on whales (IMO 2009).

Vessel-Source Discharges: The International Convention for the Prevention of Pollution from Ships (MARPOL), of which Canada is a signatory, sets standards for discharges from ships and also deals with ship-source pollution from accidents. This convention prohibits the discharge of bilge water into the marine environment that contains oil concentrations over 15 parts per million (Gard 2011).

Marine Waste and Debris: The impacts that marine waste and debris have on marine ecosystems are slightly different from those of other activities mentioned throughout this report since they generally occur over an extended period of time. MARPOL directly addresses and prohibits the disposal of plastics and garbage from ships in Annex V (IMO 2012b). Despite this international regulation, it is estimated that ships still discard approximately 6.5 million tons of plastic per year (Derraik 2002).

5.5.2 Federal and Provincial Policy and Legislation

Bycatch: Aside from the national action plans discussed previously, Canada employs other policies and legislation in an effort to reduce bycatch. Section 33 of the Fishery (General) Regulations (FGR) (1993) requires that any fish caught incidentally must be returned to the place where it was retrieved, but states that exceptions can be made where specified (e.g., Atlantic Fishery Regulations). Furthermore, in an effort to prevent high-grading, Section 34 of the FGR states that the dumping of fish caught in accordance with the *Fisheries Act* is prohibited. Measures such as the mandatory release of incidental catch and the mandatory retention of target species are designed to reduce the incidences of bycatch and are explicitly outlined in the FGR. Some examples of other measures used in specific fisheries to reduce bycatch are described below.

There are a number of strategies for specific fisheries that have been implemented to reduce bycatch. Integrated fisheries management plans (IFMPs) have been created by DFO in an effort to "guide the conservation and sustainable use of marine resources" (DFO 2012a). Many IFMPs describe measures to prevent bycatch in a particular fishery and improve post-release survival. For example, in the IFMP for Canadian Atlantic Swordfish and Other Tunas, a management measure for maintaining species diversity is to minimize incidental mortalities on non-targeted species. Other measures within the swordfish and tuna fishery that are used to reduce bycatch include size requirements, proper handling and release of species at risk (such as leatherback turtles), the use of circle hooks, and practicing live release (DFO 2012b). While there are numerous measures in place to reduce bycatch, more research is needed to fully understand the impacts of this fishery.

Lastly, gear modifications and licence conditions for specific fisheries have been designed to promote sustainable fishing, and in some cases, minimize incidences of bycatch. For example, undersized crab and small non-target species have been identified as the bycatch species for the snow crab fishery. As a result, a condition of snow crab fishing licences is that undersized or non-target species be subject to a mandatory release and gear must conform to size restrictions in order to prevent undersized catch. There have also been gear modifications in the scallop fishery that have resulted in a reduction of groundfish bycatch while maintaining the same amount of scallop catch (DFO 2009). Several other fisheries throughout the Scotian Shelf are required to follow similar regulations and gear modifications.

Precatch Losses and Ghost Fishing: Nationally, there are no policies directly related to the regulation of precatch losses and ghost fishing. However, there are some that indirectly address these issues. For example, the Policy to Manage the Impacts of Fishing on Sensitive Benthic Areas was developed by DFO in an effort to reduce impacts from fisheries on benthic marine ecosystems. Protection of these ecosystems is achieved through such measures as fisheries closures, gear restrictions and gear modifications (DFO 2012c). In addition, some IFMPs and national management plans require fish harvesters to label their gear and in some cases, fish harvesters may be fined for lost gear. Biodegradable panels or materials are also required for the gear in particular fisheries (e.g., snow crab) so that if gear is lost, it does not ghost fish for much longer than a regular fishing season.

Vessel Strikes: A right whale recovery strategy has been developed through *SARA* that addresses the many threats to right whales, including vessel strikes (Brown et al. 2009). The objective is to reduce vessel strikes by obtaining a better understanding of the risks associated to right whales from vessels and creating management strategies that help to reduce those risks through collaboration with the shipping industry (Brown et al. 2009). An example of one of these collaborative management strategies is the Coast Guard "Notice to Mariners," which provides information on the Roseway Basin Area to be Avoided.

Vessel-Source Discharges: Canadian law and regulations implement the marine pollution provisions of MARPOL. Transport Canada enforces the Vessel Pollution and Dangerous Chemicals Regulations (2012) under the *Canada Shipping Act*, which prohibits vessels within Canadian waters and Canadian vessels in other waters from releasing bilge water that contains oil concentrations above 5 parts per million.

Large Oil Spills: The *Emergency Management Act* assigns the Minister of Public Safety the responsibility for managing response efforts during an environmental emergency. The minister is also responsible for assessing environmental response management plans and strategies. The Federal Emergency Response Plan works to harmonize the response efforts between all organizations and parties involved in environmental emergency response (Government of Canada 2011). The Canadian Coast Guard is one of the first responders in the event of an oil spill and they have stores of equipment across the region. There are also private companies, such as the Eastern Canadian Response Corporation (ECRC) that are fully equipped to respond to a spill event to aid the Canadian Coast Guard. In the Maritimes Region, a group of federal, provincial and non-governmental departments and organizations, known as the Regional Environmental Emergencies Team (REET), are called together in the event of a spill to share information and plan the response activities (Environment Canada 2012).

In addition to the emergency response described above, the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and associated legislation and regulations are responsible for environmental protection during all phases of offshore petroleum activities. The CNSOPB requires all offshore operators to have an Environmental Protection Plan in place and be able to demonstrate that they are able to respond to an environmental emergency, if one were to occur (DFO 2011d). They set standards for environmental protection during offshore oil and gas development and conduct environmental assessments for offshore projects (CNSOPB 2012c).

Other Petroleum Industry initiatives: The provincial and federal government agencies that are involved in offshore oil and gas activities have worked together to develop the Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment (Government of Canada 2007). This statement is targeted mainly towards marine mammals, and while it is known that seismic activity causes behavioural changes in marine mammals, it still remains unknown whether it actually causes incidental mortality. However, this initiative is a precautionary approach to conducting this activity and lowers the overall impact on marine mammals.

Marine Waste and Debris: In addition to MARPOL Annex V, which Canadian vessels are also expected to adhere to in an effort to reduce waste and plastics from entering the oceans, Section 98 of the *Vessel Pollution and Dangerous Chemicals Regulations* (2012) under the *Canada Shipping Act* (2001) addresses marine debris. Additionally, the *Canadian Environmental Protection Act* also regulates vessel pollution. While both laws address various aspects of marine waste and debris disposal, there are concerns with enforcement and compliance (Derraik 2002).

5.5.3 Industry and Community Led Initiatives

Bycatch: The fishing industry itself is engaging in activities to lessen bycatch. These measures range from being somewhat formal to informal (e.g., avoiding areas where they have experienced a lot of bycatch). There are also initiatives between DFO and the fishing industry to work together on research projects to examine bycatch patterns in an attempt to mitigate the issue (DFO 2012c). Within the swordfish/tuna fishery, licence holders must take a turtle handling certification course and have dehooking gear on board their vessel in order to reduce post-release mortality.

In 2013, the groundfish fishing industry in the Maritimes Region implemented a conservation strategy for skate species. This strategy includes the development of a laminated card providing fish harvesters with best practices for handling live skates, a skate identification guide to improve accurate reporting of discarded skate species and a recommended move-away protocol when encountering large quantities of thorny skate. The industry has also implemented a measure requiring the mandatory release of thorny skates by all groundfish vessels.

Some international NGOs are attempting to develop creative solutions to encourage a reduction in bycatch levels. WWF International launched the International Smart Gear Competition in 2004 which encourages fishermen and industry to develop cost-effective and innovative ways to modify fishing gear or practices to reduce bycatch (WWF 2012). WWF then works with industry and other relevant parties to test and begin implementation of winning ideas.

Ghost Fishing: In an effort to eliminate impacts from ghost fishing caused by derelict lobster traps, DFO staff and local fish harvesters came together to recover more than 500 “ghost” lobster traps from Saint John Harbour in New Brunswick (Recchia 2010). The fish harvesters helped to identify areas where they suspected traps would have been lost. They were then collected by the harvesters themselves and fisheries officers. Harvesters do not want to lose their gear because it can be costly to them, so they are willing to adhere to regulations to reduce the loss of gear and may also develop measures of their own. Transmitting devices can be attached to gear to allow for retrieval if it is lost.

Vessel Strikes: The voluntary area to be avoided on the Scotian Shelf set up by the IMO is largely complied with by industry and the majority of vessels now avoid the Roseway Basin (Vanderlaan and Taggart 2009).

Large Oil Spills: Response to large oil spills that occur as a result of a tanker accident are in part the responsibility of the International Tanker Owners Pollution Federation (ITOPF) (ITOPF 2010). Members of ITOPF pay a fee and in the case of an accident, members receive response aid in the form of funding or physical response efforts from the federation. For offshore oil and gas operations, the International Petroleum Industry Environmental Conservation Association (IPIECA) provides information to operators on best practices for the industry (IPIECA 2012). Nationally, the Canadian Association of Petroleum Producers (CAPP) works to prevent spills through responsible operations, but also responds to spill events (CAPP 2012).

Marine Waste and Debris: Some local initiatives aim to reduce marine waste and debris on the Scotian Shelf. For example, the Ship to Shore program developed by Clean Nova Scotia works with Nova Scotian fishermen to encourage them to transport garbage back to shore instead of throwing it overboard (Clean Nova Scotia 2012).

5.6 INDICATOR SUMMARY

Indicator	DPSIR Element	Status	Trend
Number of oil and gas developments on the Scotian Shelf	Pressure	Good – Currently 7 offshore platforms operating on the Scotian Shelf.	No trend – Less activity than there has been in the past; however, it is expected to increase.
Amount of commercial vessel traffic on the Scotian Shelf	Pressure	Fair – A large number of vessels currently transit the Scotian Shelf; potentially causing incidental mortality.	Unknown – Systems for tracking and analysing the number of vessels transiting the shelf have only recently been put in place.
Vessel discharges of oily substances	State	Good – Discharges and spills are monitored by NASP	Unknown – Difficult to track; likely less oil entering the environment in the last 10 years because of regulations and monitoring.
Non-target fish species as percent of total catch (groundfish fishery)	State	Fair – Non-target fish species make up about 12% of the total catch in the western Scotian Shelf haddock fishery	Unknown – Needs to be tracked over a longer time period.
Non-target species as percent of total catch (shrimp fishery)	State	Good – Bycatch is currently estimated at less than 2% in the Scotian Shelf shrimp fishery.	Improving – Before the early 1990s, there were high levels of bycatch.
Number of depleted species and species at risk where a threat to recovery is incidental mortality	Impact	Poor – Currently 17 marine species listed under SARA; many other species are considered depleted.	Worsening – No species have recovered and others have been assessed by COSEWIC as “at risk.”
Number of oiled seabirds in beach surveys	Impact	Poor – More than 2000 oiled birds were collected in Sable Island beach surveys, 1996-2005.	Unknown – No information over a long time period.
Changes to community structure of marine ecosystems due to incidental mortality	Impact	Unknown – Difficult to attribute observed changes to incidental mortality; however, changes have been seen elsewhere and may be occurring on the Scotian Shelf.	Unknown
Integrated fisheries management plans	Response	Good – There are IFMPs which address incidental mortality for most Scotian Shelf fisheries.	Improving – Efforts to reduce incidental mortality are included in most IFMPs.

Data Confidence

- For commercial fisheries, landings of target and bycatch species are recorded in fishing logs; fisheries observer data is a good source of information on a variety of species that are returned to the water.
- The Canada-Nova Scotia Offshore Petroleum Board tracks discharges by offshore oil and gas operations.

Data Gaps

- Much of the knowledge of non-retained bycatch is from observer data. Fish harvesters may change their fishing practices when observers are aboard, thus it is not clear if observer data represents a “true” picture of bycatch. Determining how much mortality is actually occurring is difficult.
- Enforcement of vessel discharges and other sources of pollution is difficult; NASP data is patchy and has more effort where there have been incidents (e.g., grounding of vessels, known accidental discharges).
- Information on impacts of many of the pressures addressed in this report is patchy; there are no regular systematic surveys, e.g., of oiled seabirds or animals entangled in marine debris.
- Vessel strikes sometimes go unreported.

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6. INVASIVE SPECIES[14]

Greg Klassen, Tau Biodiversity, Pollett, NB

6.1 ISSUE IN BRIEF

Introductions of non-native species, and the biological invasions that may result, are increasingly considered to threaten native biodiversity in the marine environment (Carlton and Geller 1993; IUCN 2000). Worldwide, the number of introduced marine species continues to grow in a linear or even exponential manner (Boudouresque et al. 2005). Species introductions are sometimes called a form of "biological pollution," but unlike some other forms of pollution the introduction of a species is generally irreversible, and the impact does not decrease over time nor with distance from the source, but instead can continue to increase in spatial scale and intensity over time.

The damage caused by invasive species to native species and ecosystems is known to cause biodiversity loss (IUCN 2000). Some invaders are "ecosystem engineers" with the potential to permanently change ecosystems and habitat (Crooks 2002). Competition with or predation upon native species, or the introduction of diseases (pathogens) or parasites, can alter food webs and the flow of nutrients within ecosystems. While marine species have most likely been transported by human activities for as long as humans have moved around the world, the volume and frequency of transport has intensified in the past several decades (Carlton and Geller 1993).

Linkages

This theme paper also links to the following theme papers:

- Climate change and its Effects Ecosystems, Habitats and Biota
- Species at Risk

At least 22 introduced species are documented from the Scotian Shelf, and to date at least seven of these have demonstrated ecological and/or economic consequences in the region, and are most likely invasive. Pressures such as global and local shipping, recreational boating, aquaculture, climate change, habitat disturbance and facilitation by established introduced species will continue to inoculate, and enhance the establishment of, non-indigenous species to the Scotian Shelf (**Figure 6-1**). As these processes continue, and research leads to greater understanding of the non-indigenous species already present, it is likely that more introduced and invasive species will be added to this list in the future. Management of invasive species on the Scotian Shelf has only recently been initiated, and should benefit from ongoing regulatory reforms at the international, federal, and provincial level.

Term	**Definition**
Introduced, exotic, alien, non-native or non-indigenous species	*Any species intentionally or accidentally transported and released by humans into an environment or facility with effluent access to open-water or flow-through system outside its present range*
Invasive species	*A non-indigenous (non-native) species, the introduction of which into an ecosystem may cause harm to the economy, environment, human health, recreation, or public welfare*

Source: A Canadian Action Plan to Address the Threat of Aquatic Invasive Species (CCFAM 2004).

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[14] Completed April 2012.

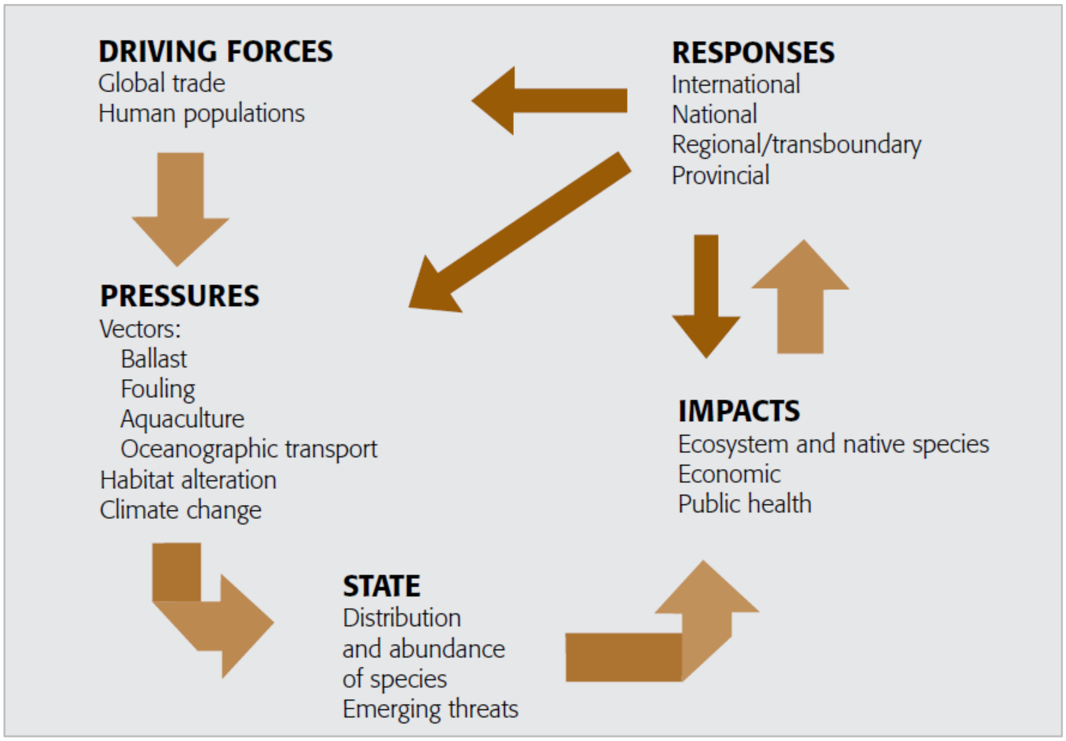

Figure 6-1: Driving forces, pressures, state, impacts and responses (DPSIR) to marine invasive species on the Scotian Shelf. The DPSIR framework provides an overview of the relationship between the environment and humans. According to this framework, social and economic developments and natural conditions, as driving forces, exert pressures on the environment which result in changes in the state of the environment. Resultant impacts on ecosystems, economy, and human health may elicit government or societal responses that modify the driving forces or pressures.

6.2 DRIVING FORCES AND PRESSURES

For millennia, natural barriers such as oceans provided isolation in which unique species and ecosystems evolved. However, in the past century, major global forces have combined to breach these barriers (IUCN 2000). The number of introduced species in an ecosystem is a function of both the supply of potential invaders, and the susceptibility of the ecosystem to invasion (Crooks et al. 2011). Drivers of biological invasions operate at several scales and levels, for example increase of trade operates at the regional or global scale, and factors resulting in fragmentation or disturbance of ecosystems at the local scale (Rodriguez-Labajos et al. 2009). Globalisation and growth in the volume of trade, an increasing emphasis on free trade, and improvements in the speed of transport combine to move species more effectively than ever before. Disturbances to the receiving ecosystem, whether due to global forces such as climate change, or regional pressures on habitats, may make it easier for the inoculated species to become established. The presence of non-indigenous species already established in the ecosystem may also increase the likelihood of survival and establishment of newly arrived non indigenous species, a process known as facilitation (Simberloffe and Von Holle 1999). For example, the growth of the invasive coffin box bryozoan *Membranipora membranacea* on kelp *Laminaria* sp. on the Scotian Shelf made the kelp prone to breakage and facilitated the invasion of kelp beds by a second invasive species, the oyster thief alga *Codium fragile fragile* (Scheibling and Gagnon 2006).

The driving forces that influence the supply of potential invaders are mainly associated with human activities (because for a species to be considered introduced, it must have been transported by humans to a region which it could not have reached by natural dispersal), and cannot be separated from underlying socio-economic development processes (Rodriguez-Labajos et al. 2009). A species that is subsequently dispersed from an area into which it has been introduced, into another area that was not part of the native range, even if this dispersal occurs by natural means such as oceanographic currents, is still considered an introduced species in the second area. In contrast, the dispersal by natural means of a species from its native range, in the absence of human-assisted transport, is considered a range expansion.

6.2.1 Global Trade and Shipping

Commercial shipping is considered to be one of the most significant vectors of introduction for non-indigenous aquatic species. More than 80% of global trade moves by ship, and the merchant shipping fleet grew by 8.6% in 2010 (United Nations Conference on Trade and Development, 2011). An increase in the volume and frequency of ocean crossing vessels since the 1970s is correlated with increased worldwide introductions of non-indigenous species near the close of the 20th century (Carlton 1996). Ship-based vectors of invasive species include ballast water and sediments in the ballast tank, bilge water, and fouling of hull, sea chest/water intake, anchor, chain, and propeller shaft.

A large number of commercial vessels originating from outside Canada’s Exclusive Economic Zone pass through waters of the Scotian Shelf, either bound for ports in Nova Scotia or to other locations in Atlantic Canada or the Great Lakes. Ports in Nova Scotia (Halifax, Little Narrows, Liverpool, Mulgrave, Point Tupper, Port Hawkesbury, Sheet Harbour, Shelburne, Sydney and Yarmouth) receive between 1000 and 2000 international ship arrivals annually (Kelly 2004). Halifax is the major port in Atlantic Canada (**Figure 6-2**). Most of the international arrivals originated from the east coast of the USA or Western Europe.

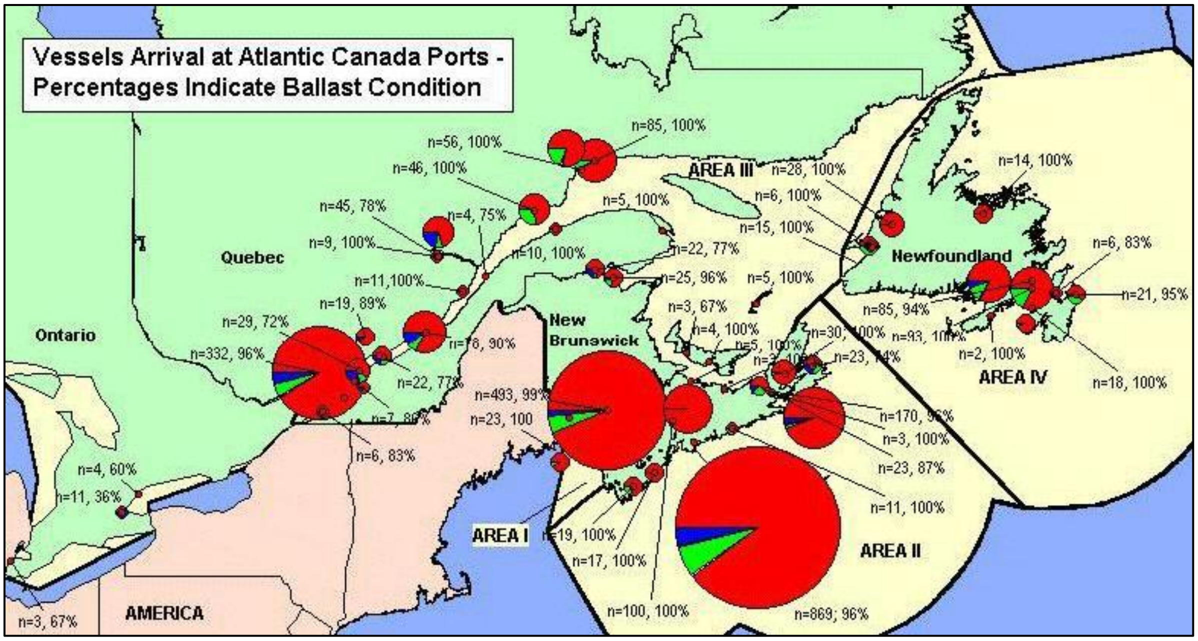

Figure 6-2: International vessel arrivals in ports of Atlantic Canada in 2002. Halifax, the largest port, had 869 vessel arrivals, of which 96% were in full or partial ballast. In the pie chart, red indicates partial ballast, green full ballast, and blue no ballast (Kelly 2004).

6.2.2.1 Ballast Water: Ballast water samples from 86 ships arriving from international ports and sampled in the St. Lawrence Seaway in 1991-1992 contained three diatom and ten dinoflagellate species not recorded from Atlantic Canada, out of a total of 102 taxa identified (Subba Rao et al. 1994). In all, 21 potentially bloom-forming, red tide and/or toxic genera were represented in the samples.

Ballast water sampling of 98 ships arriving in Atlantic Canada in 2001-2002 found 349 phytoplankton taxa, of which 44% were indigenous, 25% were non-indigenous, and 31% were of unknown geographic affiliation (Carver and Mallet 2004). Twenty taxa were classified as toxic or harmful, of which seventeen taxa were known to accumulate in shellfish and cause gastrointestinal or neurological illnesses in consumers and the remaining three taxa were known to cause fish kills. In total, five taxa were non-indigenous. Another 33 phytoplankton taxa were assigned to a "possible concern" category, e.g., bloom-forming species, or members of a genus in which other species were known to be toxic or harmful. In the same study, 75 microzooplankton species were detected, but were not identified to species and could not be evaluated for risk (Carver and Mallet 2004).

Sampled ballast water in 63 ships arriving in Atlantic Canada in 2007-2009 contained 96 taxa of zooplankton, of which 10% were non-indigenous (DiBacco et al. 2011). The samples were dominated by copepods, which accounted for 89% of zooplankton density. Ballast sediments (i.e., the sediments on the bottom of the ballast tanks) in these vessels contained the cysts of 14 non-indigenous dinoflagellate species not yet recorded from Canadian waters, including four harmful and/ or toxic species (Casas-Monroy et al. 2011).

6.2.1.2 Hull fouling: Hull fouling is another important vector of invasions. In Halifax, video analysis of the hulls of 20 commercial vessels (average length 220 m) found that on average each hull carried 3,618 individuals belonging to 15 species. On average, each hull carried 3.2 non-indigenous species not yet established in the region (Sylvester et al. 2011). Further, with the international ban on tributyltin (TBT)-based antifouling hull paints in 2003, hull fouling has the potential to increase in the future. Decreased use of TBT-based paints has been correlated with increased hull fouling (Carlton 2001).

Exploration or oil production may increase shipping pressures on the Scotian Shelf. Shipping traffic would increase and many of the ships would be arriving in ballast (for example, 85% of vessels arrived at the oil refinery at Come-by-Chance, NL, in ballast; Blakeslee et al. 2010). Depending on the source of the ballast water, this could increase the risk of novel species introductions. In addition to increasing shipping pressure, oil and gas platforms are also a vector for transport of invasive species. Non-indigenous species are often present on oil drilling platforms (Page et al. 2006), which would be towed to the region. Rigs then often remain anchored in one location for extended periods of time, becoming colonized by hull foulers as a sort of artificial reef, before being moved to the next drilling site. Drilling rigs also use ballast water to control stability and buoyancy similar to ships.

6.2.2 Aquaculture

Long-distance transfers of species brought into new areas for aquaculture have often been responsible for species introductions, including intentionally introduced species, as well as "hitch-hiking" epibionts and parasites (Ruiz et al. 2000). This is unlikely to be a factor in introductions to the Scotian Shelf at present; international transfers of shellfish for aquaculture took place in previous decades but have not occurred recently (Locke et al. 2007; A. Locke, pers. comm.).

6.2.3 Climate Change

Climate change may affect both the likelihood of uptake of species at their place of origin, and their likelihood of establishing a viable population if released on the Scotian Shelf. For example, ocean conditions may be linked to annual variations in the population size of European green crab (Yamada and Kosro 2010). Global warming may reduce or eliminate oceanic temperature "barriers" to dispersal (see *Climate change and its effects on ecosystems, habitats and biota*), or alter the relative competitive abilities of native versus non-native species. Recently invaded tunicate species in New England outcompete and overgrow native tunicates and tunicate species that invaded New England more than two decades ago in years with above-average temperatures, but rarely do so in below-average temperatures (Stachowicz et al. 2002). Climate change may also enhance the establishment of tropical and subtropical species carried to the Scotian Shelf in the warm Gulf Stream (Wroblewski and Cheney 1984). Typically these survive in Nova Scotian waters for short periods only, and do not overwinter (Markle et al. 1980). Finally, climate change may allow an introduced species to become invasive, perhaps even after decades of presence as an apparently harmless addition to the local biota, if the altered climate provides better growing conditions for the species (Witte et al. 2010).

6.2.4 Regional or Local Scale Pressures

Local movement of smaller vessels is often implicated in the spread of non-indigenous species from an initial point of introduction. Shipping vectors involved in local dispersal are likely to be fishing vessels, recreational boats, slow-moving barges, or dredging rigs moving between ports or fishing grounds. Commercial tuna fleets, for example, move between the Scotian Shelf and Prince Edward Island seasonally (Locke et al. 2007). Recreational vessels often move frequently between ports, both by water and over land on trailers (Darbyson et al. 2009). Some of the larger vessels carry ballast water, but the fouling of hulls or other gear is more likely to be involved in local transport (Darbyson et al. 2009).

Local aquaculture transfers frequently take place within Nova Scotia or between Nova Scotia and neighbouring provinces. Elsewhere, bivalve aquaculture transfers have been implicated in the transport of several tunicate species (Carver et al. 2006a, b). Cyst-forming toxic and nuisance phytoplankton may commonly be transported in the guts of transferred bivalves (McKindsey et al. 2007).

6.2.5 Oceanographic Conditions and Habitat Alterations

Oceanographic transport of non-indigenous species is more likely to occur at the local than at the global scale. Species which could be carried on ocean currents include planktonic species, species with planktonic larval stages, as well as species carried on floating marine debris (e.g., discarded/lost fishing or aquaculture gear and plastics) or floating vegetation (e.g., macroalgae, grasses, etc.).

Pollution or habitat disturbance can aid the establishment of non-indigenous species (Bando 2006). Many non-indigenous species live in a wide variety of habitats (which allows them to readily adapt to new environments) or are tolerant to disturbed environments (for example, polluted harbours, from which they may be transported by ships). Sometimes native species are less well-adapted to adverse conditions and are outcompeted by the new arrivals.

6.3 STATUS AND TRENDS

6.3.1 List of Species

Significant information gaps exist with respect to the introduced or invasive species of the Scotian Shelf. No formal species list has ever been compiled. The species listed **in Tables 6-1 and 6-2** present a conservative picture of 22 known introductions on the Scotian Shelf and almost certainly underestimate the introduced flora and fauna of the region. For most of these species, insufficient data exist to describe the abundance, trends and range distribution. Targeted monitoring programs for marine invasive species in Nova Scotia focus primarily on tunicates (in particular, trends in *Botrylloides violaceus*, *Botryllus schlosseri* and *Ciona intestinalis* populations, and surveillance for new species inoculations) (Sephton et al. 2011) and on the European green crab (Tremblay et al. 2005, Vercaemer et al. in prep.). The public is encouraged to report sightings of any unusual species to Fisheries and Oceans Canada (http://www.qc.dfo-mpo.gc.ca/publications/envahissant-invasive/carnet_anglais.pdf).

Table 6-1: Freeliving species considered to be introduced on the Scotian Shelf (source: Locke and Hanson, unpub. ms.).

Taxon	Species	Common name	Date and place first reported	Reference
Bacillariophyta	*Coscinodiscus wailesii*		2000, central and western Scotian Shelf	Head and Harris 2001
Chlorophyta	*Codium fragile fragile*	Oyster thief, Sputnik weed, Green fleece	1989, Mahone Bay	Bird et al. 1993
Phaeophyta	*Fucus serratus*	Serrated rockweed	1903, Mulgrave	Bell and MacFarlane 1933
	Colpomenia peregrina		1960, Atkins Point (Halifax Co.)	Bird and Edelstein 1978
Rhodophyta	*Bonnemaisonia hamifera*	Hookweed, Pink cotton wool	Late 1960s, Bras d'Or Lakes and Atlantic coast	Chen et al. 1969; McLachlan and Edelstein 1971
	Furcellaria lumbricalis		1989, Chedabucto Bay area	Novaczek and McLachlan 1989
	Neosiphonia harveyi		1992, Mahone Bay	McIvor et al. 2001
	Seirospora interrupta		1983, St. Margarets Bay	Bird and Johnson 1984
Trematoda	*Convoluta convoluta*		1995, near Halifax	Rivest et al. 1999
Mollusca	*Ostrea edulis*	European oyster	1978-1980, Ketch Harbour and East Dover (intentional introduction)	Muise et al. 1986
Crustacea	*Caprella mutica*	Japanese skeleton shrimp	2005, Mahone Bay	Locke, pers. obs.
	Praunus flexuosus	Bent mysid	Before 1980, Nova Scotia zooplankton	Mauchline 1980
	Carcinus maenas	Green crab	1954, Wedgeport	MacPhail and Lord 1954
Bryozoa	*Membranipora membranacea*	Coffin box bryozoan	1992, Mahone or St. Margarets Bay	Scheibling et al. 1999
Ascidia	*Ciona intestinalis*	Vase tunicate	Population outbreak 1997, Lunenburg; may have been present earlier	Cayer et al. 1999
	Botryllus schlosseri	Golden star tunicate	Present "for several decades", Atlantic coast and Bras d'Or Lakes	Carver et al. 2006a
	Botrylloides violaceus	Violet tunicate	2001, Lunenburg and Mahone Bay	Carver et al. 2006b

Table 6-2: Parasitic species considered to be introduced on the Scotian Shelf (Locke and Hanson, unpub. ms.).

Taxon	Species	Common name	Host	Date and place first reported	Reference
Protozoa (Mycetozoa)	*Haplosporidium nelsoni*	MSX	American oyster, *Crassostrea virginica*	2002, Bras d'Or Lakes	Stephenson et al. 2003
Protozoa (Sarcodina)	*Paramoeba invadens*		Sea urchin, *Strongylocentrotus droebachiensis*	1980-1983, southeastern NS	Scheibling and Stephenson 1984; Jellett et al. 1989
Platyhelminthes (Trematoda)	*Prosorhynchus squamatus*		Blue mussel, *Mytilus edulis*	1996, southeastern NS	McGladdery and Stephenson 1996

6.3.2 Emerging Threats

6.3.2.1 Species Present on the Scotian Shelf

***Botrylloides violaceus*, Violet tunicate, and *Botryllus schlosseri*, Golden star tunicate:** Violet and golden star tunicates are similar in ecology although they originate from different parts of the world. Both are colonial tunicates that occur as fouling species on natural and artificial substrates. Natural dispersal is by very short-lived planktonic larvae (maximum duration of larval stage is approximately 36 hours), or by reattachment of budded fragments. Unattached fragments can drift and survive for up to 150 days, and those which are attached to a floating substrate have the potential to survive longer (Carver et al. 2006b). While the short-lived nature of the larvae makes them unlikely to be dispersed in ballast water, it is possible that drifting fragments or colonies could be taken up in ballast water. Both species are well-adapted to dispersal on fouled boat hulls, especially slower boats such as recreational vessels, barges and fishing boats (Carver et al. 2006b). Transfers and harvests of cultured bivalves have also been implicated in the transport of these tunicates (Carver et al. 2006b)

The violet tunicate is a recent arrival in North America, most likely originating in Japan (Carver et al. 2006b). The first observation in Atlantic Canada was in Lunenburg and Mahone Bay in 2001. Golden star tunicate has been present on the Scotian Shelf (Atlantic coast and Bras d'Or Lakes) for several decades and in the Bay of Fundy since approximately 1983 (Carver et al. 2006b). Both species are currently distributed in nearshore waters of the Scotian Shelf from Wedgeport to Dingwall, including the Bras d'Or Lakes (Sephton et al. 2011).

***Ciona intestinalis*, Vase tunicate:** The vase tunicate is a solitary tunicate that is most likely native to northern Europe, but is sometimes considered cryptogenic (of unknown origin) in eastern North America (Carver et al. 2006a). The earliest record in Atlantic Canada dates from 1852, but the species was rarely observed and was not recorded in the scientific literature on the Scotian Shelf until population outbreaks occurred along the southeastern coast of Nova Scotia in the late 1990s (Cayer et al. 1999; Carver et al. 2003). By 2003, it was also reported at aquaculture operations in the Isle Madame area of Cape Breton Island (Carver et al. 2006). Currently, the species occurs in nearshore, sheltered locations along the Nova Scotian coast from Wedgeport to Dingwall, but has not been observed in the Bras d'Or Lakes (Sephton et al. 2011).

The most important means of dispersal of *C. intestinalis* is shipping, especially hull fouling on slow-moving vessels such as barges, fishing or recreational vessels (Carver et al. 2006a). The species can also be transported as a hitchhiker on aquaculture transfers (A. Locke, pers. comm.). There is limited potential for natural dispersal, which occurs by means of non-feeding planktonic larvae that typically remain in the water column for only a few days (Carver et al. 2006a). Juvenile and adult *C. intestinalis* have also been observed to raft on drifting eelgrass *Zostera marin*a and oyster thief *Codium fragile fragile* (Carver et al. 2006a; Kanary et al. 2011).

***Carcinus maenas*, European green crab:** The green crab was first observed on the east coast of North America in Massachusetts in 1817 and was most likely transported from its native range (coasts of Europe and North Africa) in the ballast of ships (Grosholz and Ruiz 1996). This first wave of introductions spread up the coast of New England, reached Passamaquoddy Bay, NB, in 1951, and was first reported on the Scotian Shelf, in Wedgeport, NS, in 1954 (Leim 1951; MacPhail and Lord 1954). Further dispersal up the Atlantic coast of Nova Scotia, however, appeared to “stall” south of Halifax from the mid-1960s to the mid-1970s (Audet et al. 2003). It was speculated that green crab had reached its northern temperature limit in North America. However, by the late 1970s, green crabs were reported at Whitehead, south of Chedabucto Bay, 600 km north of the nearest known population (Audet et al. 2003). It is likely that these crabs represented a second, genetically distinct, introduction of green crabs to North America, which appears to have taken place either in Halifax or Chedabucto Bay, probably by means of ballast water (Roman 2006). By 1997, green crabs were found all along the Scotian Shelf at least as far north as Ingonish and had spread into the Gulf of St. Lawrence (Audet et al. 2003). In 2001, northern Nova Scotia and Gulf of St. Lawrence populations were found to be composed of genotypes found nowhere else in North America; however, populations south of Halifax and into the Bay of Fundy included genotypes from both northern Nova Scotia and the original US form (Roman 2006). The northern Nova Scotia genotypes match those found in the northern part of the green crab’s native range, in Scandinavia and the North Sea (Roman 2006) and appear more tolerant of cold temperatures (A. Locke, pers. comm.). The northern genotypes are also significantly more aggressive, are more effective foragers, and may be outcompeting the US genotype, at least in the northern portion of the North American range (Rossong et al. 2011). Assuming that the northern genotype continues to increase in numbers in southern NS, it is likely that the impacts of green crabs in this area will also increase.

The European green crab is ranked among the 100 “worst alien invasive species” in the world (Lowe et al. 2000). It is a voracious omnivore and aggressive competitor with a wide tolerance of salinity, temperature, oxygen and habitat type (Klassen and Locke 2007). In all areas where the green crab has invaded, its potential for significant impacts on fisheries, aquaculture and the ecosystem has caused concern. Because the green crab has the ability to alter entire ecosystems through habitat modification, predation, and competition, it is considered an “ecosystem engineer” (Crooks 2002). Specific threats to fisheries, observed in Atlantic Canada, include (but are not limited to) predation on bivalves, competition with other decapods, and damage to eel fisheries (Klassen and Locke 2007). Anecdotal accounts suggest that levels of impacts on the Scotian Shelf appear to have increased in recent years, and are likely to continue to increase due to a recent genetic shift in green crab population structure.

> Undoubtedly, man’s activities are partially responsible for the remarkable spread of [green crabs]…I have seen live crabs in crates of live lobsters and have noticed them aboard sardine carriers and fishing boats.
>
> Scattergood, 1952

***Codium fragile fragile*, Oyster thief:** The oyster thief is a green alga that most likely originated in Asia but has been found in shallow, coastal waters of the Scotian Shelf since 1989, when it was first seen in Mahone Bay, NS (Bird et al. 1993). The first observations were on scallop aquaculture floats and on mussels, but it is unlikely these were the source of the infestation as the cultured stocks were of domestic origin. Bird et al. (1993) suggest recreational boat traffic or transport in water masses from the Gulf Stream are likely vectors. Initial dispersal followed prevailing currents to the south, suggesting predominantly natural dispersal. By 1991, the species was found from Mahone Bay to Prospect Bay, and began to be observed in the drift and on natural substrates. Within the next decade large populations had become established in Mahone Bay, St. Margarets Bay and at Cape Sable Island (Hubbard and Garbary 2002). In 2000, oyster thief was found along 95 km of the Atlantic coast of Nova Scotia, by 2007 it was found along 445 km of coast (Watanabe et al. 2010). By this time, the alga had spread to the north, suggesting a mix of natural and anthropogenic vectors of dispersal. Currents, shipping, aquaculture, and entanglement in fishing nets are all potential vectors (Carlton and Scanlon 1985).

***Membranipora membranacea*, Coffin box bryozoan:** The coffin box bryozoan, a native of Europe, was first seen in Mahone Bay or St. Margarets Bay in 1992 and became abundant in the fall of 1993 (Scheibling et al. 1999). The Nova Scotian inoculation probably originated from an introduction in the Gulf of Maine, which was detected at the Isles of Shoals in 1987, reaching the northern Gulf of Maine by 1993 (Harris and Mathieson 1999). Infestations of the bryozoan spread rapidly in the kelp beds of southwestern Nova Scotia. In 2000, the bryozoan was found in shallow habitats over 100 km of coastline, by 2007 it could be found along the entire Atlantic coast of Nova Scotia, about 650 km. The species was observed continuously throughout these ranges wherever kelps were present, suggesting natural dispersal via planktonic larvae was predominant (Watanabe et al. 2010).

Phytoplankton: The presence of numerous non-indigenous phytoplankton species in the ballast tanks of ships (e.g., Subba Rao et al. 1994; Carver and Mallet 2004; Casas-Monroy et al. 2011) suggests that there must be many non-indigenous phytoplankton found on the Scotian Shelf, although no list has been published. In the Bay of Fundy, 22 previously unrecorded planktonic diatoms and dinoflagellates have been detected since 1995 and are presumed to be non-indigenous species (Martin and LeGresley 2008; Klein et al. 2010). An example of a non-indigenous phytoplankton species suspected to have been introduced in ballast water is the bloom-forming diatom *Coscinodiscus wailesii*. This Pacific species, previously unknown from the Scotian Shelf, was abundant and widespread throughout the central and western Scotian Shelf in the spring of 2000 (Head and Harris 2001). A known invader of northern European waters, the species is considered a nuisance even in its native range. The cells of *C. wailesii* are too large for many zooplankton (e.g., calanoid copepods) to eat, which may disrupt the flow of energy through the food chain. Mucilage produced by the diatom clogs fishing nets, and it is noxious to edible seaweeds harvested in Japan (Head and Harris 2001).

6.3.2.2 Species Present in Waters Near the Scotian Shelf

***Didemnum vexillum*, Pancake batter tunicate:** The pancake batter tunicate, occasionally called “the blob” in the media, is a colonial organism which is most likely native to Japan (Lambert 2009). The pancake batter tunicate has not yet been recorded in waters of Atlantic Canada (Martin et al. 2011; Sephton et al. 2011; A. Locke pers. comm.). It has been present on the bottom in the American waters of Georges Bank since 1998 (Valentine et al. 2007; Lambert 2009; Lengyel et al. 2009), and on wharves at Eastport, Maine since 2003 or 2004 (Bullard et al. 2007; Lambert 2009). Over 230 km^2 of Georges Bank is covered 50-90% by this species (Valentine et al. 2007). Introductions throughout much of the world (the eastern

USA, several European countries, the west coast of the USA and Canada, and New Zealand) have been attributed to shipping, either hull or sea chest fouling (Lambert 2009). Adult colonies grow as fouling organisms attached to surfaces, where their potentially rapid rate of growth often causes hem to become nuisance organisms. Colonies grow on both artificial and natural surfaces including boats, wharves, buoys and marine algae, where they may form hanging tendrils (hence the name, the "blob"). Colonies also grow on the sea bed, where they develop a lumpy appearance like uncooked pancake batter (Daniel and Therriault 2007). Natural dispersal occurs by planktonic larvae produced through sexual reproduction, as well as budding (asexual reproduction) of fragments of colonies that break off and drift to new locations. Local dispersal may also occur on fouled vessels and aquaculture gear (Lambert 2009).

***Diplosoma listerianum*, Compound sea squirt:** The compound sea squirt has been detected in the Magdalen Islands, Quebec, since 2008 (Willis et al. 2011). It had recently been classified as a likely potential invader of Atlantic Canada, likely to be able to survive throughout the region (Locke 2009), but so far has not been observed to spread from its original area of introduction in Quebec. The species is widely distributed in nearshore waters of New England (e.g., Massachusetts and New Hampshire) (Willis et al. 2011). Like all other invasive tunicates presently found in Atlantic Canada, this colonial species has the potential to become a nuisance on suspended mussel aquaculture equipment (Gittenberger 2009; Rocha et al. 2009).

***Styela clava*, Clubbed tunicate:** In Atlantic Canada, clubbed tunicate occurs only in the estuaries of Prince Edward Island, where it was first detected in 1997 (Locke et al. 2007). To the south of the Scotian Shelf, the species is widely distributed in New England as far north as Maine (Clarke and Therriault 2007). Clubbed tunicate is most common in sheltered habitats with low wave action, such as bays and estuaries. It attaches to a range of artificial substrates including boat hulls (Clarke and Therriault 2007). In Prince Edward Island, this species has caused serious fouling problems, weighing down suspended mussel aquaculture gear, moorings, floating docks and ropes (A. Locke, pers. comm.).

***Eriocheir sinensis*, Chinese mitten crab:** In Atlantic Canada, Chinese mitten crab has been detected only in the St. Lawrence River in fresh and estuarine waters from about 150 km above to 110 km below Quebec City (Veilleux and de Lafontaine 2007). In the northeastern USA, the crabs have been reported from the Hudson River, Delaware Bay and Chesapeake Bay. A mathematical model of the environmental requirements of the crab has identified all of Atlantic Canada as suitable for its establishment (Herborg et al. 2007). The Chinese mitten crab is catadromous, meaning that the adults live in freshwater rivers but migrate downstream to salt water to spawn. It is listed among the "100 worst alien invasive species," mainly because of its ability to spread rapidly and develop very large populations once introduced to an area, as well as the impacts of these populations (Veilleux and de Lafontaine 2007). In particular, the adult crabs burrow into the clay banks of rivers, often causing collapse of the river bank. Another concern is that the crabs are the intermediate hosts of a parasite, the oriental lung fluke *Paragonimus westermani,* which can be transferred to mammals. In humans, the parasite causes tuberculosis-like symptoms. So far, no North American populations of the crabs have been found to carry the parasite, probably because a snail that the parasite requires to complete its life cycle has not been introduced to North America (Veilleux and de Lafontaine 2007).

6.4 IMPACTS

6.4.1 Ecosystem Impacts

The impacts of invasive species on ecosystems are not fully understood, but are known to include alterations in predator-prey and competitive interactions, parasitism, and effects on habitat (**Table 6-3**). These impacts show that introduced species, currently widely distributed on the Scotian Shelf have interfered with the community structure, biodiversity and functioning of a variety of ecosystems in Nova Scotia; these species should be considered to be invasive. Perhaps the most complex example of how this has occurred is the ongoing change to the kelp bed-urchin barrens ecosystem off the Atlantic coast of Nova Scotia.

Table 6-3: Examples of impacts of marine introduced species on native species and habitats in the Scotian Shelf ecosystem. These species should be regarded as invasive species in Nova Scotia. With the exception of MSX, which is found only in the Bras d'Or Lakes, each of these species is widely distributed in coastal waters of the Scotian Shelf.

Impact	Species	Impact	Source
Predation	Green crab	Predation on a wide variety of taxa, including juvenile American lobster, *Homarus americanus*.	Elner 1981; Klassen and Locke 2007
Competition (Food)	Green crab	Diet overlap with native rock crab, *Cancer irroratus* and American lobster, *Homarus americanus*	Elner 1981; Klassen and Locke 2007
Competition (Space)	Vase tunicate, Violet tunicate, Golden star tunicate	Overgrow and compete for space with native fouling species	Daniel and Therriault 2007; Carver et al. 2006a,b
	Oyster thief	Overgrows areas denuded of kelp, *Laminaria sp*., preventing re-establishment of kelp beds and disrupting the kelp-sea urchin barrens cycle.	Scheibling and Gagnon 2006
Parasitism	MSX	Increased mortalities of infected American oyster, *Crassostrea virginica*	Ford and Haskin 1982
Habitat	Green crab	Digs up and damages eelgrass beds.	Klassen and Locke 2007
	Oyster thief	Attachment to eelgrass, *Zostera marina*, and infaunal bivalves such as American oyster, *Crassostrea virginica*, in soft-bottom habitats; sometimes leading to the buoyant oyster thief floating away with the attached species.	Garbary et al. 2004
	Oyster thief and coffin box bryozoan	Replacement of kelp, *Laminaria* sp., resulting in reduced habitat quality for species for which kelp is a critical habitat, e.g., green sea urchin, *Strongylocentrotus droebachiensis* and American lobster, *Homarus americanus*	Scheibling and Gagnon 2006; Wharton and Mann 1981

Case study: impacts of two non-indigenous species in kelp beds of Nova Scotia: The rocky subtidal zone along the Atlantic coast of Nova Scotia has historically alternated between two states, kelp beds and "urchin barrens," where the kelp has been destructively grazed by the sea urchin *Strongylocentrotus droehbachiensis* (Watanabe et al. 2010). The urchin barrens return to the kelp-bed state when periodic outbreaks of disease decimate the local sea urchin populations. The interaction between oyster thief and coffin box bryozoan has disrupted this cycle. The bryozoan initially facilitated the replacement of kelp beds by the oyster thief. Initially, the bryozoan was found almost exclusively growing over fronds of kelp, but these fronds became brittle and were fragmented by wave action during the fall (Schiebling et al. 1999). By mid-November, formerly lush kelp beds were reduced to stands of stipes which eventually died and decomposed. Oyster thief cannot compete for space with healthy beds of kelp, but is able to establish rapidly in areas where kelp is absent. In many of these areas, dense, mono-specific stands of oyster thief developed and inhibited the recolonization of kelp (Scheibling and Gagnon 2009). Oyster thief is of lower nutritional quality than kelp, and its presence resulted in changes in the benthic community structure. By facilitating the removal and replacement of kelps, the bryozoan altered the habitat of species such as sea urchins and American lobsters (Chapman et al. 2002). The bryozoan grows poorly on oyster thief. Following the reduction in its preferred substrate (kelp), the bryozoan switched to other seaweeds, but these are not subject to defoliation by the bryozoan (Watanabe et al. 2010). Simultaneously, the area around the epicenter of the invasion seems to be returning gradually to kelp beds, generally where oyster thief has been dislodged by wave action and winter storms. A "boom and bust" cycle is commonly observed during the first few years after an invasion, after which a new equilibrium or cycle may be established (Boudouresque et al. 2005). Over time, the percent cover of oyster thief has declined; it was the dominant canopy alga at 54% of sites where it occurred in 2000, but at only 15% in 2007 (Watanabe et al. 2010). Since large populations of the bryozoan persist on alternative seaweed substrates, future increases in the kelp canopy may result in another episode of infestation and defoliation by the bryozoan, which in turn may be followed by a recurrence of the proliferation and spread of oyster thief (Watanabe et al. 2010).

6.4.2 Socio-Economic Impacts

There are numerous examples of impacts of invasive species on aquaculture, fishing, shipping, and recreation in Nova Scotia (**Table 6-4**). Currently, the effects of tunicates on aquaculture are most extensively studied and are presented here as a case study.

Case study: impacts of Ciona intestinalis on aquaculture: The first case of vase tunicate infestation in Atlantic Canada occurred in the summer of 1997, when a significant fouling problem developed on a mussel farm in Lunenburg and ultimately resulted in loss of the crop (Cayer et al. 1999; Carver et al. 2006a). In 1998 and 1999, vase tunicate fouling continued to be a problem for oyster and scallop aquaculture in Lunenburg (Carver et al. 2003). In 2000, a mussel farm in Mahone Bay and mussel and scallop operations near Chester experienced tunicate fouling problems and anecdotal reports suggest similar problems were experienced by fish growers in the Shelburne area (Carver et al. 2006a).

Economic losses to the shellfish industry in Nova Scotia have been partly due to inhibited growth and yield of shellfish through food and space competition (Daigle and Herbinger 2009). Mussel meat yields decreased and water content increased rapidly for the first 500 g of tunicates/m of sock, indicating a rapid loss of condition. Mussel size and density decreased with increasing tunicate densities, and the relationship predicts a loss of 1.4 kg of mussels/m of sock for every 1 kg/m increase in tunicate density. Up to 50% mussel mortality was observed with heavy tunicate fouling (2 kg tunicates/m of sock) (Daigle and Herbinger 2009; DFO 2010). Also, the vase tunicate infestations resulted in loose attachment of mussels leading to mussel loss at the time of harvest. Increased sock weight caused injuries to aquaculture workers, damage to equipment, and increased costs of harvesting, transporting, and processing. In Prince Edward Island, the cost of harvesting, transporting and processing mussel socks infested with the clubbed tunicate, a species with similar body form to the vase tunicate, was 15% of the gross landed value of the mussels (A. Locke, pers. comm.).

Changes in cultural practices have been recommended as possible mitigation measures. Frequent gear rotation, cleaning gear with power washers or air drying, fallowing the aquaculture leases, adjusting the height of the mussel lines to allow crab predation on the tunicates, and adjusting work schedules to deploy gear after periods of tunicate recruitment will help reduce, but not eliminate fouling (Carver et al. 2003; Vercaemer et al. 2011). At present, mechanical methods (specially designed equipment with high pressure (~700 psi) nozzles to wash off or kill (by physical damage) the fouling tunicates) or chemical (e.g., hydrated lime) treatments are used. The costs of treating fouling by *C. intestinalis* are in the order of $1 per metre of mussel socks (Carver et al. 2006a). Loss of products and additional efforts and operating costs are leading to mussel farm closures. For the year 2011 alone, 26 full- or part-time jobs have been lost from 4 rural Nova Scotia mussel operations (D. Sephton, pers. comm.).

Table 6-4: Examples of socio-economic impacts of marine introduced species in the Scotian Shelf ecosystem.

Activity	Species	Impact	Source
Aquaculture	Vase tunicate	Competition with blue mussel, *Mytilus edulis*, in suspended culture. Added weight on aquaculture gear. Removal and disposal problem during processing of harvest.	Carver et al. 2003
	MSX	Increased mortality of cultured American oyster	Stephenson et al. 2003
Fishing	MSX	Increased mortality of wild populations of American oyster	Stephenson et al. 2003
	Green crab	Interference with eel fishery, damage to captured eels (but note possible benefit as lobster bait)	Klassen and Locke 2007
	Hookweed	Nuisance entanglement in fishing nets	Hanson, pers. comm.
Shipping	Vase tunicate, Violet tunicate, Golden star tunicate	Fouling of hulls, motors, and other surfaces.	Carver et al. 2006a, b
Impacts on recreation	Vase tunicate, Violet tunicate, Golden star tunicate	Fouling of floating docks, added weight makes docks difficult to remove at end of season	Carver et al. 2006a, b

6.4.3 Public Health Impacts

The public health impacts most likely to occur are associated with phytoplankton introductions from ballast water or sediments. As explained in Section 2.1.1 (Ballast water), ships in Atlantic Canada may contain many potentially dangerous phytoplankton species. Of the 102 taxa collected by Subba Rao et al. (1994), 21% had the potential to form blooms, red tides, and/or toxins. Of the 349 taxa found by Carver and Mallet (2004), 5% were taxa known to accumulate in shellfish and cause gastrointestinal or neurological illnesses in consumers, 1% were known to cause fish kills, and 9% were classified as being of “possible concern” (bloom-forming, or related to toxic or harmful species. Of 51 taxa found in ballast sediments, 8% were identified as harmful and/ or toxic species (Casas-Monroy et al. 2011).

In the spring of 2000, the phytoplankton of the central and western Scotian Shelf contained large numbers of a non-indigenous diatom, *Coscinodiscus wailesii* (Head and Harris

2001). No public health impacts are documented from this known nuisance species, but it provides an example of how a large bloom of a previously unobserved non-indigenous species could rapidly spread throughout much of the Scotian Shelf.

6.5 ACTIONS AND RESPONSES

6.5.1 International

Canada formally committed to control, eradicate or prevent the introduction of invasive species that threaten ecosystems, habitat or species under the 1992 *United Nations Convention on Biological Diversity*.

The United Nations Environmental Program addresses aquatic invasives in the context of ballast water and aquaculture. The *Code of Conduct for Responsible Fisheries* (1995) is concerned with fishing practices and aquaculture. The *International Convention for the Control and Management of Ships' Ballast Water and Sediments* was adopted in 2004. The ICES (International Council for Exploration of the Seas) *Code and Practice on the Introduction and Transfer of Marine Organisms* (2004) is another aquaculture-focused initiative.

6.5.2 National

Early regulations about species introductions in Canada were primarily directed to address the risks of intentional introductions. The *Fisheries Act* (1985) addresses risk in the context of fish stocking, live bait, and aquaculture. Regulatory reforms to the Act, currently under development, have been suggested to expand the scope of the Act to cover other, unintentional, vectors. The *National Wildlife Policy* (1990) states that non-indigenous species should not be introduced into natural systems. The *Canadian Biodiversity Strategy* (1995) provides for identifying and monitoring alien organisms, screening standards and risk assessment. In 1999, the *Canadian Environmental Protection Act* requires risk assessments be undertaken before permitting a species introduction.

Canada's *Ballast Water Control and Management Regulations* (the Regulations), pursuant to the *Canada Shipping Act* (2001), came into force in June of 2006, and served to harmonize ballast water management in Canadian waters with provisions set out in international and United States law (Transport Canada 2007). The Regulations identify vessels that must manage their ballast water, define acceptable ballast water exchange and treatment standards, stipulate requirements for ballast water management and reporting, and provide rules for acceptable ballast water exchange activity in Canadian waters. Acceptable zones for ballast water exchange are defined in the Regulations and associated guidance materials (**Figure 6-3**; Transport Canada 2007). These zones are designed to help reduce the risk of invasive species introductions while permitting safe and economically feasible areas to conduct ballast water exchange

On September 19, 2001, at the Joint Council Meeting of Federal, Provincial and Territorial Ministers of Wildlife, Forests, and Fisheries and Aquaculture, the Ministers concluded that the threat of invasive alien species to biodiversity was one of four priority issues that must be addressed to further the implementation of the 1996 *Canadian Biodiversity Strategy*. This resulted in the documents *Addressing the Threat of Alien Invasive Species* (2002) and *An Invasive Alien Species Strategy for Canada* (2004). The Invasive Alien Species Partnership Program (2004) supports the goals of the Strategy.

Canada's guiding document on aquatic invaders is *A Canadian Action Plan to Address the Threat of Aquatic Invasive Species* (2004), developed by the Aquatic Invasive Species Task Group created in 2002 by the Canadian Council of Fisheries and Aquaculture Ministers (CCFAM). The former Task Group is now known as the National Aquatic Invasive Species Committee. The *National Code on Introductions and Transfers of Aquatic Organisms* (2003) was also developed at the request of the CCFAM, and sets standards for assessing intentional introductions and transfers of aquatic organisms. Nova Scotia applies this code through a provincial introductions and transfers committee.

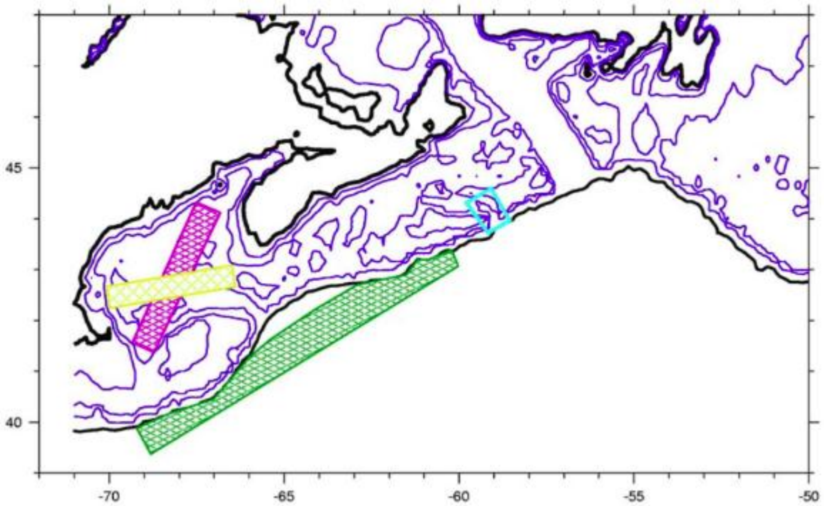

Figure 6-3: Recommended ballast water exchange zones on the Scotian Shelf and Gulf of Maine. The magenta zone indicates that traffic transiting to/from the Bay of Fundy should exchange in the Gulf of Maine, in waters deeper than 100 m. The yellow zone indicates that traffic crossing the Gulf of Maine and using a coastal route on the Scotian Shelf should similarly exchange in the Gulf of Maine, in waters deeper than 100 m. The green zone is the preferred exchange zone for on-shelf traffic heading to/from Nova Scotia, plus vessels following a shelf-break path. Exchange should occur in waters deeper than 1000 m, west of Sable Island and the Gully, and away from the entrance to the Northeast Channel (Transport Canada, 2007).

Initiatives of Fisheries and Oceans Canada include the Aquatic Invasive Species Program, which includes research (e.g., Brickman 2006; Brickman and Smith 2007; Vercaemer et al. 2011; Wong and Vercaemer, submitted) and monitoring, (e.g. Sephton et al. 2011). It includes various outreach products and collaborative initiatives and a toll-free reporting line for non-indigenous species sightings in Nova Scotia. DFO's Centre of Expertise for Aquatic Risk Assessment has led risk assessments on species already present on Scotian Shelf (green crab, vase tunicate, golden star tunicate, violet tunicate) and potential threats to the Scotian Shelf (mitten crab, clubbed tunicate, pancake batter tunicate). DFO also contributes to the funding of the Canadian Aquatic Invasive Species Network (CAISN), which focuses on research on pathways of introduction, factors affecting species establishment, and management of invasive species.

6.5.3 Regional

The Northeastern Aquatic Nuisance Species Panel is the coordinating body for protection of ecosystems in northeastern North America from invasive aquatic nuisance species, but has no regulatory power. It is a regional panel under the U.S. Aquatic Nuisance Species Task Force.

Both the province of Nova Scotia and Fisheries and Oceans Canada are represented on the panel. Since the problems caused by invasive species cross international and other jurisdictional boundaries, an important role of the panel is to promote cooperation and collaboration in the control, eradication, monitoring and prevention of invasive species, consistency in policies and enforcement between jurisdictions. Outreach products and best management practices are also shared.

A MSX emergency response plan exists for Atlantic Canada (McGladdery and Stephenson 2005). Following the discovery of MSX in the Bras d'Or Lakes in 2002, the plan was developed to prevent spread of the parasitic disease to the rest of Atlantic Canada. MSX is a reportable disease under the international regulations of the World Organization for Animal Health, because it is considered a serious threat to the commercially significant Eastern oyster, *Crassostrea virginica*. MSX concerns a wide diversity of stakeholder interests, because oyster production spans federal and provincial authorities, First Nations' traditional food fisheries, commercial fisheries, licensed aquaculture lease-holders, processing plants and brokerage operations, and roadside/retail marketer activities. Positive, negative, and buffer zones for MSX in Canada have been established. Surveillance of oyster-producing areas occurs throughout Atlantic Canada, with emphasis on the buffer zone where the first indications of any spread might be expected (McGladdery and Stephenson 2005).

6.5.4 Provincial

At the provincial level, the Nova Scotia Introductions and Transfers Committee is chaired by Fisheries and Oceans Canada and includes members from the province of Nova Scotia and industry. Fishery (General) Regulations prohibit the release of live fish into any fish habitat without a license. This committee reviews proposals to move aquatic organisms from one water body to another according to guidelines established by the *National Code on Introductions and Transfers of Aquatic Organisms*. The code applies to all activities in which live aquatic (freshwater and marine) organisms are introduced or transferred into fish-bearing waters, or fish rearing facilities such as aquaculture. The committee evaluates the risk of harmful alterations of receiving ecosystems, deleterious genetic changes in indigenous fish populations, and risks to aquatic animal health if pathogens or parasites were to accompany the organisms to be moved. The committee then advises the decision-making authority (DFO).

The Nova Scotia government is reforming regulations specific to the possession of live fish under the *Fisheries and Coastal Resources Act*. The amendments to prohibit the possession of live fish are intended to reduce the number of illegal fish introductions in Nova Scotia, and the consequent adverse effects on native ecosystems and species (http://www.gov.ns.ca/fish/sportfishing/angling/fcra-q-and-a.pdf).

The Nova Scotia Department of Aquaculture and Fisheries actively monitors for coastal invasive species, especially tunicates (e.g. Cayer et al. 1999). Recent examples include partnering with DFO for biofouling monitoring and rapid assessment activities on the Eastern Shore and in the Bras d'Or Lakes.

6.5.5 Community

The Invasive Species Alliance of Nova Scotia was established in 2008. Its activities include informing, engaging and coordinating stakeholders to address the issues of all invasive alien species in Nova Scotia. Another project of the Alliance is a legislative review and gap analysis. Among many other funding sources, the Alliance is partially supported by the Invasive

Alien Species Partnership Program, a federal initiative managed by Environment Canada. The IASPP provides funding to provinces, municipalities, educational institutions, and nongovernment organizations, as well as to other groups who are working in support of the goals of the National Strategy. The goal is to engage Canadians in actions to prevent, detect, and respond rapidly to invasive alien species in order to minimize the risk the species pose to the environment, economy and society.

6.5.6 Management Practices

Throughout this document, a number of management practices that reduce the risk of introducing or spreading non-indigenous species have been mentioned. The following management practices have been recommended by DFO:

General:

- Learn about invasive species and how to identify them. A resource for identification of the marine invasive species found in Nova Scotia is: http://www.qc.dfo-mpo.gc.ca/publications/envahissant-invasive/carnet_anglais.pdf
- Do not move organisms from one area to another.
- Never release live bait, aquarium fish or plants into an open water body or sewer.

When taking your boat out of the water:

- Inspect and remove fouling plants and animals from boat, motor, anchor, trailer, and equipment with freshwater or spray with vinegar (protect your eyes).
- Clean hull and dispose of removed material far from the water.
- Drain water from motor, bilge and wells. If possible, let equipment dry completely.
- Use environment-friendly anti-fouling paint or products on your boat hull.

Shellfish harvesting:

- Clean shellfish where they were collected.
- Move as little water as possible with the shellfish.
- Spread any leftover water on the lawn.
- "De-sand" shellfish in the original water or in a bucket with water that will be thrown onto the lawn.

Diving and other water sports:

- Rinse equipment with fresh water after every trip.
- Let equipment dry completely.

What to do if you find invasive species:

- Try to identify them. A photograph will be helpful for the report.
- Note the location (GPS coordinates if possible) and observation date.
- Contact the DFO invasive species reporting line for Nova Scotia at 1-888-435-4040.

6.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR	Assessment[1]	Trend[2]
Number of established marine invasive species	Growth in global trade and other human activities	Driving force, Pressure	Poor	-
Distribution and spread of marine invasives	Increase in regional vectors and habitat pressures (i.e., hull fouling, aquaculture, habitat modification, climate change)	Pressure	Fair	-
Losses incurred by fishery and aquaculture industry	Losses of fishery resources from invasive species impacts	State	Poor	-
Costs incurred or spent on invasive species management	Investment in marine invasive management programs and education	State	Fair	-

[1] Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.

[2] Trend: is it positive or negative in terms of implications for the state of the environment? It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Key:
Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?

Data confidence

- Information on the number of species on the Scotian Shelf was derived from a literature review and represents a very conservative number of marine introductions and invasives.
- Species of unknown origin were not included in the review, and it is likely that some of these may have been introduced.

Data gaps

- Large data gaps exist.
- For most species addressed in this report, insufficient data exist to describe the abundance, trends and range distribution.
- Existing monitoring programs do not address most habitats and taxa. Targeted monitoring programs for marine invasive species in Nova Scotia focus primarily on fouling species and on the European green crab. There is little information on offshore species.
- Information on ecosystem and economic impacts is lacking. DFO is currently undertaking a national socio-economic assessment case study of invasive tunicates

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Climate Change

7. CLIMATE CHANGE AND ITS EFFECTS ON ECOSYSTEMS, HABITATS AND BIOTA[15]

Nancy Shackell (Overall Lead) and John Loder (Physics), Fisheries and Oceans Canada,
Dartmouth, NS

7.1 ISSUE IN BRIEF

Anthropogenic climate change, including warming, is due to increased greenhouse gas (GHG) emissions largely from the use of fossil fuel. The rate of warming during the past 50 years has been about twice that during the last 100 years (IPCC 2007b). Climate change has had biological effects world-wide (reviewed in Parmesan 2006; Rosenzweig et al. 2008). Consistent with the expected earlier springs and longer summers, changes in timing of seasonal events and distribution were observed in 59% of 1598 species in the latter half of the 20th century (Parmesan 2006).

This theme paper reviews the potential effects of climate change on ecosystems, habitats and biota on the Scotian Shelf. Driving forces include anthropogenic global climate change and natural climate variability. These drivers in turn affect the environment and biota. Globally, it is expected that climate change will have impacts on productivity, distribution and the timing of seasonal events. However, it is important to recognize there is limited understanding as to how climate change at the global scale will affect regional and local ecosystems. Management and adaptation strategies will have to be based on current understanding of the system (**Figure 7-1**).

The Scotian Shelf has not yet experienced drastic ecological impacts due to climate change but impacts may accrue slowly over time (e.g., decades). Subpolar water flowing towards the equator and subtropical water flowing poleward both influence the Scotian Shelf oceanography. Changes occurring to the north in the Labrador Current and to the south in the Gulf Stream can be expected to influence the Shelf's climate and ecosystems.

7.2 DRIVING FORCES AND PRESSURES

7.2.1 Anthropogenic Climate Change

While greenhouse gases (GHGs) are naturally released into the environment, those released as a result of human activities are considered to be the main driver of climate change. At a global level, elevated levels of carbon dioxide (CO2) (a greenhouse gas), are mainly produced by the burning of fossil fuels (59%) but also by land-use change (18%) such as agricultural clearing and timber harvest (Baumert et al. 2004). GHGs absorb radiative energy from the Earth, so the heat gets trapped near the Earth's lower atmosphere instead of escaping into the upper atmosphere—that trapping warms the Earth's temperature. Global average temperature increased by 0.045°C per decade from 1856-2005 and the rate of warming accelerated between 1981 and 2005 (0.18°C per decade) (see Figure 1. of FAQ 3.1, IPCC 2007b). The Northern Hemisphere is warming faster than the tropics, the land is warming faster than the oceans, and the Arctic is warming twice as fast as the global average (IPCC 2007b).

Canada contributes 2% of the total GHG emissions, ranking 9th in absolute amount, 7th on a per capita basis and 1st based on energy consumption per capita (Baumert et al. 2005). From 1990–2008, Canada's GHG emissions increased by 24%. The greatest increases were in energy production (i.e., fossil fuel production and refining subsectors, electricity and heat generation subsector [energy]) and transportation.

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[15] Completed April 2012.

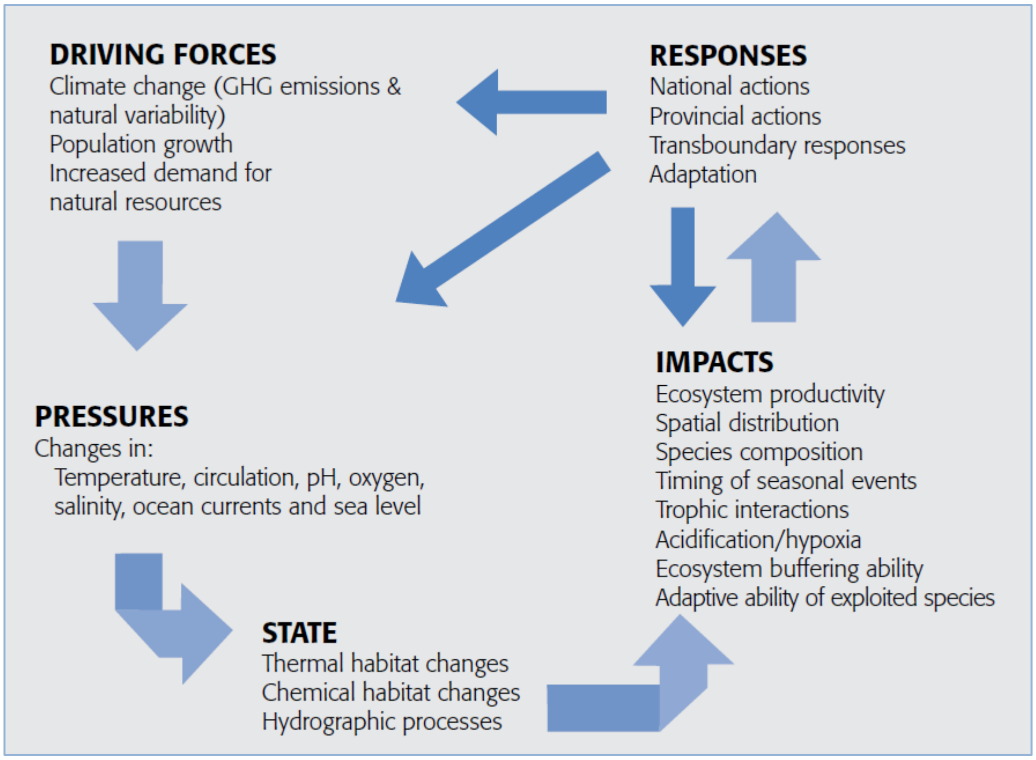

Figure 7-1: Driving forces, pressures, state, impacts and responses (DPSIR) to climate change on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human well-being, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

The anthropogenically-derived GHG emissions are directly related to economic growth and its continued reliance on fossils fuels (IPCC 2007a). Nova Scotia specifically has a continued reliance on coal as its electricity source. Nova Scotia's population in 2006 was just less than 1 million (934,405) and had grown 5% since 1986, representing 2.9% of Canada's population (Nova Scotia Department of Finance 2006). While the population growth in Nova Scotia is low, economic growth in Nova Scotia is driven largely by international trade. In 2005, the majority (80%) of Nova Scotia's international trade was with the US. The absolute population size of the US, our major international market, as well as demand from other provinces will influence fossil fuel use in the province.

Intergovernmental Panel on Climate Change (IPCC) is a large collection of international scientists, initiated by the United Nations and the World Meteorological Organization, working on climate change and its impacts.

7.2.2 Natural Conditions

The physical oceanography of the Scotian Shelf is described in detail in *The Scotian Shelf in Context*. Its variability is determined by the competing influences of i) atmospheric forcing and solar heating, ii) the western North Atlantic's large-scale current systems (the Gulf Stream and Labrador Current), and iii) local factors such as tides, river discharge and topography. The Scotian Shelf is located in a large-scale oceanographic "transition" zone (ICES 2011) between the relatively warm and saline (subtropical) offshore waters of the Gulf Stream, and the cooler and fresher shelf waters supplied by the (subpolar) Labrador Current and outflow from the Gulf of St. Lawrence (**Figure 7-2**).

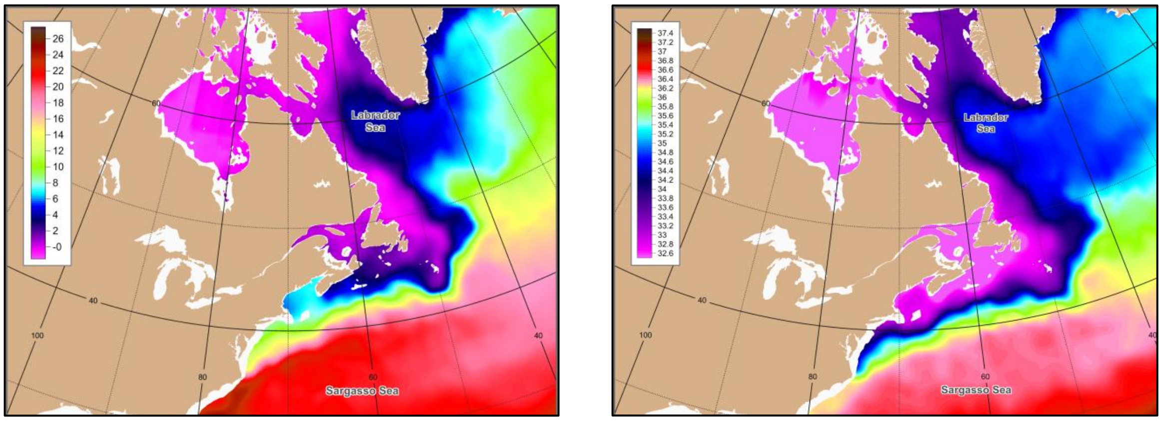

Figure 7-2: Climatological annual-mean distributions of temperature (left) and salinity (right) at 50 m below the sea surface in the NW Atlantic (I. Yashayaev, Bedford Institute of Oceanography, Fisheries and Oceans Canada).

The greatest natural variability in the Scotian Shelf's oceanography is the seasonal variation. In addition, Atlantic Canada is strongly affected by the North Atlantic Oscillation (NAO), a natural mode of variability in the large-scale atmospheric pressure and wind pattern (see e.g., Hurrell and Deser 2010). The state of the NAO Index (either negative or positive) modifies the volume of subpolar water moving west past the Grand Bank, which influences temperature and salinity over the Scotian Shelf (Petrie 2007). Successive years of positive wintertime NAO anomalies (involving stronger and cooler northwesterly winds over the Labrador Sea) result in cooler water from the Newfoundland Shelf reaching the eastern Scotian Shelf. Negative NAO years result in a reduction in the volume of slope water moving around the Tail of the Grand Bank which then leads to warmer subtropical slope water intruding onto the central and western Scotian Shelf at depth.

Another natural mode of variability which affects the Scotian Shelf is the Atlantic Multidecadal Oscillation (AMO) — a measure of sea surface temperature in the North Atlantic with quasi-periodicities of 20–30 and 60–70 years (Frankcombe and Dijkstra 2011; Reid and Valdés 2011). From the 1970s to the past decade, the AMO was in a warming phase for the North Atlantic which has been suggested to be a contributing factor to observed ocean warming on the Northeastern United States shelf (Nye et al. 2009). The mechanisms and periodicities of the AMO are still under debate, and one suggestion is that it is partly linked to changes in the Atlantic Meridional Overturning Circulation (AMOC). The latter is the Atlantic component of the so-called global ocean "conveyor belt". AMOC variability has also been suggested to affect the north-south position of the Gulf Stream (Joyce and Zhang 2010) such that the influences of the NAO, AMO and AMOC on the Scotian Shelf may be inter-related.

7.2.3 Potential Oceanographic Changes

Natural variability will continue to be a major factor in future ocean climate change. During the next decade or two (while anthropogenic changes are emerging), climate on the Scotian Shelf may still be predominantly influenced by natural variability or anthropogenic perturbations of this variability. The coupled atmosphere-ocean climate models used in the IPCC's Fourth Assessment Report (AR4) have poor resolution of the western North Atlantic's transition zone, and do not represent the NAO and AMO well. Hence, caution should be used in "downscaling" the global long-term projections of the AR4 models to the Scotian Shelf, especially for the next decade or two. The probable tendencies for mid-century (or late-century) regional climate change in some ocean variables can nevertheless be estimated from a combination of knowledge of atmosphere-ocean dynamics (ICES 2011; Reid and Valdés 2011), past regional ocean climate variability, and AR4's projected changes in key larger-scale forcings. The tendencies for the physical-chemical variables that are most important ecologically and most likely to change significantly on the Scotian Shelf can be summarized as follows:

- **Ocean temperature and acidity** can be expected to increase with increased CO2 concentrations. Increases should be largest in the upper layers (75–100 m in winter and 20–30 m in summer). The increased ocean acidity will result in a lowering of calcium carbonate saturation in the upper ocean, with effects on calcareous organisms and other aspects of the ecosystem.
- **Sea level** can be expected to rise associated with the global trends of increased ocean volume due to heating and melting glaciers, enhanced tides, the potential northward expansion of the subtropical gyre, and natural continental subsidence (sinking) in the region. The number of intense storms is expected to increase and the track of extratropical storms is expected to shift northward resulting in higher extreme storm surges, which would further enhance extreme high-water levels and coastal erosion.
- Net **salinity** changes on the mid-century time scale are uncertain because multiple factors can cause opposite tendencies. Increased salinity at depth on the mid to outer shelf can be expected due to the increasing influences of slope water of subtropical origin. In contrast, melting Arctic sea ice and the increased precipitation at mid to high latitudes are expected to result in reduced salinities of the (shelf) water moving onto the Scotian Shelf from the Newfoundland Shelf. The influence of regional freshwater run-off (from land) is less clear due to complications such as the expected changes in precipitation varying with season and increased evapo-transpiration (due to warmer air) affecting run-off . However, it is expected that there will be reduced salinities in near-surface coastal waters in spring.
- Warmer, fresher surface water should result in an increase in the vertical density **stratification** and an increase in mixed-layer depths, but the effect can be expected to vary seasonally and spatially. At the shelf-water/slope-water interface at depths of 75–150 m (base of the winter surface and summer intermediate layers), the warmer fresher surface water combined with increased (slope-water) salinity at depth should lead to increased year-round stratification, as well as an earlier onset of spring-summer stratification near the surface (upper 30 m).
- Large-scale changes in **ocean circulation** may include a northward shift of the Gulf Stream and a reduction in the extent of subpolar slope water west of the Grand Bank. This is based on the expected tendencies for a slowing of the AMOC and more positive NAO anomalies because of the intensification of the atmospheric polar vortex (IPCC 2007b). This would result in higher salinity in the slope water off the Scotian Shelf, more frequent "warm" slope water intrusions onto the shelf, and changes in chemical properties such as nutrients and dissolved oxygen.

- Increased stratification and reduced depths of winter convection can be expected to result in reduced **dissolved oxygen** concentrations at depths below the winter layer on the Scotian Shelf, such as in the intruded slope water at depth. This would be further exacerbated by the expected increased contribution of dense subtropical water.
- With the expected changes in stratification and in the source of slope water at depth, there will probably also be changes in **nutrient concentration**. However, as with dissolved oxygen, nutrient concentrations are influenced by multiple factors including complex biogeochemical processes, such that it is difficult to project the net effects of climate change.

7.3 STATUS AND TRENDS

7.3.1 Temperature

Available data for air and ocean temperature in the NW Atlantic during the past century indicate substantial natural variability on decadal time scales. For example, the 1950s was one of the warmest decades in the 20th century for air and ocean temperature in the Scotian Shelf region while the 1960s was one of the coldest. Trends estimated from time series starting in the 1950s may be very different from those estimated from those starting in the 1960s. Caution needs to be used in interpretations of the limited existing ocean datasets with regard to their implications for future change.

Meteorological records, in some cases extending back before 1900, provide the best indicators of long-term regional climate change. Coastal air temperature records between the Grand Bank and the Gulf of Maine generally show a net increase over the past century in the 0.6–1.7°C range. Sable Island, which had a change of about 1°C, is probably the most representative of the Scotian Shelf. This magnitude is similar to the observed global and North American averages of about 1°C reported in IPCC (2007b, Chapter 3), and to the simulated change of about 0.7°C for eastern North America in IPCC (2007b, Chapter 9). This suggests that significant anthropogenic warming is occurring in air temperature over the Scotian Shelf (averaged over decadal variability).

The longest records (85–90 years) of ocean temperature and salinity in the region are coastal temperatures measured at St. Andrews, Halifax, and the Prince 5 monitoring station in the Bay of Fundy (**Figure 7-3**). The Bay of Fundy observations indicate an increase of about 1°C per century, consistent with the increases observed at US coastal sites in the Gulf of Maine and northern Middle Atlantic Bight (Shearman and Lentz 2010), as well as the air temperature changes noted above. The limited observed change at Halifax (a slight but insignificant decrease) may reflect a local influence (e.g., coastal upwelling) such that the pattern observed at Halifax may not represent the entire shelf.

The longest and most continuous record of offshore/mid-shelf temperature and salinity is from Emerald Basin (**Figure 7-4**). Its surface temperature shows little net change since the relatively warm 1950s but, considering patterns both to the north (e.g., Newfoundland) and south (US), it is plausible that a longer record would show a net increase. Sparse earlier observations from Emerald Basin, and the longer records from Prince 5 and the Gulf of St. Lawrence (Gilbert et al. 2005) point to a long-term warming trend of the deep water shelf waters during the past century, such that there is a substantial basis for inferring that there has been such a trend in the Scotian Shelf's subsurface waters.

Since 1985, SST estimates from remote sensing indicate a widespread increase by over 1°C on the Scotian Shelf. However, the natural warming phase of the AMO since the 1970s may be contributing to the recent warming (Nye et al. 2009; Polyakov et al. 2010).

7.3.2 Salinity

Robust indications of long-term changes in ocean salinity are even more difficult to obtain than those for temperature, because of the greater dearth of high-quality measurements. Salinity in the upper 500 m of the North Atlantic north of 42°N (the Scotian Shelf's latitude range is 42–44°N) has decreased over the period 1955–98 (IPCC 2007b), consistent with the expected change associated with sea-ice melting and more rain at high latitudes The salinity time series from Prince 5 in the outer Bay of Fundy (**Figure 7-3**) indicates a net depth-averaged (90 m) decrease of 0.1–0.2 psu over about 85 years. The salinity time series from Emerald Basin (**Figure 7-4**) indicates a net decrease of 0.1–0.2 psu at the surface and a net increase of about 0.2 psu at depth. These net changes are clearly influenced by natural variability.

Overall, there have been decadal-scale variations with magnitudes comparable to (or greater than) the long-term changes, such that the contributions of natural and anthropogenic variability are unclear. There have been claims of anthropogenic freshening of Arctic origin during the past two decades (e.g., Drinkwater et al. 2004), but it is unclear whether this is a reliable long-term trend or a transient feature associated with natural variability.

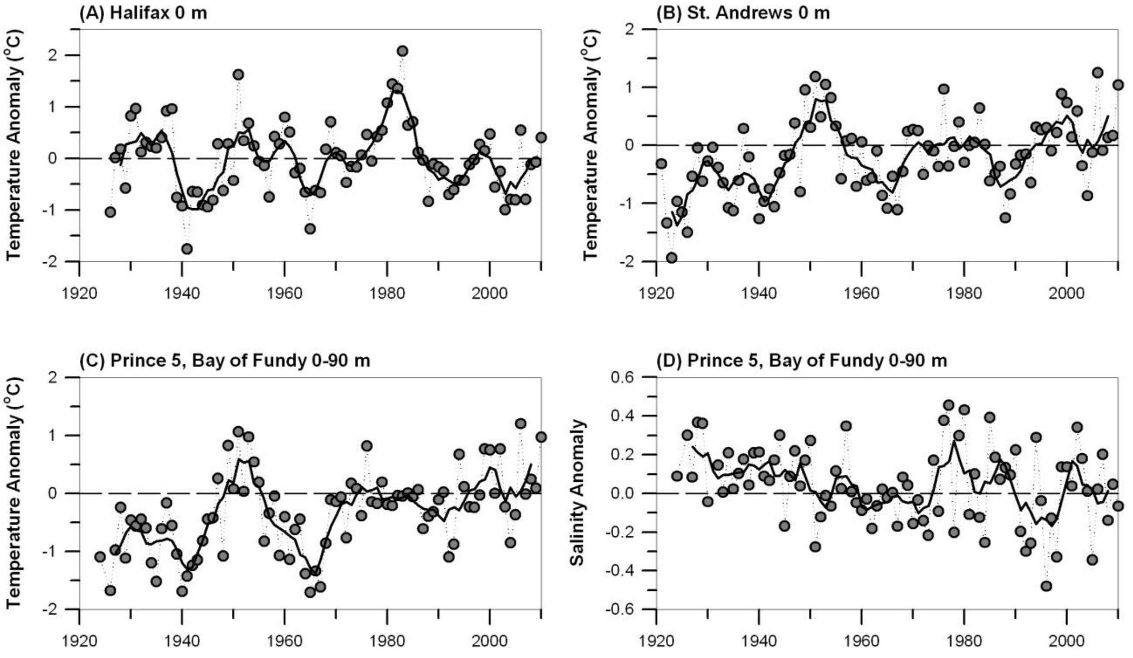

Figure 7-3: The longest ocean temperature and salinity records available for the Scotian Shelf and Bay of Fundy: annual anomalies of coastal temperature (circles joined by dashed line) and their 5-year running means (heavy black line) for (A) Halifax Harbour and (B) St. Andrews, NB; and annual anomalies of depth-averaged (0–90 m) (C) temperature and (D) salinity for the Prince 5 monitoring station at the mouth of the Bay of Fundy. The anomalies are relative to the 1971–2000 means (Petrie et al. 2011).

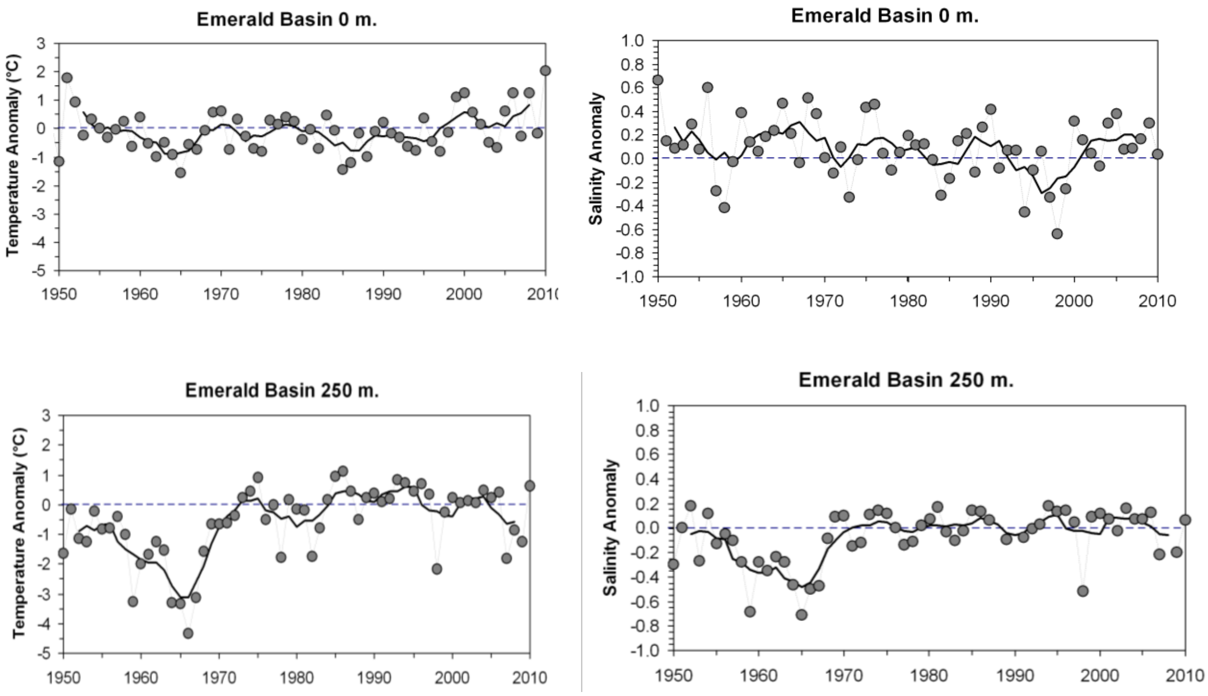

Figure 7-4: Annual-mean temperature and salinity anomalies (circles joined by dashed line) at the surface and near-bottom at a long-term monitoring site in Emerald Basin on the central Scotian Shelf, with their 5-year running means (heavy black line). The anomalies are relative to the 1971–2000 means (R. Pettipas, Bedford Institute of Oceanography, Fisheries and Oceans Canada).

7.3.3 Stratification

Upper-ocean stratification has increased over the Scotian Shelf and adjoining shelf regions during the past 60 years (**Figure 7-5**) (Petrie et al. 2011). Analyses suggest that it has arisen from a combination of the surface warming and freshening described earlier, with warming (freshening) the dominant influence on the western (central and eastern) Shelf (Brian Petrie, Bedford Institute of Oceanography, Fisheries and Oceans Canada, pers. comm.).

Typically, in the spring/summer, warmer, fresher, less dense water lies over colder, saltier denser water, creating a boundary so the vertical water column is “stratified.” The winter winds and cooling break down this stratification and cause vertical mixing that takes oxygen to the deeper water and brings nutrients to the surface, feeding phytoplankton growth in the spring.

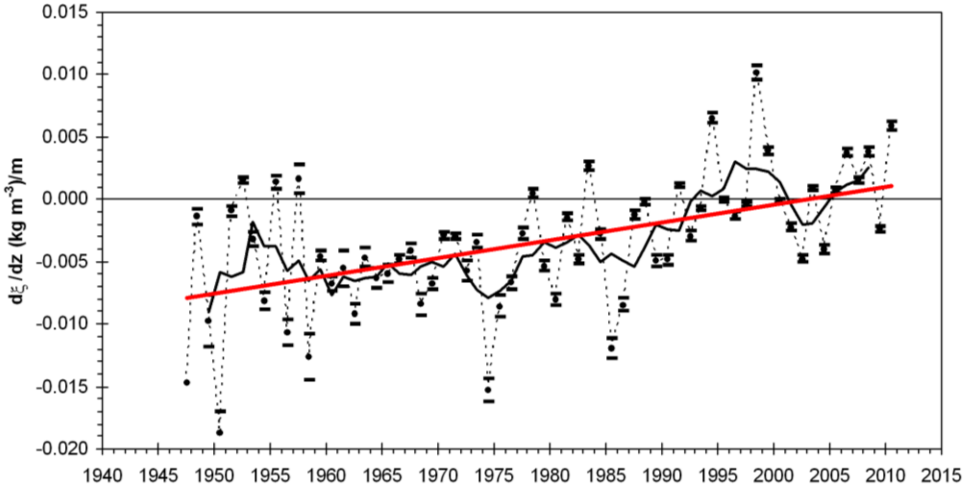

Figure 7-5: Annual-mean anomalies (solid circles joined by dashed line with standard error estimates) and 5 year running means (heavy black line) of the vertical stratification gradient over the upper 50 m on the Scotian Shelf, based on historical temperature and salinity data. The red line is the long-term trend indicating an increase of 0.4 kg/m^3 over 60 years (Petrie et al. 2011).

7.3.4 Chemical Ocean Properties

7.3.4.1 pH: The ocean routinely absorbs carbon dioxide (CO_2), but the additional CO_2, produced through increased human activities, has changed the ocean's chemical balance. Atmospheric concentrations of CO_2 are about 40% higher than before industrialization, and about 33% of that excess has entered the surface of the ocean (Doney et al. 2009). The CO_2 absorbed in the ocean forms carbonic acid which lowers the pH as the net CO_2 input increases. Global surface ocean pH has decreased by 0.1 units (i.e. the surface ocean has become more acidic) since pre-industrialization beginning in 1750 (IPCC 2007b), and is expected to reduce further by 0.3 to 0.4 units by 2100 (reviewed in Doney et al. 2009). Sparse data from the Scotian Shelf indicate a decrease in pH of 0.1–0.2 since the early 1930s (Worcester and Parker 2010). The available atmospheric and ocean data, and current understanding of the global carbon cycle, point clearly to ongoing ocean acidification on the Scotian Shelf. There is concern that the increasingly acidic Arctic outflow will affect Atlantic Canadian waters downstream (Azetsu-Scott et al. 2010; see also *Ocean Acidification*).

7.3.4.2 Dissolved Oxygen: There has been a widespread decrease in dissolved oxygen concentrations and oxygen saturation levels in the slope-derived deep waters in the Gulf of St. Lawrence and on the Scotian Shelf (**Figure 7-6**; Petrie and Yeats 2000; Gilbert et al. 2005). Gilbert et al. (2005) reported a 50% reduction in dissolved oxygen concentration at depth in the St. Lawrence Estuary since the 1930s, and estimated that between one-half and two-thirds of this change was associated with the warming and increased fraction of subtropical slope water noted earlier. Petrie and Yeats (2000) reported higher oxygen at depth on the Scotian Shelf in the 1960s, also consistent with the increased influence of cool and fresh subpolar slope water during that decade. However, data sparseness makes it difficult to identify any long-term trends on the Scotian Shelf.

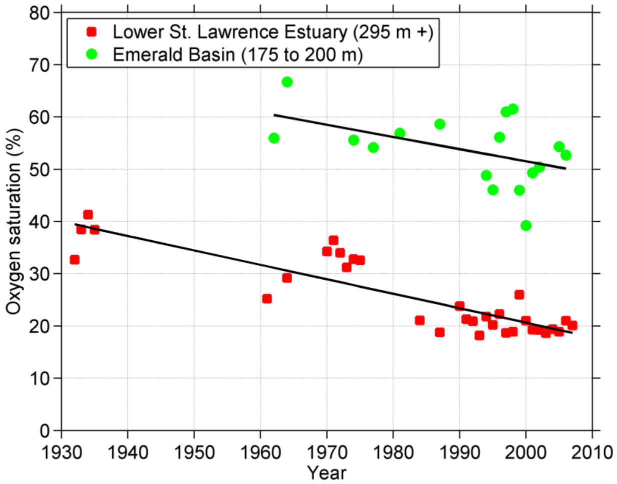

Figure 7-6: Annual means of oxygen saturation at depth in the Gulf of St. Lawrence and in Emerald Basin on the Scotian Shelf (D. Gilbert, Institut Maurice-Lamontagne, Fisheries and Oceans Canada).

7.4 IMPACTS

While the short term (seasonal, decadal) natural variability swamps anthropogenic change, we can anticipate more gradual anthropogenic change over the longer term (50 years). To date, the surface water has been warming since the 1980s, similar to the air temperature. There is some evidence of localized lower levels of dissolved oxygen and increased acidity, although no clear evidence of a long term trend in the circulation. Much of the relevant science topics (e.g., effects of acidification) are still highly active areas of research. While a comprehensive and precise assessment is not yet possible, there is enough knowledge to broadly assess potential climate change impacts. Related documents include Frank et al. (1990) and Fogarty et al. (2007). Climate change affects species' physiology, phenology and distribution. Those changes will in turn affect species interactions, which then affect species composition of an ecosystem.

7.4.1 Lower Trophic Level Production

Plankton are tightly coupled to climate variability. Changing oceanographic conditions affect not only the abundance of plankton, but also the composition. Coupled climate models suggests that phytoplankton production will increase in northern latitudes by 2040–2060 because of a longer growing season, and decline in the tropics because increased stratification will impede nutrient mixing in the upper water column (reviewed in Sherman et al. 2011).

Globally, the range of responses to climate change will vary because phytoplankton abundance is dependent on local combinations of controlling factors including nutrient availability, vertical and horizontal mixing light regime, amount of UV radiation, and level of thermal stratification. In general, in subpolar waters the warming/freshening of the surface waters may lead to longer or stronger stratification. That stratification would impede vertical mixing and limit nutrient availability. In contrast, coastal upwelling may increase due to an increase in

The **spring bloom** refers to the seasonal increase of phytoplankton abundance in the spring, dependent on light, nutrient upwelling, temperature and seasonal stratification of the water. In our region, there is also a lesser fall bloom when fall winds cause stratification to break down a bit, surface waters start to cool and the warmer deeper waters rise delivering new nutrients to the surface.

the land/sea temperature gradient, which would increase nutrient availability. To date, there is no clear picture as to whether anthropogenic climate change will increase or decrease primary production (Reid and Valdes 2011). On the Scotian Shelf there is typically a larger spring bloom, followed by a lesser, but longer duration fall bloom. The current trend on the Scotian Shelf indicates that phytoplankton abundance was higher in the early 1990s as compared to the 1960s (Head and Pepin 2010) whereas there was no annual trend in chlorophyll (index of phytoplankton growth) from 1997–2009 because of an increased spring bloom and a decreased fall bloom (Li et al. 2006; Li et al. 2009). Also, phytoplankton abundance more than doubled in the Labrador Sea that has warmed in the spring at a rate of (0.19+/-0.07°C/yr) since the mid-1990s (Li et al. 2006). What happens in the Labrador Sea will eventually influence the Scotian Shelf.

In terms of composition, warmer water favours more numerous but smaller organisms (for example picoplankton), while colder water favours fewer bigger organisms (Moran et al 2010; Reid and Valdes 2011; reviewed in Bode et al. 2011). This pattern could be used to predict that a warmer ocean will result in a change in the types and numbers of phytoplankton (Moran et al. 2010). The effects of stratification could exacerbate the preference for smaller sizes. As well, the increased amounts of picoplankton (really small plankton <2 μm) in Arctic Ocean outflow may eventually affect the Scotian Shelf (reviewed in Bode et al. 2011).

Phytoplankton size is relevant to the higher trophic levels. Fewer bigger organisms generally transfer energy more efficiently up the food chain. If higher temperatures lead to smaller organisms, energy flow through the ecosystem will be re-directed and less efficient (Li et al. 2006) and could not support the productivity of historical fisheries (Bode et al. 2011).

Adaptive ability of species

High levels of dispersal and genetic variability, and the ability of an organism to adapt to the environment within their lifetime are crucial to evolutionary adaptation. The copepod Calanus finmarchicus is highly capable of tracking suitable habitat. Provan et al. (2009) used DNA analysis to show that this important zooplankton was able to keep high levels of genetic variability over millennia, through ice ages (359 000–566 000 BP), and through high dispersal rates. The life history traits of small organisms lead them to grow fast, reproduce early and die young so that they can adapt faster through shorter generation times (Genner et al. 2010). Small-bodied organisms are favored in warmer waters possibly due to metabolic laws. Metabolic rate increases with temperature, which increases growth rate so they can reproduce earlier. Warmer temperatures would favor smaller-bodied organisms.

Zooplankton eat phytoplankton and are tightly coupled to their dynamics. To date, there have been no directional shifts in zooplankton production nor in species composition, although their dynamics are intimately tied to water mass composition (Johnson et al. 2011). *Calanus finmarchicus* occurrence has been experimentally shown to decrease as stratification increases, especially the younger copepodite stages. *Calanus finmarchicus* are the main source of fatty oil-rich food for larval fish, such as cod, in our region. If stratification continues to increase, we might expect lower availability of *Calanus finmarchicus* at some critical level (Reygondeau and Beaugrand 2011). Currently, that level is locally unknown.

7.4.2 Fisheries Production

Climate change is expected to redistribute the global fish catch potential. Catch is predicted to decline in the tropics and increase in northern latitudes. Canada's catch potential is expected to increase by about 5% by 2050 in a high GHG emission scenario but decrease <10% if emissions stabilized at 2000 levels (Cheung et al. 2010). When this model was reconfigured to account for expected effects of acidification, lower oxygen and smaller-celled phytoplankton, catch potential estimates were much reduced (Cheung et al. 2011).

The early life stages of fish populations are critical determinants of fish productivity and in a healthy population, are determined by climate and food availability. There is no question that climate plays a critical role in the population dynamics of northern temperate regions (Groger and Fogarty 2011) but so too does fishing (Frank et al. 2005). In the past few decades, researchers have tried to partition the effects of climate and the fishery on ecosystems. Increasingly, the view has evolved to acknowledge that the effects of climate and exploitation cannot be separated (see Journal of Marine Systems 79 [2010] and ICES Journal of Marine Science 68[6] [2011]).

Heavy fishing causes a reduction in diversity from the individual to the ecosystem level and diversity is the main buffer against climate variability (Perry et al. 2010; Planque et al. 2010). At the ecosystem level, an inability to tolerate both intense fishing and environmental variability can lead to community changes. For example, jellyfish and ctenophores eat zooplankton and fish larvae. Forage fish and groundfish larvae, such as cod, compete with jellyfish/ctenophores for zooplankton (Frank 1986). When forage fish or groundfish larvae decline, jellyfish and ctenophores have more zooplankton to eat and increase (Suthers and Frank 1990). To exacerbate their increase, jellyfish benefit in warmer, eutrophied water, and low levels of dissolved oxygen (Purcell 2011). Jellyfish and ctenophores thrive in human-impacted waters (Link and Ford 2006; Purcell 2011).

At the population/species level, intense fishing can lead to a truncation in the age/size structure, loss of sub-populations and a change in life-history traits, all of which renders them much more susceptible to environmental variability and chance events (Perry et al. 2010; Planque et al. 2010). Population variability increases at high levels of fishing and the population is less able to buffer environmental variability (Botsford et al. 2011). In effect, fishing renders populations more sensitive to climate variability (Hsieh et al. 2008).

> “Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal feasible means of reducing the impacts of climate change.”
> - Brander 2007

Importantly, in a global analysis of how fish production will respond to climate change, Brander (2007) asserts that fishing will remain the largest threat to fish production, including both captive (aquaculture) and wild fisheries, but that the impacts of climate and fishing interact. It is these interactions, which are not completely understood, that limits our ability to predict how production will change (Murawski 2011). A very generalized prediction for temperate regions is that there will be a community turnover through the arrival of warm-water species and the loss of cold-water species (MacNeil et al. 2010).

7.4.3 Chemical Oceanographic Properties

7.4.3.1 Ocean Acidification: Acidification is expected to impact physiology, including reproduction, and calcification processes (see *Ocean Acidification*). Such impacts will affect plankton and favour non-calcifying species. The effects of acidification are compounded by the expected increase in temperature and the solubility of CO^2. Such complex effects translate into complex ecological effects on bacteria (that produce CO^2) and zooplankton (that eat phytoplankton). This reorganization of the lower food chain will penetrate the rest of the food chain (Blackford 2010).

7.4.3.2 Hypoxia: Oxygen is essential for aerobic metabolism and the amount of dissolved oxygen (DO) affects growth, distribution and productivity. Warmer water cannot hold as much oxygen. When levels of dissolved oxygen become too low for biota, the condition is called hypoxia, and that lower threshold depends on the species. For example, there is an impact on growth and abundance of cod below 70% oxygen saturation level (Ekau et al. 2010; see refs in Gilbert et al. 2005; see refs in Chabot and Claireaux 2008).

In general, sediment-dwelling, longer-lived, immobile species would be most vulnerable (**Figure 7-7**). These species are actively involved in re-working the sediments through bio-irrigation (tube and burrow animals transport oxygen to the deeper sediments by breathing and flushing water from their tubes/burrows, thereby enhancing aerobic respiration and exchange of nutrients) and bioturbation (moving the sediment around and distributing oxygen below the surface and exchanging nutrients—much like earthworms). As such, their absence would clearly affect other organisms. Larger benthic organisms including echinoderms such as sea cucumber, and crustaceans such as lobster, need more oxygen and so are also vulnerable in low oxygen settings, whereas annelids, molluscs and cnidarians are less sensitive (reviewed in Middleburg and Levin 2009). Oxygen is declining at a faster rate in the coastal ocean than in open ocean (>100 km offshore) (Gilbert et al. 2010), which implies that coastal populations will be more affected than offshore populations.

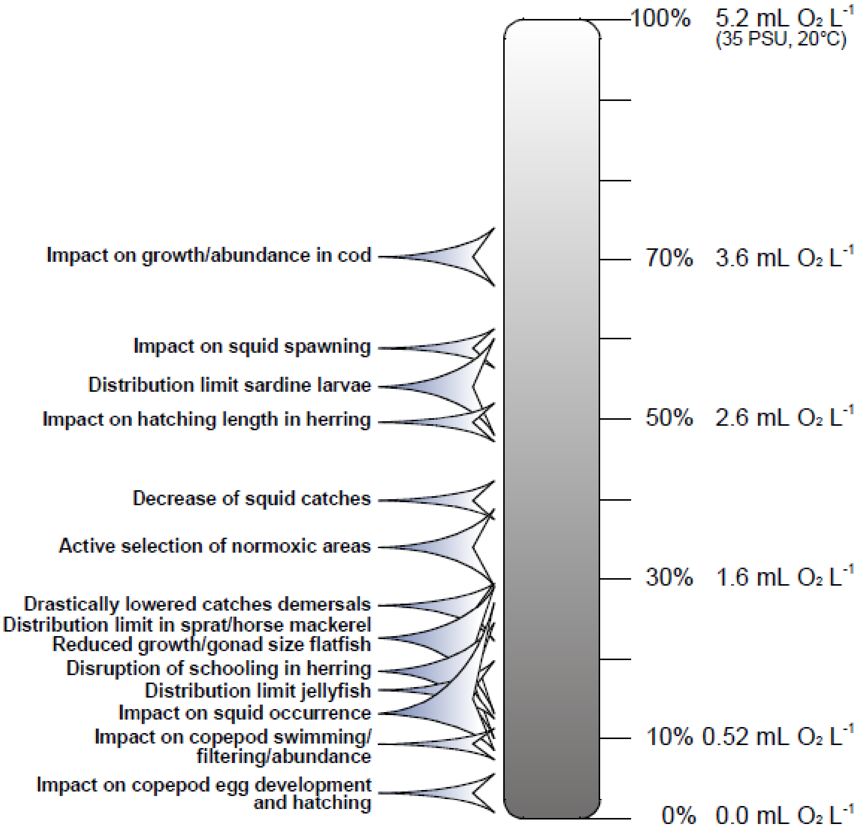

Figure 7-7: Behaviour and physiology responses of marine organisms to various oxygen saturation levels (Ekau et al. 2010).

7.4.4 Shifts in Spatial Distribution

Temperature is arguably the major determinant of growth, reproduction, feeding and distribution for all marine biota. As the temperature of the ocean changes, so does the distribution of organisms that live in the ocean, as described above for plankton. Global projections using a bioclimatic model predict that demersal marine organisms in the Northwest Atlantic will migrate poleward from 2005–2050, whereas pelagic marine organisms will migrate faster because the surface layers are expected to warm faster and pelagic species are more mobile (Cheung et al. 2009). The most extreme responses to climate change have been documented in the Northeast Atlantic and the Northwest Pacific, where SST has been consistently increasing (Parmesan 2006; reviewed in Drinkwater et al. 2010).

Locally, temperature regime continually modifies fish distribution and composition. When the eastern Scotian Shelf was inundated by cold water, cold-adapted capelin flourished (Frank et al. 1996). Variations in the NAO induce temperature anomalies and can cause changes in the latitudinal diversity gradient of fish (Fisher et al. 2008). Species in the temperate to subarctic North Atlantic feed and spawn from -2 to 20°C, but the majority feed at 0–4°C and spawn from 2–7°C (Rose 2005). Warming will influence changes in distribution. However, it is possible that the temperature tolerances of opportunistic species have been underestimated by using simple survey data. Using electronic tags, Righton et al. (2010) were able to determine that cod were much more tolerant than previously considered.

There have been shifts in distribution at lower latitudes (Nye et al. 2009) as well as in the eastern North Atlantic (Hofstede et al. 2010), where change is occurring rapidly. However, large changes in community assemblages on the Scotian Shelf up to the mid-2000s have been due to intense fishing, not warming (Frank et al. 2005; Shackell and Frank 2007). The same is true for the Northeast US (Fogarty and Murawski 1998; Auster and Link 2009; Shackell et al. 2012) and elsewhere in temperate waters (Blanchard 2001). The mechanism of change is that the removal of dominant commercial fish allows either their prey or less commercial species to thrive as was observed on the Scotian Shelf (Koeller et al. 2009).

Seasonal patterns of animals are evolved behaviours adapted to environmental conditions. In temperate marine climates, there is often a limited window when conditions for growth, feeding or reproduction are optimal. The timing of these events is called phenology.

7.4.5 Changes in Timing of Ecosystem Events

<u>7.4.5.1 Seasonal Events</u>: Climate change has caused a shift in the timing of seasonal events (phenology) of plants, animals and marine organisms around the world (reviewed in Visser and Both 2005). The ability to adapt phenology (the timing of seasonal events such as reproduction, migration) to climate change varies widely among species but can be generally predicted if the seasonal cues (e.g. temperature, light) to seasonal behaviour are well known. Seasonal cues are known for many (Greve et al. 2005) but not all key species.

A key taxon is the plankton, the base of the food chain. There was no directional trend towards earlier spring blooms on the Scotian shelf since 1998 (see Figure 4a in Song et al. 2010) although fresher surface waters can cause earlier spring blooms and later fall blooms (Song et al. 2011). However, the observed trend in salinity changes is expected to eventually affect phytoplankton phenology given that salinity is one of the strong determinants of spring bloom timing from 1998–2008 (Song et al. 2010). The authors hypothesize that the additional influx of surface freshwater from the fresher (low-salinity) Scotian Shelf water helps set up stratification, in addition to warming in the spring.

Although several global examples of changes in marine plankton phenology exist (see also Li et al. 2006), plankton are naturally extremely variable. Researchers are working on how to assess changes in phenology in response to climate change so that a more uniform and global picture can be achieved (reviewed in Ji et al. 2010). The current time series of remote sensing (since 1998) of chlorophyll may be too short to detect long-term change because the natural intrinsic variability is so high, but researchers are developing models to improve interpretation of observational, noisy data (Platt et al. 2009).

7.4.5.2 Trophic Interactions and Match-Mismatch Theory: If climate change will shift timing of seasonal events then it will also affect trophic interactions if predators and their prey respond differently to a shift in seasonal events. Many species are adapted to give birth during a time when peak abundances of their young will coincide with peak abundances of their prey, as survival depends on having enough to eat (reviewed in Stenseth and Mysterud 2002; Durant et al. 2007). That is, the predator's timing in peak abundances will "match" the peak abundance of their prey. When peak abundances do not coincide, this is referred to as "mismatch" and the predator's likelihood of survival is reduced. Suppose that two trophic levels, fish larvae and their copepod prey are triggered by different seasonal cues. It follows that a mismatch may be more likely if those different cues do not co-vary in a changing climate (**Figure 7-8**). However, if phytoplankton abundance increases as a result of climate change, this might offset the effects of a mismatch between predator and prey (Durant et al. 2007). In a review of 11 species showing changes in phenology, 8 were mismatched because of the trend in climate change (Visser and Both 2005 and see review in Durant et al. 2007). Such mismatches are expected to affect energy flow to higher trophic levels, and will have implications on the ecosystem.

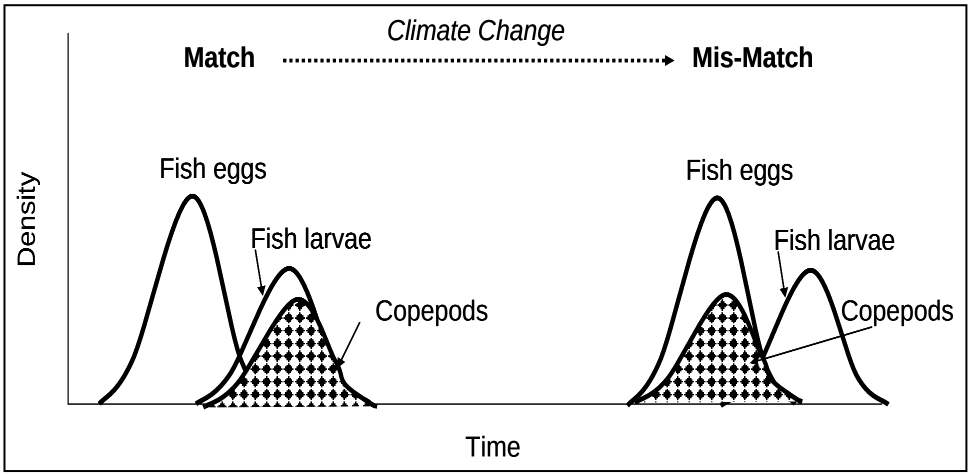

Figure 7-8: Match-Mismatch in the marine environment. Many fish are adapted to spawn so that peak larvae abundance will coincide with their copepod prey. If copepod peak abundance occurs earlier due to climate-induced shift in seasonal cues, and fish do not adapt in the same direction, peak abundances between predator and prey will be mismatched.

7.5 ACTIONS AND REPONSES

7.5.1 Government Policy and Action Plans

The United Nations Framework Convention on Climate Change (UNFCCC) has set targets to reduce GHG emissions and has asked nations for effective accountability measures to meet those targets. Reductions in GHG emissions requires international action and responses. Canada ratified the United Nations Framework Convention on Climate Change in 1992. There have been several international UN fora designed to negotiate among countries to combat climate change. The most notable to date was the Kyoto Protocol designed in the late 1990s. The Kyoto protocol is an international agreement to fight global warming and calls for emissions reductions. Targets varied for developed and developing countries. For Canada, the target was a reduction of 6% of greenhouse gas emissions from 1990 levels by the 2008–2012 period. That is, the average level of GHG emissions should be 6% lower than the 1990 levels during the period 2008–2012. Canada ratified the Kyoto protocol in 2002 and so committed the country to reduce GHG emissions. However, Canada's 1990 emissions were 592 megatonnes (Mt) CO_2 equivalent, and in 2007 they were 747, representing a 26.2% increase in Canadian GHG emissions (**Figure 7-9**), meaning Canada was 33.8% above the Kyoto target in 2007 (Government of Canada 2010). Canada announced that it would withdraw from the Kyoto protocol in December 2011; however, current Canadian legislation remains in force.

UN fora subsequent to Kyoto (e.g. Bali, Copenhagen) set other targets under other accords (Government of Canada 2010). Canada's current commitment is as follows: "The Government of Canada is committed to reducing Canada's total greenhouse gas emissions by 17 per cent from 2005 levels by 2020 – a target that is inscribed in the Copenhagen Accord and aligned with the United States" (Government of Canada 2011). That reduction would be 17% of 731, which would mean a target of 606.73 Mt CO2 equivalent GHG emissions by 2020.

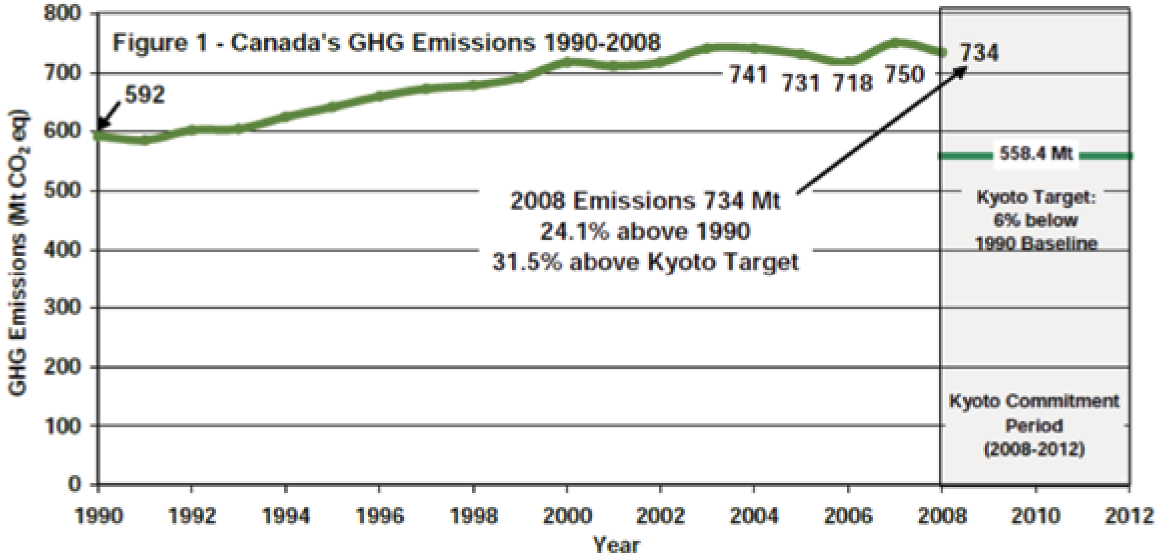

Figure 7-9: Canadian GHG emission trend and Kyoto Target from National Inventory Report 1990–2008: Greenhouse Gas Sources and Sinks (Government of Canada 2010)

The *Kyoto Protocol Implementation Act* (2007) is Canada's legislation to address climate change. The act requires the government to formulate a climate change plan every year until 2013. Nova Scotia has a climate change action plan (Province of Nova Scotia 2011a). The Nova Scotian government has set targets under the *Environmental Goals and Sustainable Prosperity Act* (*EGSPA*) proclaimed in 2007. In 2010, the province had fully articulated goals and objectives to reduce its environmental footprint, including GHG emission reduction. This legislated target is 10% below 1990 GHG levels by 2020. Legislation of targets is still rare and should be noted (Province of Nova Scotia 2011b).

In addition to reducing greenhouse gas emissions, there is also a need to respond to changes in the ecosystems that are already occurring or predicted to occur. The Nova Scotia Climate Change Directorate (within the Department of Environment) is responsible for ensuring all departments understand the impacts of climate change on their operations and develop adaptation plans to ensure they are prepared for climate changes and their subsequent impacts. The Government of Canada has a national Climate Change Adaptation Program, which funds activities in several departments. From a global perspective, Canada is considered a country with a high capacity to adapt to climate change based on a suite of indicators, including health, education, size of the economy and governance system (Allison et al. 2009).

7.5.2 Monitoring and Research

Atlantic Canada marine ecosystems are monitored by Canadian provincial and federal agencies, principally, Fisheries and Oceans Canada (DFO) and Environment Canada. In 1999, DFO established the *Atlantic Zonal Monitoring Program* (AZMP) (http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/azmppmza/index-eng.html). The main objectives of AZMP are to collect and analyze biological, chemical, and physical data to characterize and understand the causes of oceanic variability at different time scales; and to provide the multidisciplinary data sets that can be used to establish relationships among the physical, chemical and lower trophic level components of the ecosystem and their links to higher trophic levels.

Global generalities may be projected, but each region needs to be examined for local effects. Globally, researchers have created models that use IPCC-class climate results to examine ecosystem scenarios. For example, Cheung et al. (2009) used a "bioclimate envelope" global model and predicted that by 2050, there will be local extinctions and invasions, resulting in a 60% species turnover relative to current biodiversity patterns. The general consensus is the field has progressed greatly, but would be improved by a better mechanistic understanding of how climate shapes biology, as well as an improvement in IPCC-class climate model predictions, in particular at regional and local scales (Stock et al. 2010).

> "The principal brake to climate change remains reduced CO_2 emissions that marine scientists and custodians of the marine environment can lobby for and contribute to."
>
> - Brierley and Kingsford, 2009

Numerous changes in phenology, species distribution, community composition have been ascribed to climate change in the last 30 years (reviewed by many but see Walther et al. 2002). Our ability to know what communities and ecosystems will look like is hampered because global climate change affects regions so differently. More importantly, it is difficult to predict complex ecological interactions in the absence of climate change, and even harder in its presence. It will always be difficult to predict beyond broad generalities. It is the broad generalities outlined in this paper that may be used to inform policy, and for identifying future research avenues.

In the fall of 2011, the DFO announced a new program called the Aquatic Climate Change Adaptation Services Program (ACCASP). The goal is integrate the evident climate change into existing DFO planning processes. This “adaptation” will be accomplished through directed research on climate change projections and impacts on freshwater and marine ecosystems as well as other vulnerable areas of DFO responsibility. The program also aims to develop adaptation tools for use in DFO management and decision-making.

7.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR	Assessment[1]	Trend[2]
GHG Emissions	Global warming and other long-term climate changes.	Driving Force	Poor	-
Natural climate variability	Regional near-term climate change.	Driving Force	Good	/
Gulf Stream Position	Potential northward shift resulting in increased subtropical influences.	Pressure	Good	/
Increasing Ocean Temperature	Implications for Sustainable and Prosperous Ecosystems.	Pressure	Fair	/
Increasing Vertical (Density) Stratification	- Effects on primary production. - Effects on oxygenation of subsurface waters.	Pressure	Fair Fair	/ -
Ocean acidification (pH)	Low growth and high mortality in some species.	Pressure	Fair	-
Ecosystem productivity	Climate-induced reduction of ecosystem services with respect to phytoplankton and fishery yield.	Impact	Good	/
Shifts in species distribution	Change in availability of fishery resources.	Impact	Fair	/
Ecological timing	Change in timing of seasonal events may affect trophic interactions.	Impact	Unknown	?
Nova Scotia's Action on Climate Change	Province of Nova Scotia's response to climate change.	Response	Unknown	?
Aquatic Climate Adaptation Services Program (DFO)	Integration of climate change into existing DFO planning processes.	Response	Unknown	?

[1] Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.

[2] Trend: is the trend positive or negative in terms of implications for the state of the environment? It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Key:
Negative trend: - Positive trend: + Unclear or neutral trend: / No assessment due to lack of data: ?

Data Confidence

- Available datasets for atmospheric variables and ocean temperature and salinity are adequate for describing regional climate variability during the past 60–90 years, but the ocean datasets are not widespread or long enough for separating anthropogenic and natural climate variations with confidence.
- The sparser and shorter available data sets for chemical and plankton variables are adequate for describing variability during the past decade or two, but also not long enough for identifying whether there are changes occurring due to anthropogenic climate change.
- Longer datasets for upper trophic levels of fish are adequate for identifying changes but the latter tend to be dominated by fishing influences such that it is difficult to identify climate change influences.
- While existing climate models represent large-scale variations in the Earth's climate system well, they do not have an adequate representation of the Gulf Stream, Labrador Current and Atlantic Canadian shelves to provide projections of regional ocean climate change with confidence.

Data Gaps

- The limited duration of all available ocean and marine ecosystem datasets limits the identification of anthropogenic climate change and its impacts. Ongoing monitoring programs and resulting indices are needed, including sensitive biogeochemical variables such as ocean acidity and dissolved oxygen.
- Improved indices of large-scale ocean circulation changes (e.g. Gulf Stream, Labrador Current) are needed since such changes could lead to regime shifts at some trophic levels.
- Since there can be important influences on both lower and higher trophic levels from changes in the ocean climate's seasonality (e.g. onset of spring stratification affecting plankton blooms and fish recruitment), it is important that climate and ecosystem indices resolve the seasonal cycle in key variables.
- Development of metrics for fish populations which include fishing impacts is needed in order to identify climate change influences on fish.

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8. OCEAN ACIDIFICATION[16]

Kristian Curran and Kumiko Azetsu-Scott, Fisheries and Oceans Canada, Dartmouth, NS

8.1 ISSUE IN BRIEF

There is no more important geophysical relationship on Earth than that between our atmosphere and the ocean. The atmosphere overlies 100% of our planet, while the ocean covers 75% of its surface. This provides a large surface area in which the two interact. An interaction of particular importance is the movement of atmospheric gases into the ocean, which serves to balance their concentrations in the atmosphere. As such, an elevated carbon dioxide concentration in the atmosphere results in an elevated carbon dioxide concentration in the surface ocean (i.e., upper 100–200 metres or so) (Sabine et al. 2004; Royal Society 2005). As carbon dioxide dissolves in the surface ocean a certain proportion reacts with seawater to form carbonic acid, which is a weak acid that increases the dissolved hydrogen ion concentration and decreases pH. This phenomenon is commonly referred to as "ocean acidification" (Feely et al. 2004; IPCC 2007a)[17]. The relationship between the Earth's atmospheric carbon dioxide concentration and surface ocean pH is complicated by the ocean's ability to buffer carbonic acid formation (Caldeira et al. 1999). Buffering is a mechanism that can keep pH at a relatively stable level despite the addition of an acid, due to the presence of another chemical constituent that reacts with the acid to neutralize its presence. In the ocean, the principal buffering agent is carbonate. It acts to neutralize the presence of carbonic acid in the sea.

Over time periods greater than 10 000 years, marine ecosystems are able to regulate changes in ocean pH through carbonate buffering (Caldeira et al. 1999). Over shorter timescales the ocean cannot easily respond. Today's concern regarding ocean acidification resides in its unprecedented rate of occurrence, due to the significant amount of carbon dioxide that has been added to the atmosphere over the past 250 years. Ocean acidification that occurs over a period of a couple of hundred years can show significant negative impacts on the state of the marine ecosystem. Over the past 50 years, the atmospheric carbon dioxide concentration has increased by 75 parts per million (ppm) (NOAA 2011). This exceeds by100-fold a known period of similar rapid increase that occurred over a 6000-year time period following the last Ice Age (IPCC 2001; Royal Society 2005). Since 1750, ocean pH has decreased from 8.2 to 8.1, which is equivalent to a 30% increase in the hydrogen ion concentration in the sea (Royal Society 2005). The potential effects of ocean acidification include altered seawater chemistry; decreased growth and productivity of calcium carbonate-based organisms; changes in respiration in large invertebrates, fish, and some zooplankton; increased growth of certain seaweeds and sea grass; changes in species composition and dominance; societal and economic impacts; and other potential impacts that presently remain unknown.

Linkages

This theme paper also links to the following theme papers:
- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Primary and Secondary Productivity
- Marine Habitats and Communities
- Trophic Structure

Science on the cause of ocean acidification is robust, while more studies regarding its potential effects on marine ecosystems are urgently needed (Royal Society 2005; Fabry et al.

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[16] Completed October 2012.

[17] Ocean acidification is an effect of "ocean carbonation," which is the addition of atmospheric carbon dioxide to the ocean. Ocean carbonation, rather than ocean acidification, is perhaps a better characterization of the primary driver behind the range of marine-related impacts associated with increased atmospheric carbon dioxide levels.

2008; ICES 2008; CBD 2009; Doney et al. 2009; ICES 2011). A decrease in ocean pH is certain to occur over the coming century and longer due to present day atmospheric carbon dioxide levels, even with legislative or policy-driven reductions in carbon dioxide emissions to the atmosphere. Since a decrease in surface ocean pH and its associated impacts cannot be easily reversed, adaptive measures coupled with a reduction in carbon dioxide emissions to the atmosphere will have to be pursued to protect ecosystems and human livelihoods against this phenomenon. Examples of adaptive measures include the precautionary management of natural resources in the presence of uncertain ocean acidification-driven impacts, as well as research and development of methods and technologies that will allow vulnerable ocean industries and society to adapt to a changing marine ecosystem (**Figure 8-1**). The aim of this paper is to describe the cause and effect of global ocean acidification and what it may mean for the marine ecosystem of the Scotian Shelf region of Atlantic Canada.

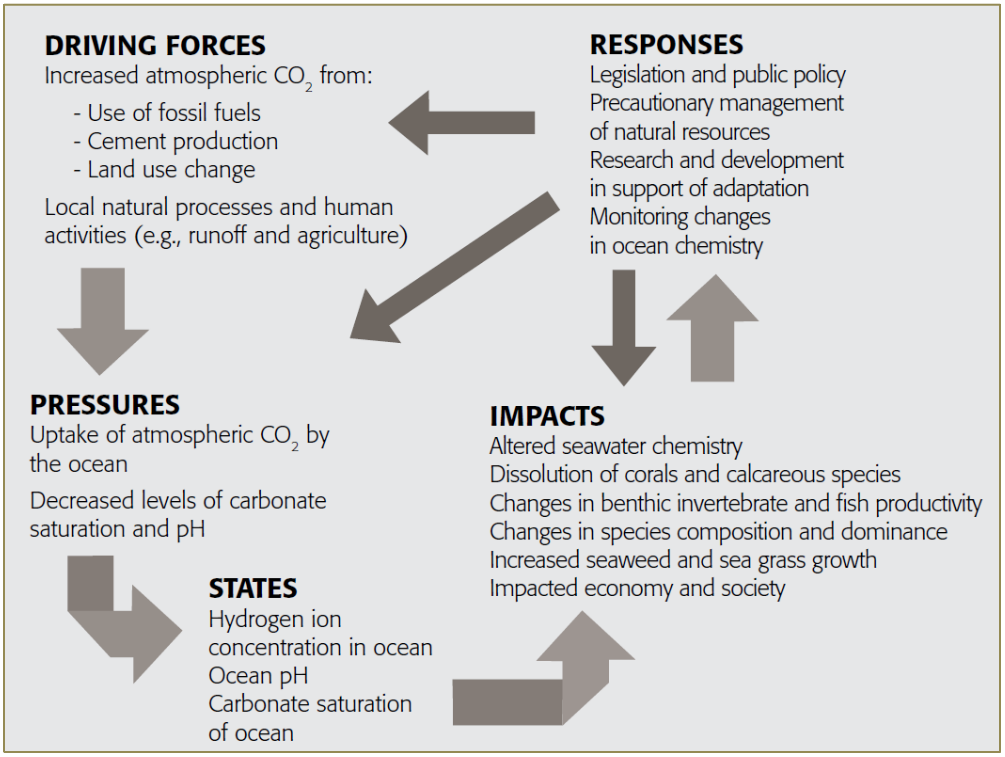

Figure 8-1: Driving forces, pressures, states, impacts, and responses (DPSIR) to ocean acidification on the Scotian Shelf. The DPSIR framework provides an overview of the relationships between the environment and human activity. According to the reporting framework, natural conditions and social and economic development (driving forces) exert pressures on the environment and, in doing so, the existing state of the environment is changed. Such changes can affect natural ecosystems, as well as humans that rely on ecosystems for their economic and social well-being. The changes, in turn, may elicit societal or government responses that influence other elements of the DPSIR framework.

8.2 DRIVING FORCES AND PRESSURES

To understand the present day concern over ocean acidification we must first understand some basic dynamics of carbon, the relationship between our atmosphere and ocean, and past patterns of ocean acidification. Carbon is found on our planet in the biosphere (e.g., plants and soils), atmosphere (e.g., carbon dioxide and methane), ocean (e.g., dissolved carbon, biota, and sediments), and underlying geology (e.g., petroleum and limestone). Through various natural and human induced processes, carbon is continually moving in different forms between these pools. This is known as the carbon cycle (see Holmen 2000). In the atmosphere, carbon dioxide is fundamental to human survival by virtue of its role in retaining heat—it is a "Greenhouse Gas" (IPCC 2007b). Over the past two centuries, however, significant additions of carbon dioxide to the atmosphere have occurred due to fossil fuel combustion, cement production, and changing land-use patterns, all of which emit carbon dioxide to the atmosphere (Houghton and Hackler 2001; IPCC 2001; Royal Society 2005; CBD 2009).

Through these activities, humans are moving large quantities of carbon dioxide into the atmosphere, and, in doing so, significantly altering its natural distribution on Earth. Since 1950, the global population has almost tripled, increasing from 2.5 to 7 billion individuals in just over 60 years (UN DESA 2011). Over a similar time period, the atmospheric carbon dioxide concentration has increased from approximately 315 ppm to 390 ppm (**Figure 8-2**; NOAA 2011), with modelled estimates suggesting an atmospheric carbon dioxide concentration of approximately 700-1000 ppm by the end of the twenty-first century (the predicted range is attributed to different model scenarios). The emission of carbon dioxide, however, remains disproportionate amongst nations, with the industrialized and developing nations emitting more carbon dioxide per capita than the often more highly-populated underdeveloped nations. For example, Canada is home to only 0.5% of the global population yet it accounts for 1.5% of all carbon dioxide emitted to the atmosphere on an annual basis. Canada currently ranks ninth as a nation in annual total carbon dioxide emissions to the atmosphere (CDIAC 2012).

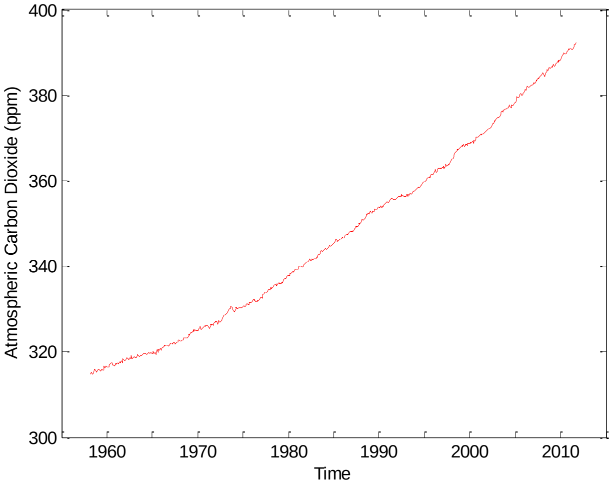

Figure 8-2: Atmospheric carbon dioxide concentration versus time since the late-1950s. Over the past 60 years, the atmospheric carbon dioxide concentration has increased by approximately 75 parts per million (ppm). The atmospheric carbon dioxide concentrations presented in this figure constitute measurements made at the Mauna Loa Observatory, Hawaii, by C. David Keeling of the Scripps Institution of Oceanography and the U.S. National Oceanic and Atmospheric Administration (source: NOAA 2011). This data has been reproduced with permission from the U.S. National Oceanic and Atmospheric Administration.

The timescale of carbon dioxide exchange from the atmosphere to the ocean is approximately a year (Wolf-Gladrow et al. 1999). This means an increase in the atmospheric carbon dioxide concentration readily translates into an increase in the dissolved carbon dioxide concentration found in the surface ocean. A product of increased carbon dioxide dissolution in the surface ocean is the formation of carbonic acid, which further dissociates in seawater to yield excess hydrogen ions that cause pH to decrease— "ocean acidification." The excess hydrogen ions then react with excess carbonate already found in the sea to form bicarbonate, which helps offset any change in pH—"carbonate buffering". In simple terms, pH is a measure of how acidic or basic a substance is. It is measured on a scale of 0 to 14, where a pH of 7 is considered "neutral" (e.g., purified water), a value less than 7 "acidic" (e.g., lemon juice), and a value greater than 7 "basic" (e.g., dish soap). At no time in the known past has the ocean ever been acidic (i.e., a pH less than 7), although it has fluctuated in its relative pH due to changes in the Earth's atmospheric carbon dioxide concentration (**Figure 8-3**, top panel; Caldeira et al. 1999; Pearson and Palmer 2000; Caldeira and Wickett 2003; Sabine et al. 2004). Aside from this global phenomenon, there are also regional and local drivers of ocean acidification, such as organic matter respiration, coastal runoff, and industrial activity, although these drivers are not discussed in this paper (see: Kelly et al. 2011; Mucci et al. 2011).

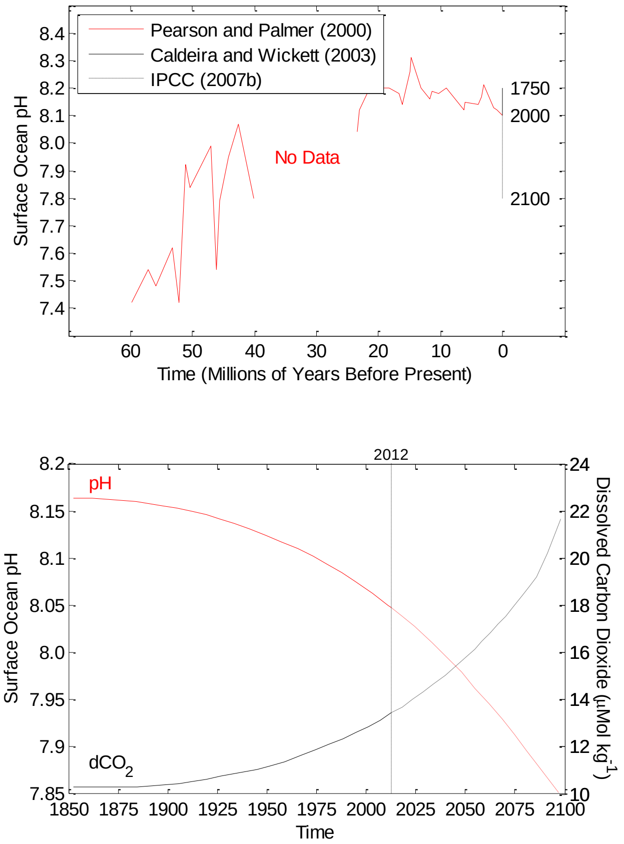

Figure 8-3: Surface ocean pH versus time. The upper panel demonstrates changes in surface ocean pH over the past 60 million years before present (solid red line), reproduced from data published by Pearson and Palmer (2000). The solid black line represents the change in pH since the Industrial Revolution (1750–2000 A.D.) (Caldeira and Wickett 2005). The dashed black line is the predicted change in pH by the end of the twenty-first century forecast using a series of global climate models outlined by Meehl and others in the Intergovernmental Panel on Climate Change report published in 2007 (IPCC 2007b, see Figure 10.24 on page 795). On the upper panel, present time is considered to be 1750 A.D (i.e., present time equals zero on upper panel). The lower panel outlines observed (solid lines) and predicted (dashed lines) changes in ocean pH (red) and the dissolved carbon dioxide concentration in the surface ocean (black) from 1850–2100 (redrawn from Feely et al. 2006).

8.3 STATUS AND TRENDS

Globally, the atmospheric carbon dioxide concentration has varied from approximately 3500 ppm almost 60 million years ago to more constant values of approximately 100-400 ppm over the past 20 million years (**Figure 8-3**, top panel; Pearson and Palmer 2000). Over the 400 thousand years before the Industrial Revolution (circa 1750), the atmospheric carbon dioxide concentration ranged between 200-280 ppm (Feely et al. 2004). Since the Industrial Revolution, the atmospheric carbon dioxide concentration has increased by 100 ppm, reaching 380 ppm in 2000, with projected concentrations of 700-1000 ppm anticipated by the end of the twenty-first century (IPCC 2007b). In contrast, the average pH of the surface ocean has decreased from 8.2 to 8.1 over this same time period (Caldeira and Wickett 2005). By 2100, it is projected that pH will further decrease by an estimated 0.15-0.35 (Figure 3, bottom panel; IPCC 2007b). In total, between 1750 and 2100, pH of the surface ocean is predicted to decrease from 8.2 to 7.8 (IPCC 2007b).

The ocean is a major sink for atmospheric carbon dioxide. From 1800 to 1994, almost half of all carbon dioxide emitted to the atmosphere from fossil fuel consumption has been absorbed by the ocean (Sabine et al. 2004). Thirty percent of this is found in the upper 200 m and 50% in the upper 400 m (Sabine et al. 2004). In contrast, only 7% is found at ocean depths greater than 1500 m (Sabine et al. 2004). The North Atlantic is a global “hotspot” for atmospheric carbon dioxide absorption, accounting for 23% of the ocean’s total uptake between 1800 and 1994, even though this region only constitutes 15% of the global ocean’s surface area (**Figure 8-4**; Sabine et al. 2004). Between 1983 and 2005, the rate of atmospheric carbon dioxide entering the North Atlantic Ocean near Bermuda increased, while pH in the region decreased by 0.037 over the same time period (Bates 2007). On the timescale of the coming decades to centuries, considered an instant in geological terms, the ocean will continue to absorb significant amounts of carbon dioxide from the atmosphere, since atmospheric concentrations are expected to double relative to their pre-industrial levels over this time period. The anticipated result is a continued increase in carbonic acid formation in the surface ocean coupled with a continued decrease in dissolved carbonate levels and, hence, an accelerated decrease in pH (Sabine et al. 2004). Unfortunately, very few long-term ocean pH time series exist (Nye 2010).

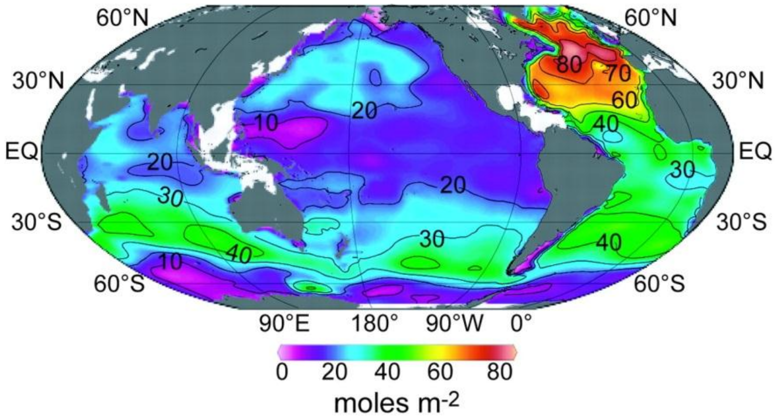

Figure 8-4: Atmospheric carbon dioxide concentration from anthropogenic sources entering ocean surface waters between 1800-1994 (Sabine et al. 2004). Waters of the North Atlantic are a major sink for atmospheric carbon dioxide, accounting for 23% of the total global ocean uptake over this time period despite constituting only 15% of the global ocean’s surface area (Sabine et al. 2004, reprinted with permission from the American Association for the Advancement of Science).

The North Atlantic, with its exceptional capacity to uptake atmospheric carbon dioxide, will likely see greater rates of ocean acidification relative to other ocean basins, especially as its ability to buffer future carbonic acid formation is continually reduced through time. Because the Scotian Shelf is found in the North Atlantic Basin, it may be particularly vulnerable to increased atmospheric carbon dioxide uptake and the accompanying changes in pH. Observations of ocean pH on the Scotian Shelf over the past several decades demonstrate a general decrease through time (**Figure 8-5**). The decrease in pH observed in Scotian Shelf waters is slightly greater than the average global ocean decrease observed over the same time period, although the cause of this remains unknown (DFO 2009). Many factors influence global climate, making it difficult to predict how the marine environment will change. The unique oceanographic environment of the Scotian Shelf as a general convergence zone between several very different water masses makes it even more difficult to determine the rate and degree to which waters of the region may acidify. Although the effects that ocean acidification may have on the marine ecosystem of the Scotian Shelf are uncertain, a concern remains that any potential impacts could be severe (ICES 2011).

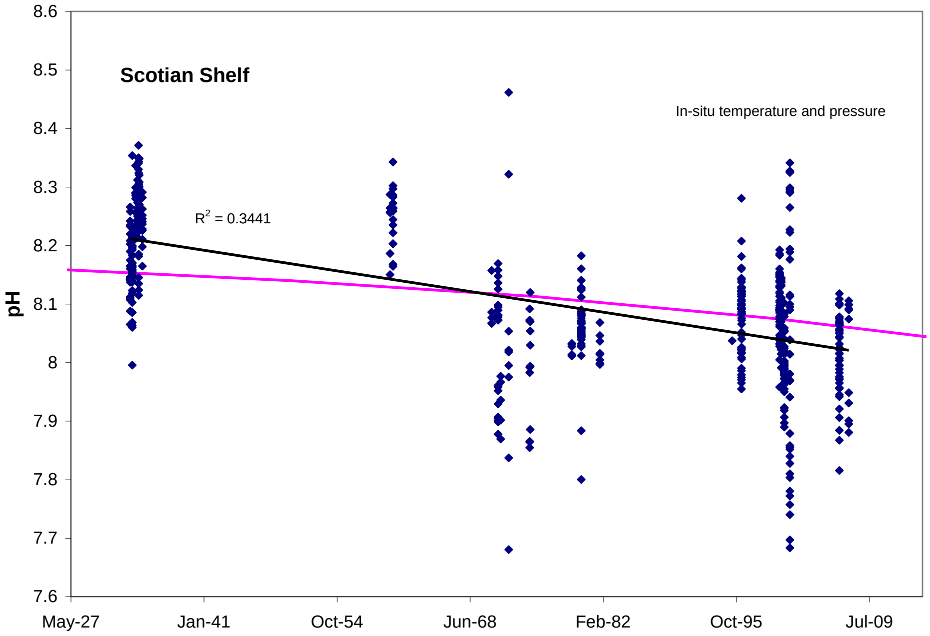

Figure 8-5: Decrease in pH on the Scotian Shelf over the past century. Time is reported in month and year (DFO 2009). Blue data points represent pH measurements from various locations on the Scotian Shelf, the black trend line indicates a decrease in pH with time, and the pink trend line represents the mean global ocean decrease in pH over the same time period.

8.4 IMPACTS

There are many potential impacts that could result from ocean acidification on the Scotian Shelf. At present, the body of scientific literature on potential effects remains limited in available field observations, while much of the existing observations are based on laboratory studies of short duration and differing research protocols (Royal Society 2005; Fabry et al. 2008; ICES 2008; CBD 2009; Doney et al. 2009; ICES 2011). This has made comparison of existing observations difficult. To resolve this challenge, the research community has come together to agree upon standard research protocols and to share and discuss its results, with many new studies on the effects of ocean acidification being published each month (see EPOCA 2012). Notwithstanding, it remains difficult to generalize existing research results regarding the impacts of ocean acidification on marine ecosystems at large as, for example, similar species often show different responses to ocean acidification between regions. On the Scotian Shelf, this task is made even more difficult due to a lack of scientific research occurring in this region on ocean acidification. **Table 8-1** provides examples of potential impacts resulting from ocean acidification that could occur on the Scotian Shelf. These are taken from scientific studies carried out in other regions of the ocean, although focused on marine attributes found on the Scotian Shelf.

Table 8-1: Potential impacts of ocean acidification that could occur on the Scotian Shelf.

Element	Impacts
Biophysical Impacts	
Carbonate saturation	Decrease in surface ocean carbonate saturation. This, in turn, affects calcium carbonate solubility. The aragonite form of calcium carbonate is more susceptible to dissolution than calcite in the short term, making aragonite-based organisms more vulnerable.
Nutrients and toxicity	Alteration of nutrient availability such as nitrogen, phosphate, and iron, leading to changes in the availability of nutrients to marine organisms that rely on them for growth and prosperity.
Marine organisms	Calcareous-based marine organisms are vulnerable to changes in dissolved carbon dioxide concentration and pH due to increased dissolution (e.g., cold-water corals).
Benthic invertebrates	Increased dissolved carbon dioxide in seawater may affect benthic invertebrate respiration, making calcareous-based organisms more susceptible to dissolution.
Marine fish	Increased dissolved carbon dioxide in seawater may lead to increased levels of carbon dioxide in the body tissue of fishes, in turn, impacting their respiration, circulation, and metabolism.
Seaweed and sea grass	Certain marine seaweeds and sea grass may exhibit increased growth rates due to increased dissolved carbon dioxide in the sea.
Ecosystem structure and function	The compounding effects of climate change (e.g., acidification, warming, and stratification) on multiple aspects of the marine ecosystem poses the greatest uncertainty, although it is believed ocean acidification alone will be enough of a driver to alter species composition and dominance in a manner that could profoundly alter marine ecosystem structure and functioning.
Socio-Economic Impacts	
Marine fisheries	Shellfish comprises the majority of the annual landed fishery value in Nova Scotia, with many of the shellfish species found on the Scotian Shelf potentially being vulnerable to ocean acidification due to their calcareous-based structures (e.g., American lobster and sea scallop).
Marine aquaculture	Many aquaculture species currently being harvested in Nova Scotia are potentially vulnerable to ocean acidification due to their calcareous-based structures (e.g., blue mussel, American oyster, and quahog clam).

8.4.1 Seawater Chemistry

Much of the surface ocean is saturated in dissolved carbonate. Ocean waters decrease in dissolved carbonate concentrations with depth. At some depth, there is a boundary above which the dissolved carbonate is in excess (i.e., oversaturated) and below which carbonate is in deficit (i.e., undersaturated)—the boundary between “excess” and “deficit” is known as the “carbonate saturation horizon” (Royal Society 2005). The saturation horizon varies in depth throughout the global ocean due to differences in temperature and pressure, much as a snow line may vary in height on mountain tops due to differences in temperature. Today, dissolved carbonate concentrations in the global ocean are at the lowest levels believed to have existed over the past 800 000 years (IAP 2009). As discussed above, dissolved carbon dioxide in the sea reduces the carbonate concentration due to its buffering mechanism. It is predicted that productive surface waters of the Arctic Ocean and Southern Ocean will be undersaturated in essential carbonate minerals by 2032 and 2050, respectively (CBD 2009).

Carbonate is an important ingredient in the formation of coral reefs, plankton shells, shellfish shells, and certain fish sensory organs by way of its reaction with calcium to form calcium carbonate. Calcium carbonate exists in the ocean in two general forms that are similar in chemical composition, but differ in their molecular packaging: calcite and aragonite. Of the two, aragonite is more soluble than calcite, so its saturation horizon is found much closer to the ocean's surface (Royal Society 2005). Long-term observations of the aragonite and calcite saturation states are not available for the Scotian Shelf, although observations from the nearby Labrador Sea demonstrate a general decrease in the aragonite and calcite saturation states over the past two decades (**Figure 8-6**). Similarly, waters of the lower St. Lawrence estuary have exhibited significant decreases in pH due to the increased accumulation of metabolic carbon dioxide in bottom waters (i.e., pH values near 7.7), decreasing both the calcite and aragonite saturation states in this region (Mucci et al. 2011).

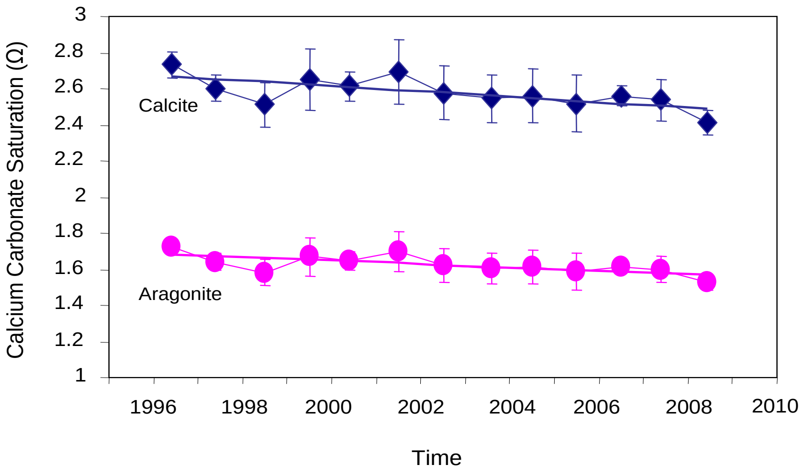

Figure 8-6: Decreasing calcite and aragonite calcium carbonate saturation state (Ω) of newly ventilated Labrador Sea Water through time. The boundary between oversaturation and undersaturation is denoted by a value of one on the figure (Ω=1), with calcite exhibiting a higher saturation state than aragonite.

Ocean acidification is also expected to alter seawater chemistry in a manner that affects the nutrients, trace metals, and toxins available to marine organisms (Royal Society 2005; Doney et al. 2009). Alterations in seawater chemistry may reduce the availability of phosphate, ammonia, and many other nutrients and trace metals that marine organisms rely on for growth (Royal Society 2005; ICES 2008). Similarly, it is believed an increase in the hydrogen ion concentration may increase the toxicity of select trace metals found in seawater. Predicting changes in seawater chemistry and its impact on marine species however is not straightforward. Changes in seawater chemistry of the Scotian Shelf may be more pronounced given its proximity to the carbon dioxide-enriched waters of the North Atlantic basin.

8.4.2 Cold Water Corals

Cold-water corals rely on calcium carbonate formation to grow. Corals of the North Atlantic are particularly vulnerable to dissolution given the basin's status as a global "hotspot" for carbon dioxide uptake (see **Figure 8-4**). In the Atlantic Ocean, the aragonite saturation horizon ranges from 0.5 to 2.5 kilometres below the sea surface, while the calcite saturation horizon ranges from 1.5 to 5 kilometres below the surface, depending on location (Royal Society 2005). Corals found at high latitudes and in cold waters are particularly at risk of dissolution, since they reside at depths and in water temperatures where carbonate saturation is already low and decreasing (Andersson et al. 2008). *Lophelia pertusa* coral is especially sensitive and vulnerable to dissolution (Royal Society 2005), with a study by Maier and co-authors (2009) demonstrating that at pH levels of 7.95 and 7.8, *Lophelia pertusa* demonstrated a reduction in its ability to form calcium carbonate by 30% and 56%, respectively. Results of the study also indicated the youngest and fastest calcifying corallites exhibited the greatest reductions in growth with decreasing pH. Models have suggested aragonite-based cold-water corals could reach their threshold of saturation in the coming decades (Andersson et al. 2008).

8.4.3 Calcifying Micro-organism Productivity

Micro-organisms are small bacteria, phytoplankton, zooplankton, and invertebrate species. They are responsible for almost half of all global primary productivity (Rost et al. 2008). Primary productivity is the production of oxygen and other organic compounds. Micro-organisms are also the basis of the marine food web. Due to climate change, changes in dissolved carbon dioxide concentrations, pH, dissolved oxygen, temperature, and stratification will all combine to influence the composition and dominance of micro-organisms in the sea. This will impact their role in respiration, nutrient cycling, and many other important biological processes (Rost et al. 2008) (see theme paper on *Climate Change and its Effects on Ecosystems, Habitats and Biota*). In some instances, however, increased dissolved carbon dioxide in ocean waters could exhibit beneficial impacts on certain micro-organism species, due to varying respiratory responses. For others, more negative responses may be observed. In short, increased carbon dioxide dissolution in the sea is expected to affect micro-organism species differently, by impacting species-specific productivity, composition, assemblage, and succession (Orr et al. 2005; Rost et al. 2008).

Calcification is important to the prosperity of many micro-organisms by way of body structure, functioning, and protection (Pörtner 2008). Calcification is often a function of complex physiological processes in organisms that make use of bicarbonate or trapped carbon dioxide rather than carbonate, thus, although carbonate saturation may be a good proxy for calcification it is not necessarily a direct driver at the organism level (Atkinson and Cuet 2008; Pörtner 2008). Some calcareous-based micro-organisms can survive extended periods of time in the absence of their calcareous structures, while many others cannot (e.g., echinoderms such as starfish) (Pörtner 2008). Typical calcareous marine micro-organisms include foraminifera (calcite shells), coccolithophores (calcite shells), and euthecosomatous pteropods (aragonite shells). They account for almost all of the flux of calcium carbonate from the ocean's surface waters to the deep sea (Fabry et al. 2008). Foraminifera and euthecosomatous pteropods are particularly important inhabitants of sub-polar regions such as the Scotian Shelf.

Micro-organisms vary in their response to ocean acidification, even within like species, and this has implications for the adaptation of individual species (Fabry et al. 2008). For lower trophic calcifying marine micro-organisms, such as *Emiliania huxleyi* (**Figure 8-7**), declines in their population may have significant implications on the ecosystem as a whole, by causing changes in food chain dynamics (Riebesell et al. 2000; Fabry et al. 2008; Rost et al. 2008). *Emiliania huxleyi* are commonly found in the waters of Atlantic Canada, including those on the eastern Scotian Shelf (Brown and Yoder 1994). The species is particularly vulnerable to changes in ocean pH. In general, acute and long-term sensitivity to dissolved carbon dioxide is likely to be highest in lower trophic invertebrate species, which are poorly suited to tolerate changes that can influence important life processes such as calcification (Pörtner 2008). The result is a lower tolerance of these species to changes in temperature that will reduce their spatial distribution, associated species interactions, and affect their role in the ecosystem (Pörtner 2008). Pteropods are particularly vulnerable to ocean acidification due to their highly-soluble aragonite shells, while very little is known about the impacts of ocean acidification on cnidarians, sponges, bryozoans, annelids, brachiopods, and tunicates (Fabry et al. 2008). In contrast, increased dissolved carbon dioxide appears to have little impact on marine diatoms (Fabry et al. 2008). Some zooplankton species may exhibit diminished respiration, with species reliant on calcium carbonate showing signs of depressed physiological function (Royal Society 2005; Fabry et al. 2008; Rost et al. 2008).

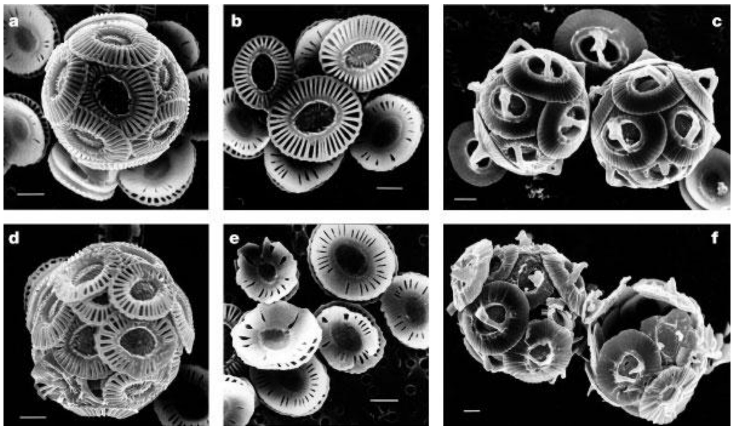

Figure 8-7. Evidence of reduced calcification in two calcareous marine coccolithophore plankton species: *Emiliania huxleyi* (see Panels a, b, d, and e) and *Gephyrocapsa oceanica* (see Panels c and f) (Riebesell et al. 2000). The organisms were exposed to simulated dissolved carbon dioxide concentrations of approximately 300 ppm by volume (Panels a–c) and 780-850 ppm by volume (Panels d–f), respectively. The scale bar represents 1 micrometre (µm) in length (one thousandth of a millimetre). At the higher simulated dissolved carbon dioxide concentrations, organisms demonstrated signs of malformation, as represented by abnormalities in their shape and roughness of their edges (reprinted with permission from the Nature Publishing Group, Macmillan Publishers Ltd: Nature, Riebesell et al. 2000).

Elevated dissolved carbon dioxide concentrations favour plankton species with high carbon demands and low surface area-to volume ratios, that is, larger micro-organism species or species that lack carbon dependence. As a result, increased dissolved carbon dioxide may cause a shift in the global ocean's planktonic community structure (Wolf-Gladrow et al. 1999). For instance, non-photosynthetic micro-organisms such as bacteria, fungi, and protists may prosper under conditions of a lowered-pH sea. Many of these organisms have greater metabolic variability, which could give them a competitive advantage (e.g., nitrogen-fixing cyanobacteria may benefit from ocean acidification) (Royal Society 2005). This could further contribute to an altered chemistry of the sea (Orr et al. 2005). Last, increased dissolved carbon dioxide in the sea may increase the extra-cellular polysaccharides found on surfaces of plankton organisms. Extra-cellular polysaccharides behave as a glue that binds multiple organisms into large aggregates, subsequently altering the residence time and flux of planktonic biomass from surface waters into the deep sea (Royal Society 2005). As a result, essential minerals and energy found in the surface ocean could also dramatically change.

8.4.4 Benthic Invertebrates and Fish

Increased dissolved carbon dioxide in seawater may alter respiration in large invertebrates and marine fish, making it more difficult for them to remove carbon dioxide from body tissues and fluids, leading to internal acidification (Royal Society 2005). This in turn affects their ability to carry oxygen in the blood, which can lead to a decrease in cellular activity, respiratory activity, and rates of protein synthesis (Royal Society 2005). Both large invertebrates and bony fish (teleost) demonstrate similar responses to reduced ocean pH at the cellular level. However, individual fish are better suited than large invertebrates to fully compensate for cellular disturbances resulting from increased carbon dioxide in their blood and tissues (hypercapnia) (Pörtner 2008). Laboratory experiments demonstrate that early life stages of large, calcifying marine organisms, including echinoderms (e.g., starfish, brittle stars, sea urchins, and sea cucumbers), bivalves (e.g., scallops, mussels, clams, and oysters), crustaceans (e.g., lobsters, crabs, shrimp, and krill), and corals are vulnerable to ocean acidification during the fertilization, cleavage, larval settlement, and reproduction stages (Kurihara 2008). Tolerances related to climate-related impacts, however, are often very different between species and their life stages (e.g., larval versus adulthood) (Pörtner 2008; Ries et al. 2009).

Many calcifying benthic invertebrates that provide ecosystem and socio-economic benefits may be vulnerable to ocean acidification. Examples of such organisms include mussels, oysters, echinoderms, and select molluscs (Fabry et al. 2008). For instance, in laboratory experiments, Gazeau and co-authors (2007) demonstrated a 25% decrease in calcification rates in blue mussels (*Mytilus edulis*) exposed to dissolved carbon dioxide concentrations predicted to be observed by the end of the twenty-first century. Blue mussels are an important species to the aquaculture industry of Atlantic Canada (Innes et al. 2012). Aquaculture of blue mussels is found along the shores of Nova Scotia, with many of the province's coastal embayments on the south shore, eastern shore, and Cape Breton Island being suitable for blue mussel cultivation (NSFA 2012). Similarly, commercially-important scallops and oysters contain aragonite, so may be vulnerable to ocean acidification, as is true for calcite-based organisms such as sea urchin, lobster, crab, and shrimp (Cooley and Doney 2009). These invertebrates are found in waters of the Scotian Shelf.

Fish appear to have more resilience to accommodate changes in pH over the short-term compared to large invertebrates and micro-organisms, although more prolonged studies on fish critical life stages are required (Ishimatsu et al. 2008). In a recent study, Baumann and co-authors (2012) exposed early life stages of the estuarine fish *Menidia beryllina* to dissolved carbon dioxide concentrations anticipated in the latter half of the twenty-first century. The study demonstrated that the egg stages exhibited higher rates of mortality than the larval stage. Although studies of physiological processes in fish are limited, acidification can lead to reduced calcification, acidiosis, hypercapnia, and metabolic suppression (Fabry et al. 2008; ICES 2008; Doney et al. 2009). At present, regional studies are either underway or being proposed to investigate the effects of ocean acidification on lobster, crab larvae, and other fishes native to the Scotian Shelf. Preliminary results indicate that the local species of American lobster and Atlantic cod appear more vulnerable to ocean acidification than their European counterparts (E. Trippel, St. Andrews Biological Station, Fisheries and Oceans Canada, pers. comm.). **Table 8-2** outlines the response of select marine species that could be vulnerable to changes in dissolved carbon dioxide concentrations and seawater pH. Many of these species are important to the commercial fishery and aquaculture industries of Nova Scotia.

Table 8-2: Reported response of select species vulnerable to changes in dissolved carbon dioxide concentrations and pH. Many of the species are important to the commercial fishery and aquaculture industries of Nova Scotia, although species-specific results often do not translate equally between different regions of the sea. To date, none of the following species found on the Scotian Shelf have been tested directly or have had Scotian Shelf-specific results published in the literature. See Tables 2 and 3 in CBD (2009) for other responses of a broader range of benthic and pelagic marine species to ocean acidification.

Common Name (*Species Name*)	**Life Stage**	**Exposure and Duration**	**pH**	**Effects**	**Reference**
Lobster (*Homarus americanus*)	Adult	CO_2 = 409–2856 parts per million (ppm) for 60 days	Not Available	Increased net calcification rate with exposure to increased carbon dioxide concentration	Ries et al. (2009)
Sea scallop (*Placopecten magellanicus)*	Egg	Exposure not available. Exposed for 5 hours	less than 7.5	Polysperm (egg fertilized by more than one sperm) and slow cleavage rate	Desrosiers et al. (1996)
Blue mussel (*Mytilus edulis*)	Adult	CO_2 = 421–2351 ppm (by volume) for 2 hours	7.46–8.13	Decreased calcification rates of up to 25% with decreased pH	Gazeau et al. (2007)
	Adult	CO_2 = 409–2856 ppm for 60 days	Not Available	No change in net calcification rate with exposure to increased carbon dioxide concentration	Ries et al. (2009)
American oyster (*Crassostrea virginica*)	Larval	Exposed to varying hydrochloric acid concentrations for ten days	6–9. 25	At pH less than 6.75 the growth rate decreased and at pH less 6.25 mortality rate increased	Calabrese and Davis (1966)
Quahog clam (*Mercenaria mercenaria*)	Larval	Exposed to varying hydrochloric acid concentrations for ten days	6–9.25	At pH less than 6.75 the growth rate decreased and at pH less 6.25 mortality rate increased	Calabrese and Davis (1966)
	Juvenile	CO_2 = 50,000 ppm (by volume) for 21 hours	7.1	Shell dissolution	Green et al. (2004)

8.4.5 Seaweed and Sea Grass Growth

Preliminary studies indicate that certain marine seaweeds and sea grass could exhibit increased growth rates due to increased dissolved carbon dioxide in the sea (Royal Society 2005). This is supported by the study of low pH, coastal hydrothermal vent environments, which exhibited high dissolved carbon dioxide concentrations and high sea grass production at a pH of 7.6 (Hall-Spencer 2008). Interestingly, shifts from coralline benthic communities to benthic communities dominated by sea grass and algae have also been observed in other marine areas of relatively low pH (Hall-Spencer 2008; Wootton et al. 2008; CBD 2009). These ecosystems are commonly characterized by low species diversity. Further research on this topic is required, since observations from such highly specialized ecosystems generally may not be reflective of a lower pH ocean.

8.4.6 Species Composition, Dominance, and Ecosystem Structure and Functioning

Ocean acidification-related effects may vary from impacts at the cellular level up to individuals, populations, and species, making it difficult to predict the compounding effects of climate change at the ecosystem level (Fabry et al. 2008; Pörtner 2008). Without question, ocean acidification will alter species abundance and composition leading to shifts in marine ecosystem structure and functioning over the long-term (Royal Society 2005). Species composition and dominance is determined by a combination of environmental factors such as predator-prey relationships, ocean currents, temperature, and nutrient availability and by species-specific factors such as passive versus active mobility. Ultimately, the nature of these intertwined relationships, and how ocean acidification and other natural and human-induced pressures may interact, will determine the resilience of an ecosystem to adapt to any change in the ocean's carbon dioxide concentration, pH, and carbonate saturation state (Guinotte and Fabry 2008; Pörtner 2008). The primary concern moving forward is how marine ecosystems will respond to ocean acidification, coupled with existing pressures associated with human activity (e.g., marine industries and pollution), natural variation (e.g., El Niño and La Niña), and other climate-induced impacts such as ocean warming (Pörtner 2008).

8.4.7 Impacts on Society and Economy

The upper 1000 metres of the ocean contains most of the world's wild fish catch which, indirectly, supports fisheries aquaculture through the fish feeds it provides to this industry (Warren 2009). Preliminary studies suggest that climate change may result in a 60% turnover in global marine species biodiversity, with numerous local extinctions and simultaneous species invasions likely to affect a range of marine ecosystem services (Cheung et al. 2009). Ironically, humans' dependence on marine ecosystem services make them particularly vulnerable to the impacts of ocean acidification—fisheries and aquaculture being particularly noteworthy.

In 2006, Nova Scotia fisheries directly employed 9500 skippers and crew, with shellfish accounting for approximately 80% of the total landed value of all captured fish species (Gardiner Pinfold 2009). The total landed value was $657 million, with approximately $525 million being attributed to shellfish landings such as scallop, lobster, and crab. Recall that shellfish may be particularly vulnerable to ocean acidification. Post-catch processing of commercial fishery landings in 2006 further employed 5700 full time equivalent positions (Gardiner Pinfold 2009). The total processed fish value was $900 million, with approximately $510 million in exports.
Processing was primarily associated with shellfish landings (Gardiner Pinfold 2009). In 2006, the marine aquaculture industry in Nova Scotia directly employed 440 full-time equivalent positions, with the primary species cultivated being blue mussels, American oyster, and salmon (Gardiner Pinfold 2009). Again, blue mussel and oyster may be particularly vulnerable to ocean acidification. The total harvested aquaculture value was $42 million, with approximately $1.4 million in exports. Cumulatively, commercial fisheries, post-catch processing, and aquaculture contributed more than $1.1 billion to Nova Scotia's Gross Domestic Product in 2006, again with the majority of this being attributed to shellfish (Gardiner Pinfold 2009). Approximately $770 million supported regional household incomes (Gardiner Pinfold 2009). Not accounted for in the

Gardiner Pinfold (2009) report was the number of indirect jobs associated with the fishing and aquaculture industries (e.g. seafood restaurants), which tends to increase dramatically from directed fishery catch and aquaculture harvesting up to post-catch processing, shipping, and retail (NYSG 2001; Cooley and Doney 2009).

In Nova Scotia, 3.4% of all employment in 2006 was directly tied to commercial fishing, post-catch processing, and aquaculture (Gardiner Pinfold 2009). Additional employment associated with the supporting transport and retail sectors also contributed significantly to the regional economy. Furthermore, there is value associated with the issuance of commercial fishery licences, fish processing licences, and aquaculture site leases (Cooley and Doney 2009). The number of issued licences in 2006 was approximately 3500, 290, and 350, respectively, totalling about 4100 issued licences associated with the fishing and aquaculture industries operating in the waters of Nova Scotia (Gardiner Pinfold 2009). Last, recreational fisheries and associated tourism also support regional economies through permitting fees, equipment, travel, lodging, and other associated sales and rentals (Cooley and Doney 2009). In Nova Scotia, rural economies are particularly dependent on fisheries and aquaculture for their well-being.

8.4.8 Other Potential Impacts

Many potential impacts of ocean acidification remain unknown due to a lack of research, such as a potential for change in the optical and acoustical properties of low pH ocean surface waters. For example, as tiny calcareous organisms that scatter light in the surface ocean become more susceptible to dissolution this may have significant effects on the transmission of light in the surface ocean (Balch and Utgoff 2009). It is believed that low frequency sound may also travel much farther, due to the absence of chemical constituents available to absorb low frequency acoustic waves. This could result in higher ambient noise levels found in the sea (Brewer and Heste 2009). What these effects may mean for marine species and ecosystems, however, largely remain unknown and in many instances are still under debate (Joseph and Chiu 2010; Udovydchenkov et al. 2010).

8.5 ACTIONS AND RESPONSES

Miles and Bradbury (2009) indicated that three challenges confront governments in responding to ocean acidification: 1) uncertainty in its effects; 2) decadal to centennial timescales in which effects may occur, with the effects only beginning to be observed towards the latter part of the twenty-first century; and 3) difficulty agreeing to a shared solution amongst nations, since the policies of any one nation cannot resolve ocean acidification alone. The response of global governments to address ocean acidification can be broken down into prevention and adaptation (Warren 2009). Prevention refers to a need to reduce carbon dioxide emissions to the atmosphere. Adaptation refers to a need to prepare humans and accommodate ecosystems for the effects of ocean acidification. In practice, both prevention and adaptation are required, since even a reduction in carbon dioxide emissions to the atmosphere today will not halt the effects of ocean acidification to come over the next few centuries.

8.5.1 Legislation and Policy

Prevention of continued ocean acidification over the long-term is only possible through a reduction in carbon dioxide emissions to the atmosphere (Pacala and Socolow 2004). Changes in legislation and public policy that address land use change and our reliance on a carbon-based economy can promote emission reductions. In Nova Scotia, the *Environmental Goals and*

Sustainable Prosperity Act (2007) mandates a 10% reduction in greenhouse gas emissions below 1990 levels and sets targets and timelines in which electricity sources are to come from renewable energy. If governments are to be prepared for the impacts of ocean acidification by the end of the twenty-first century, public policy choices need to be made now (Cooley and Doney 2009). The challenge remains in the science community's ability to translate climate change research and development into meaningful policy options, balanced with economic considerations, which are readily understood by political decision makers and the public at large (Meyer 2012).

8.5.2 Precautionary Management

Precautionary management targeted at the ecosystem level is advocated as a reasonable climate change adaptation solution (NOAA 2012). Marine protected areas (MPAs) are believed by many to be the most effective means to protect already vulnerable marine species and habitats from ocean acidification and other climate change impacts. A marine protected area is a coastal or marine area given special status to conserve and protect its natural habitat and marine life. Marine protected areas offer protection vis-à-vis limitations on human activities in their boundaries (Cooley and Doney 2009). This could allow ecosystems to accommodate changes in, for instance, ocean pH without facing additional human-induced pressures caused by activities such as fishing or offshore petroleum development. To date, MPAs and Coral Conservation Areas have been used to protect certain unique and vulnerable marine ecosystems on the Scotian Shelf (DFO 2012), although they have not been designed with the effects of ocean acidification in mind.

8.5.3 Research and Monitoring

In support of greater research regarding climate change adaptation in Canada, the federal Treasury Board approved a funding package—*Helping Canadians Adapt to a Changing Climate*—in 2010 to complement previous federal government research initiatives on this topic. Fisheries and Oceans Canada (DFO) was awarded $16.5 million of funding over a five year period, with research to commence in 2011. The DFO research program is called the Aquatic Climate Change Adaptation Services Program (ACCASP). The ACCASP funding is being directed at three primary program components: 1) development of risk assessments to identify key marine vulnerabilities to climate change; 2) carry out ocean science research projects to increase understanding of future climate change and its impacts on ecosystems, infrastructure, and operations; and 3) development of systems and tools that support and promote climate change adaptation. At present (August 2012), research topics of interest are being identified, with some form of research regarding the potential effects of ocean acidification on commercial fish and aquaculture species of the Scotian Shelf being anticipated. The research will expand upon long-term monitoring initiatives of the Scotian Shelf. It is anticipated this research program will help identify potential impacts of ocean acidification on the marine waters of the Scotian Shelf (and beyond) over the coming centuries.

8.6 INDICATOR SUMMARY

Indicator	DPSIR	Policy Issue	Assessment[1]	Trend[2]
Use of fossil fuels	Driving Force	Increased use of fossil fuels leads to increased emissions of carbon dioxide to the atmosphere	Poor	-
Carbon dioxide absorption by surface ocean	Pressure	North Atlantic ocean is a global "hotspot" for the absorption of carbon dioxide into the surface ocean	Fair	-
Surface ocean pH of Scotian Shelf	State	Surface water of the Scotian Shelf is decreasing in pH at a rate greater rate than the average global ocean	Fair	-
Calcium carbonate saturation	State	Saturation of calcium carbonate in waters that influence the Scotian Shelf (e.g., Labrador Current) is decreasing	Fair	-
Invertebrate calcification rates	Impact	As pH decreases so does the ability of many invertebrates to maintain calcification rates necessary for survival at various life stages	Unknown	?
Legislated targets for carbon dioxide emission reductions	Response	Legislated targets for carbon dioxide emission reductions would resolve ocean acidification over the long-term	Poor	/
Research studies into ocean acidification (in Canadian context)	Response	The majority of research studies on ocean acidification have been completed since 2004, with many governments currently implementing research programs on this topic.	Fair	+

[1] Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.

[2] Trend: is is positive or negative in terms of implications for the state of the environment? It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Key:

Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?

Data Confidence:

The science regarding the cause of ocean acidification is robust, while more studies regarding its potential effects on marine ecosystems are urgently needed. Some effects have been extrapolated from laboratory studies.

Data Gaps:

Canada is only beginning to consider and evaluate the impacts of ocean acidification on marine species, ecosystems, and associated industries.

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Productivity

9. PRIMARY AND SECONDARY PRODUCERS[18]

Stephanie A. Boudreau, Dalhousie University, Halifax, NS

9.1 ISSUE IN BRIEF

Primary and secondary productivity are the foundational processes of the oceanic food web and are the essential building blocks of the entire ecosystem. **Phytoplankton**, comprising single-celled microscopic algae and cyanobacteria, are the major **primary producers** in the upper layers of the ocean. They remove carbon dioxide from the atmosphere, convert sunlight into biologically-available energy, and release oxygen. Phytoplankton provide a vital food source for ocean life and contribute approximately half of the world's primary production (Field et al. 1998). The most common measure of phytoplankton biomass is chlorophyll a concentration.

Zooplankton, which are **secondary producers** and primary consumers, are small animals that graze on phytoplankton, various protists, and other particulate matter. In turn, zooplankton fuel higher trophic levels by serving as prey for secondary consumers, such as other invertebrates and fish. The most important zooplankton species on the Scotian Shelf in terms of biomass is the copepod, *Calanus finmarchicus*, whose various life history stages are essential food sources for larval, juvenile and adult fish. Euphausiids (krill), especially *Meganyctiphanes norvegica*, are also an important food source for fish. Both *C. finmarchicus* and krill are also consumed by seabirds and baleen whales on the Scotian Shelf (DFO 2000). Members of the microbial community (bacteria) are, however, the dominant secondary producers in terms of their mass and contribution of energy to the ecosystem. These, like zooplankton, subsist off primary production provided by the first trophic level, although this microbial secondary production leads only to a small amount of energy that can be transferred to higher trophic levels, such as to commercially harvested groundfish.

This theme paper looks at the linkages between the primary and secondary producers and other aspects of the Scotian Shelf marine environment. Driving forces include environmental variability and climate change. These drivers affect the timing of ecosystem events and productivity (**Figure 9-1**). Changes in phytoplankton and zooplankton abundance may in turn affect other marine organisms, such as fish, seabirds, and marine mammals. Recently, an analysis reported a century scale decline in phytoplankton biomass at the large ocean-basin scale of the North Atlantic; however in shelf regions, the trend has switched from negative to positive since about 1980 (Boyce et al. 2010). Evidence of a decline, at the half-century time scale, is not present on the Scotian Shelf where a phytoplankton biomass index has increased in recent decades (McQuatters-Gollop et al. 2010). The trophic structure of the Scotian Shelf is further described in *Trophic Structure*. Due to the variable nature of the ocean, in addition to human activities, it is prudent to monitor the trends of these vital components, primary and secondary production, of the Scotian Shelf ecosystem.

Linkages

This theme paper also links to the following theme papers:
- Trophic Structure
- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Ocean Acidification
- Invasive Species

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[18] Completed March 2013.

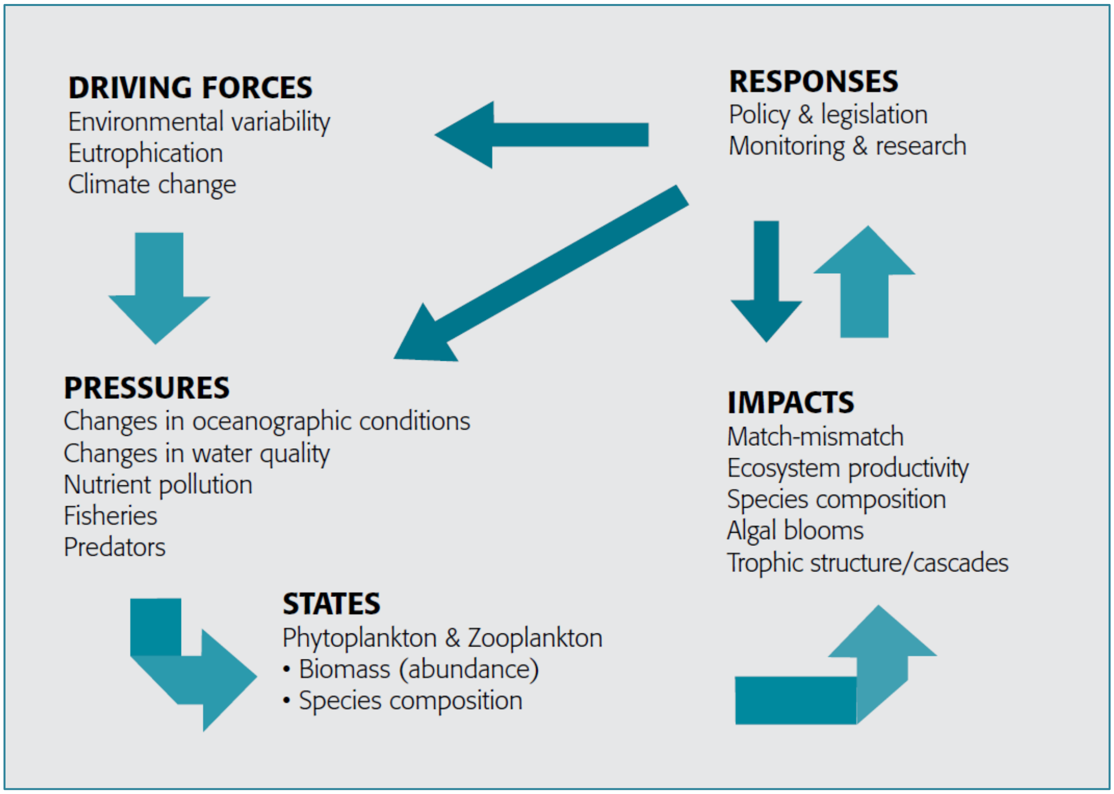


Figure 9-1: Driving forces, pressures, state, impacts and responses (DPSIR) to primary and secondary productivity on the Scotian Shelf. In general, the DPSIR framework provides an overview of the relation between different aspects of the environment, including humans and their activities. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems, and materials, which may elicit societal or government responses that feedback on all the other elements.

9.2 DRIVING FORCES AND PRESSURES

9.2.1 Natural Environmental Variability

9.2.1.1 Oceanographic Processes: The 12-month seasonal cycle is driven by the earth orbiting around the sun. The annual phytoplankton cycle on the Scotian Shelf begins in spring as energy from the sun increases during the changing of the seasons from the winter solstice to the spring equinox. At the same time, surface warming begins to stabilize the water column which has been intensely mixed over the winter. With stable stratification, phytoplankton receive both sufficient sunlight and nutrients to initiate exponential population growth. In general, diatoms (**Figure 9-2**) have evolved to take competitive advantage under these conditions of rapid growth and thus constitute the bulk of phytoplankton biomass in the spring bloom. Predictably, dissolved nutrients decrease from their peak concentration in winter to supply the demand of phytoplankton growth. With the exhaustion of winter nutrients by the spring bloom, a summer flora develops that is able to use nutrients regenerated within the ecosystem itself by the resident bacteria. Large patches of summer phytoplankton are not unusual occurrences on the Scotian Shelf (**Figure 9-3**). Summer culminates in the autumn equinox when water temperature reaches its annual maximum, accompanied by a high numerical abundance of small phytoplankton cells, which may or may not rival the bulk biomass earlier developed in the spring bloom by a much lower numerical abundance of large phytoplankton cells. In winter, phytoplankton communities appear inactive, but in some coastal settings under unusual physical and meteorological conditions that permit net growth, sporadic winter blooms of well-adapted species associations may appear.

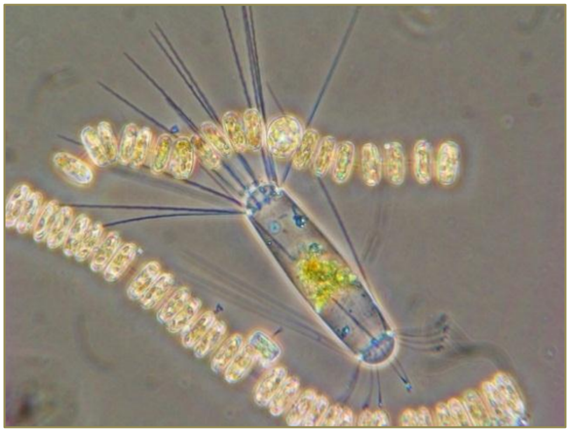
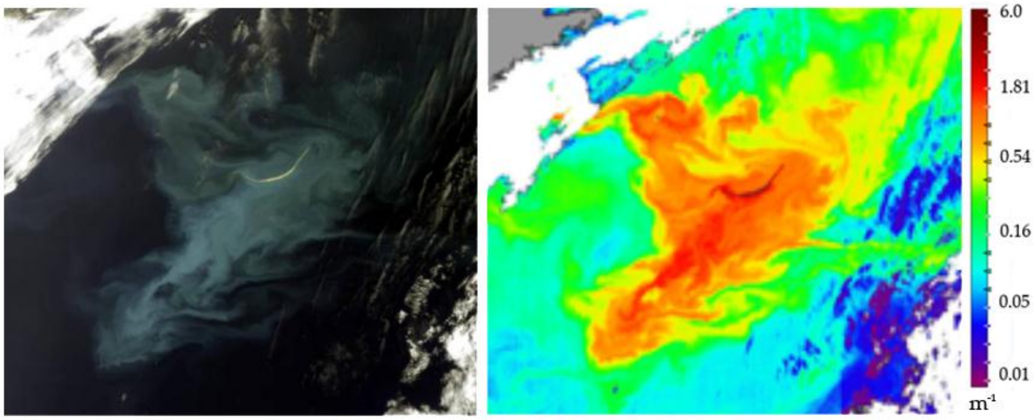


Figure 9-2: The diatoms *Corethron criophilum* and *Thalassiosira* sp. (chains) in the marine phytoplankton of Atlantic Canada waters (K. Pauley, DFO Maritimes, Ocean and Ecosystem Science Division).



MERIS FR true colour image from July 5, 2010 showing a coccolithophore bloom around Sable Island, NS.

The C2R backscattering product quantifies the bloom and can potentially be used to create a calcite index for ocean acidification studies.

Figure 9-3: A bloom of coccolithophore phytoplankton on the Scotian Shelf in July 2010 (Source: C. Caverhill, DFO Maritimes, Ocean and Ecosystem Science Division).

The Scotian Shelf is a naturally dynamic and variable ecosystem and the climate of the eastern Scotian Shelf is influenced primarily by outflow from the southern Gulf of St. Lawrence together with a lesser input of cold and low-salinity Labrador Current, while the central Scotian Shelf receives inputs of warm water from beyond the shelf-break, which mix with shelf water and flow southwest to the western Scotian Shelf. The waters of the Scotian Shelf typically form layers of varying temperature and salinity which vary by season and region (Breeze et al. 2002). The physical oceanography of the Scotian Shelf is further described in *The Scotian Shelf in Context*.

9.2.1.2 North Atlantic Oscillation: The North Atlantic Oscillation (NAO) is the dominant meteorological pattern driving North Atlantic climate over a five- to ten-year time scale. It is indexed by the sea level atmospheric pressure difference between the Azores and Iceland. High NAO leads to severe winters over the Labrador Sea, Labrador Shelf and Grand Banks. Cold and fresh conditions prevail on the Newfoundland-Labrador Shelf, the eastern Scotian Shelf and the Gulf of St. Lawrence. The opposite response (warm and salty conditions) is seen on the central and western Scotian Shelf and in the Gulf of Maine. Low NAO leads to mild winters in the Labrador Sea and Grand Banks, with a result that warm and salty conditions prevail on the eastern Scotian Shelf, with opposite conditions on the central and western Scotian Shelf (Petrie 2007). For phytoplankton on the Scotian Shelf, greater intrusion of offshore Atlantic slope water brings more nutrients during the high NAO phase. During low NAO phase, there is greater intrusion of Labrador Slope water, which is colder, fresher, lower in nitrate, and higher in oxygen than Atlantic Slope water.

9.2.1.3 Atlantic Multidecadal Oscillation: The Atlantic Multidecadal Oscillation (AMO) is the variation in North Atlantic sea surface temperature (SST) between cool and warm phases, each lasting for 20–40 years with a difference of about 0.5^{o}C between extremes. The AMO is thought to be coupled with oscillations in the atmosphere and related to slow changes in the overturning circulation of the Atlantic Ocean. For the Scotian Shelf, even the longest record of plankton observation from the Continuous Plankton Recorder (CPR) is too short to evaluate plankton responses to this mode of variability.

9.2.1.4 Sea Surface Temperature: During the last two decades water temperatures were relatively cool from 1987–1993 and 2003- 2004 and relatively warm in 1999–2000 (Worcester and Parker 2010). Phytoplankton biomass (measured as chlorophyll a, Chl-a, concentration, **Figure 9-4**) is generally higher in regions with cold surface waters, since cool temperatures are generally associated with deeper mixing and higher nutrient levels. In ecosystems like the Eastern Scotian Shelf, where ocean currents cause upwelling and cool sea surface waters, phytoplankton biomass is often high. Decadal trends in the intensity and duration of the Scotian Shelf's spring bloom show that it started earlier in the 1990s and 2000s than in the 1960s and 1970s (Sameoto 2004, Head and Pepin 2010b). One possible reason is that less stormy winter weather may have led to less intense mixing of the water column during the winter and thus allowed for earlier stratification during the spring (Zwanenburg et al. 2006). Strong seasonal cycles for Chlorophyll a and SST have been demonstrated for the entire Northwest Atlantic continental shelf, although there is no obvious relationship between them at seasonal or annual time-scales on the Scotian Shelf (Maillet 2010).

9.2.2 Anthropogenic Stressors

9.2.2.1 Eutrophication: In inshore regions of the Scotian Shelf, the possibility of sustained addition of nutrients such as nitrogen and phosphorus at concentrations significantly above natural levels (i.e., eutrophication) could lead to significant changes in the phytoplankton community. Large populations of certain phytoplankton species, such as those responsible for nuisance algal blooms, can be toxic or otherwise harmful to other organisms in the ecosystem and a risk to human health (Breeze et al. 2002). Two of the main drivers of eutrophication are agricultural runoff (i.e., fertilizers) and combustion of fossil fuels (creating the greenhouse gas nitrous oxide, N_2O) (Vitousek et al. 1997). However, for the Scotian Shelf offshore of the nearshore embayments, there is no evidence of significant nutrient enhancement (Yeats et al. 2010). This is not surprising since the nutrient fields on the Scotian Shelf are mainly affected by physical oceanographic processes such as mixing and transport (advection). Additional human activities contributing to eutrophication are detailed in *The State of the Gulf of Maine Report: Eutrophication* (Liebman et al. 2012) and additional sources of marine pollution are mentioned in *The Scotian Shelf in Context*.

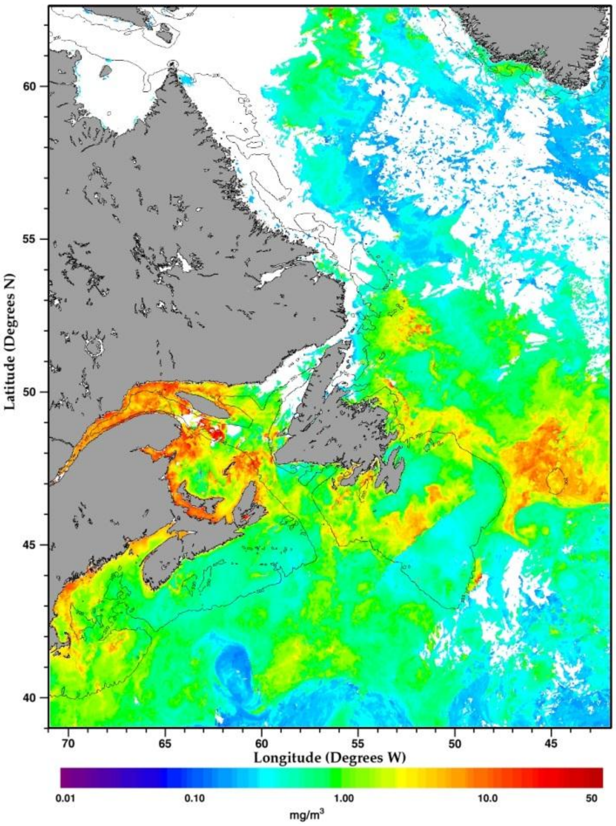


Figure 9-4: A composite of Chlorophyll a concentration, in milligrams per cubic metre (mg m-3), in Atlantic Canada from April 16 through to the 31, 2012 (BIO 2013).

9.2.2.2 Climate Change:

Temperature, Salinity and Stratification: Climate change is arguably the most important driving force of long-term change in primary and secondary productivity, not only on the Scotian Shelf but worldwide. It is expected to influence water temperature, climate regimes, ocean currents, and increase the ocean's acidity. Rising sea surface temperatures might be related to apparent declines in phytoplankton at the century time scale in large ocean basins (Boyce et al. 2010). On the Scotian Shelf and in other regions of the North Atlantic however, trends suggest otherwise (see section 9.3.1.1) (McQuatters-Gollop et al. 2011). As temperatures continue to rise, the oceans may become less dynamic resulting in a more stratified system (i.e., less mixed) with a diminished capacity to deliver nutrients to phytoplankton (DFO 2009a). Stratification on the Scotian Shelf has increased since 1960, with especially high values in the 1990s (Worcester and Parker 2010, Hebert et al. 2012). However, the possibility that this stratification is influenced by changes in both salinity and temperature means that simple predictions based solely on temperature change may have large uncertainty. The phytoplankton composition may also gradually shift to smaller individuals as waters warm (Moran et al. 2010), but smaller average cell size is not a diagnostic feature of any single driver. Additional nutrients provided by increasing eutrophication could boost phytoplankton productivity in the coastal zone, which together with a warmer and a less dynamic water column might give an increased risk for reduced water quality (such as hypoxia: low dissolved oxygen) (Liebman et al. 2012).

The Scotian Shelf is a transition zone where the southward flow of cold, fresh sub-polar water interacts with the northward flow of warm, salty sub-tropical water, but it is also affected by freshwater outflow from the St. Lawrence Estuary, which exerts a strong influence on water characteristics. Thus, climate change drives stratification by affecting both temperature and salinity. On the eastern and central Scotian Shelf, salinity exerts dominant control on stratification, but on the western Scotian Shelf, the effects of temperature and salinity are more equitable. In areas where there is a long term trend of increasing stratification, the change is most clearly observed in the summer and autumn, and not so clearly in the spring when the phytoplankton bloom is usually most intense (Brickman 2011).

In addition, under climate change, it can be expected that sea ice coverage will decrease, both in spatial extent and in occupied volume. This might have a direct effect by lengthening the growing season for phytoplankton in those limited areas of the Shelf where ice is normally expected (extreme eastern edge and Cabot Strait), but also an indirect effect, since reduced sea ice in waters upstream from the Scotian Shelf (e.g., the Gulf of St. Lawrence and Labrador Shelf) will influence the salinity downstream on the Scotian Shelf.

As the climate changes, the net changes in salinity across the Scotian Shelf are uncertain because of counteracting tendencies. On the one hand, melting Arctic ice and more freshwater discharge in northern regions and the Gulf of St. Lawrence will reduce salinity; on the other hand, a northward shift of more saline subtropical waters will increase it.

The impacts of climate change on the Scotian Shelf are further described in *Climate Change and its Effects on Ecosystems, Habitats and Biota*.

***Ocean Acidification**:* Phytoplankton have an important role in climate systems. By taking up carbon dioxide (CO_2), and by influencing the reflection and absorption of solar energy, phytoplankton significantly affect our global climate. The global increase in atmospheric and oceanic CO_2, attributed to the burning of fossil fuels, is evident in on the Scotian Shelf. There has been a documented decrease in pH (or increased acidity) of approximately 0.1 to 0.2 pH units since 1927 (DFO 2009a). It is not immediately clear what the short-term consequences of ocean acidification will be on primary and secondary productivity. It is possible that increases in CO_2 could stimulate more primary productivity, but if present trends continue, the decreases in pH will negatively affect organisms that build and maintain skeletons requiring calcium in the long-term (DFO 2009a). Organisms that may be vulnerable include members of the phytoplankton (e.g., coccolithophores), microzooplankton (e.g., foraminifera) and larger zooplankton (e.g., pteropods) communities. One zooplankton genus that is relatively abundant on the Scotian Shelf is *Limacina* spp. (**Figure 9-5**), which has a calcium carbonate shell that is degraded by low pH (Worcester and Parker 2010). At the moment it is unclear whether the abundance of this or any other organism has yet been affected by the reduction in pH on the Scotian Shelf (Johnson et al. 2012b). Potential impacts of ocean acidification on the Scotian Shelf are further discussed in *Ocean Acidification*.

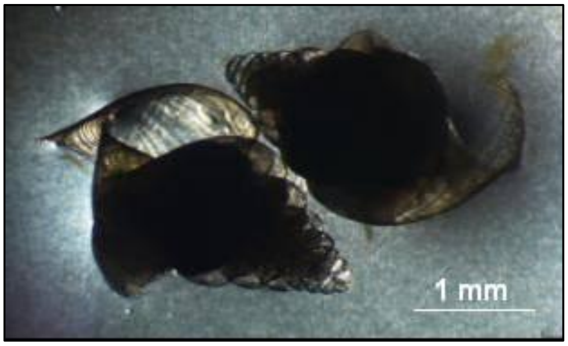


Figure 9-5: The pelagic mollusc *Limacina limacine* (M. Ringuette, DFO Maritimes, Ocean and Ecosystem Science Division).

9.3 STATUS AND TRENDS

9.3.1 Phytoplankton

9.3.1.1 Biomass and Abundance: Primary producer biomass is most commonly estimated by examining ocean colour. Because photosynthesis involves the capture of light energy by the green pigment chlorophyll *a* found universally across species of phytoplankton, its concentration is frequently used as an estimate of phytoplankton biomass. The initiation, duration, and intensity of phytoplankton blooms are reflected by seasonal development in chlorophyll *a* concentration. Two data sources that are commonly used to map the distribution of ocean colour over space and time are the continuous plankton recorder (CPR), which returns a semi-quantitative index of "greenness" (the Phytoplankton Colour Index, PCI), and remote sensing via satellite imagery (e.g., Sea-viewing Wide Field-of-view Sensor, or SeaWiFS and Moderate Resolution Imaging Spectroradiometer, or MODIS), which returns estimates of chlorophyll *a* concentration in the near-surface layer (Breeze et al. 2002). CPRs are towed by commercial vessels along oceanic trade routes (**Figure 9-6**), and have provided a relatively long time series, with irregular sampling on the Scotian Shelf between 1960 and 1976 and more regular (approximately monthly) sampling since 1991. Total phytoplankton biomass is estimated from the CPR samples by the PCI, but information is also obtained on species composition for the larger forms (e.g., Head and Pepin 2010a and 2010b).

In Atlantic Canada there appears to be a positive relationship between annual average chlorophyll concentration and fish yield, with the eastern and western regions of the Scotian Shelf having values that are higher than the Grand Bank, but lower than the southern Gulf of St. Lawrence (**Table 9-1**). CPR results indicate that the PCI and abundance of larger phytoplankton species in the Northwest Atlantic Ocean and on the Scotian Shelf were higher in the 1990s and 2000s than in the 1960s and 1970s (**Figures 9-7 and 9-8**), with the bloom occurring earlier (Head and Pepin 2010b). Monitoring by Fisheries and Oceans Canada (DFO) throughout the water column at a fixed station off Halifax since 1999 has shown considerable variability in the magnitude of the spring chlorophyll *a* peak, with a maximum of > 900 milligrams per cubic metre (mg m-3), in 2007, and a minimum of 127 mg m-3, in 2011 (**Figure 9-9**, Johnson et al. 2012b).

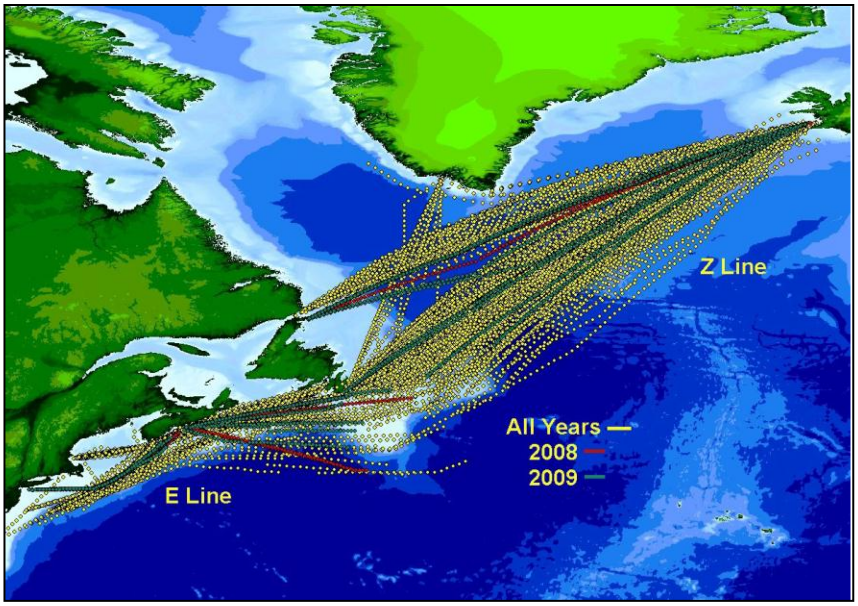


Figure 9-6: Continuous Plankton Recorder (CPR) lines and stations, 1961 to 2009 (2008 and 2009 highlighted) (from Johnson et al. 2012a).

Table 9-1: Characteristics of nine geographical areas in Atlantic Canada in terms of location, size, annual average indices of productivity (chlorophyll concentration and total fish yield) and long-term mean bottom temperature. Presented from highest to lowest chlorophyll concentration, the Eastern and Western Scotian Shelf are highlighted (adapted from Frank et al. 2006).

Location	**Size (km^2)**	**Chlorophyll ($mg\ m^{-3}$)**	**Total fish yield ($t\ km^{-2}$)**	**Bottom water temperature (^oC)**
Gulf of Maine	53909	2.06	2.702	7.12
Southern Gulf of St. Lawrence	71982	2.06	1.824	1.88
Georges Bank	106903	1.68	1.639	8.74
Western Scotian Shelf	**89266**	**1.67**	**2.496**	**6.55**
Northern Gulf of St. Lawrence	128986	1.49	1.049	3.18
Eastern Scotian Shelf	**149133**	**1.13**	**1.361**	**4.85**
St. Pierre Bank	89404	0.81	0.870	2.96
Labrador Shelf/ Northern Grand Bank	392068	0.80	1.021	1.17
Southern Grand Bank	180005	0.80	0.589	2.37

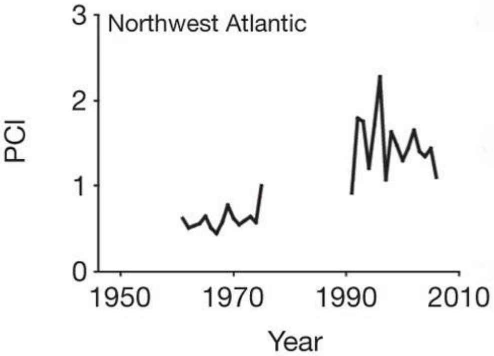


Figure 9-7: Results from the CPR survey showing increasing phytoplankton trends measured by the phytoplankton colour index (PCI) in the Northwest Atlantic (from McQuatters-Gollop et al. 2011).

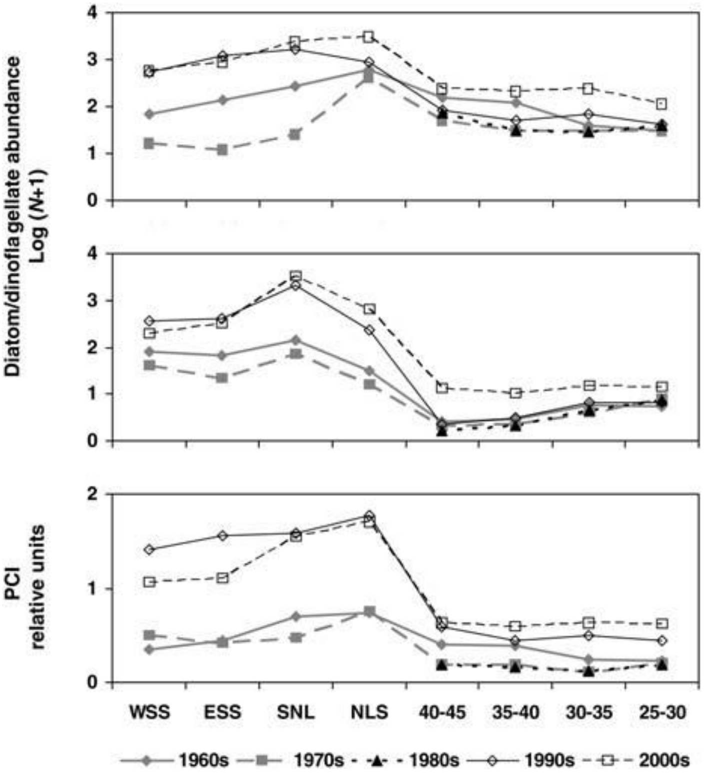


Figure 9-8: Decadal annual average abundances of three measures of primary producer biomass: diatoms (top panel), dinoflagellates (middle panel), and the phytoplankton colour index (PCI, bottom panel) in eight regions of the Northwest Atlantic. The eight regions are the Western Scotian Shelf (WSS), the Eastern Scotian Shelf (ESS), the South Newfoundland Shelf (SNL) and the Newfoundland Shelf (NLS), as well as four regions east of the NLS. The eastern regions are defined by their longitudinal limits (e.g., 40°– 45° W is bounded by 40o W and 45o W) (Head and Pepin 2010b).

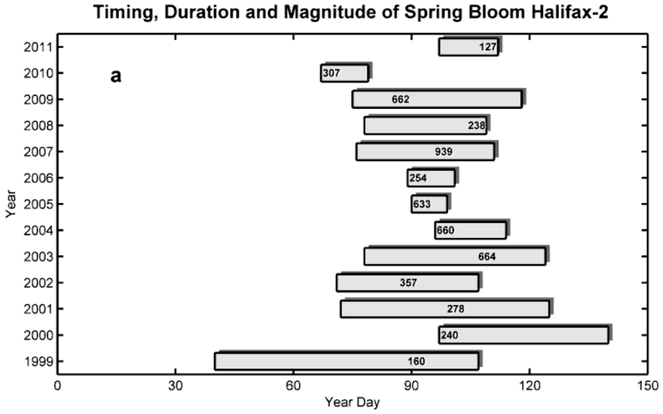


Figure 9-9: Timing (based on 40 milligrams of chlorophyll per metre squared [mg CHL m^{-2}] threshold for determining start and end of the bloom), duration (horizontal bars) and magnitude (numbers in bars, mg CHL m^{-2}) of the spring phytoplankton bloom at the Halifax 2 fixed station, 1999-2010 (Johnson et al. 2012b).

The 10-year time series (2003-2012) of satellite remote sensing observations (**Figure 9-10**) show warming trends on both the western and eastern Scotian Shelves, which are strongly driven by the very warm year of 2012. Over these 10 years, there is little indication of directional change in chlorophyll concentration on the western Scotian Shelf. In contrast, a slight positive trend can be discerned on the eastern Scotian Shelf (**Figure 9-10B**).

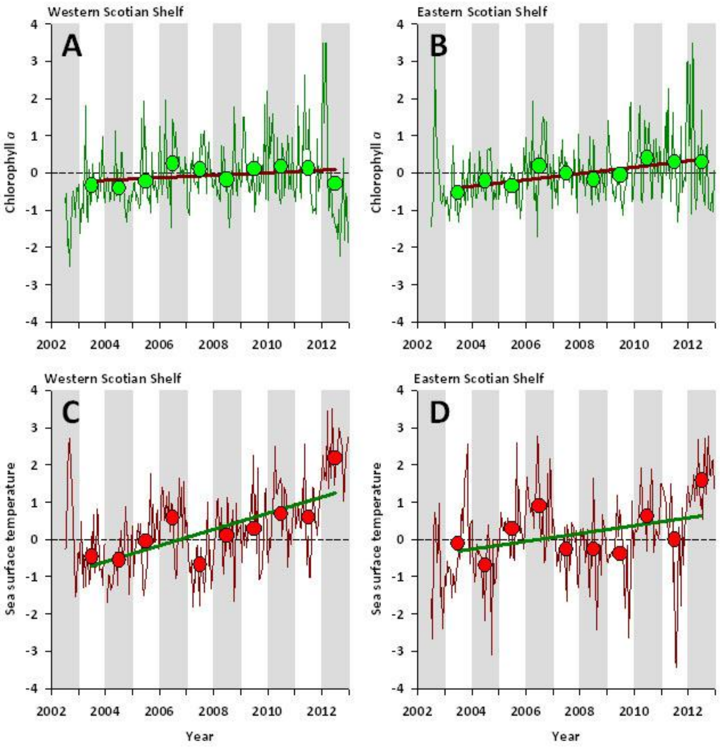


Figure 9-10: Time-series of surface chlorophyll anomalies (A,B) and sea surface temperature anomalies (C,D) from MODIS bi-weekly composites (thin lines) for the Western Scotian Shelf (A,C) and the Eastern Scotian Shelf (B,D) from 2002 to 2012. Annual average anomalies are indicated by the solid circles, and the 10-year trend is indicated by the thick lines computed by simple linear regression (Source: DFO Maritimes, Marine Ecosystem Section, Remote Sensing Unit).

9.3.1.2 Composition: Over 300 different taxa (or groupings) of plankton (phyto- and zooplankton) have been identified in the CPR samples from the Scotian Shelf (Breeze et al. 2002). The structure and composition of the phytoplankton community has not been described in detail and is typically reported as the sum of abundances of two dominant groups, diatoms (which have shells made of silica) and dinoflagellates (which can swim using flagella) (Worcester and Parker 2010). The spring bloom is typically dominated by diatoms. Dinoflagellates rarely dominate the community but they contribute significantly to blooms later in the year (Breeze et al. 2002). Many other phytoplankton taxa are known in these waters (Li et al. 2011), but there are no long-term time series records for most of them. Over the past decade, the annual average chlorophyll concentrations at the Halifax station have been relatively stable with diatoms dominating in winter and spring (>75% of the total count), and flagellates and dinoflagellates in summer and fall (sum >60% of the total count) (Johnson et al. 2012b). Diatom and dinoflagellate abundances, and the PCI were higher in the 1990s and 2000s than in the 1960s and 1970s (**Figure 9-8**), with the increases in diatom abundance and the PCI occurring mainly in the January to March period (**Figure 9-11**). In addition, in the past decade, there has been a general increase in the abundance of the smallest members of the phytoplankton assemblage, known as picophytoplankton, across broad reaches of the Scotian Shelf, and particularly in the nearshore Bedford Basin (O'Brien et al. 2012).

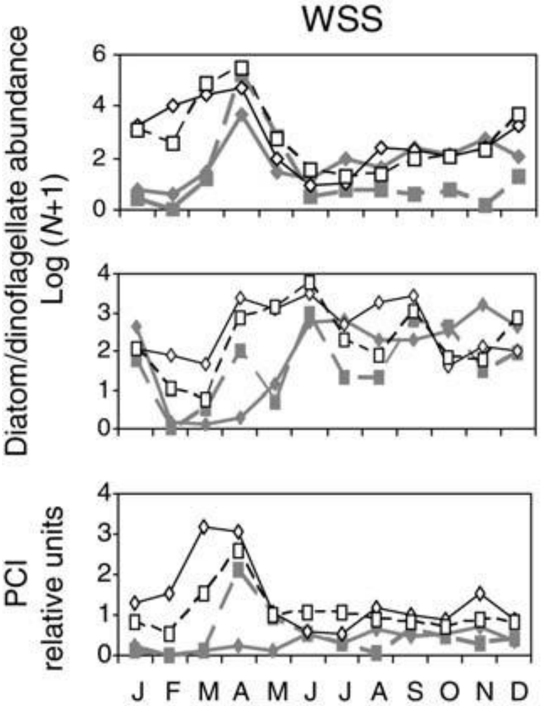


Figure 9-11: Seasonal cycles, by decade, of the abundance of diatoms (top row) and dinoflagellates (middle row) and the PCI (bottom row) for the Western Scotian Shelf (Head and Pepin 2010b).

9.3.2 Zooplankton

9.3.2.1 Biomass and Abundance: Secondary producer (zooplankton) biomass can be measured directly, in sub-samples from net tows, as wet or dry weights, or indirectly by counting individual organisms from net tows (or from CPR counts) then using pre-determined (or published) individual organism weights to calculate total biomass. Zooplankton fall into three main categories according to their body size, microzooplankton, mesozooplankton, and macrozooplankton. Copepods (mesozooplankton) (**Figure 9-12**) and euphausiids (krill, **Figure 9-13**) (macrozooplankton) make up the largest proportion of zooplankton biomass on the Scotian Shelf and are the most well-studied (Breeze et al. 2002).

Figure 9-12: The copepod *Calanus finmarchicus*, as copepodite stage 5 in a fat-rich overwintering state (M. Ringuette, DFO Maritimes, Ocean and Ecosystem Science Division

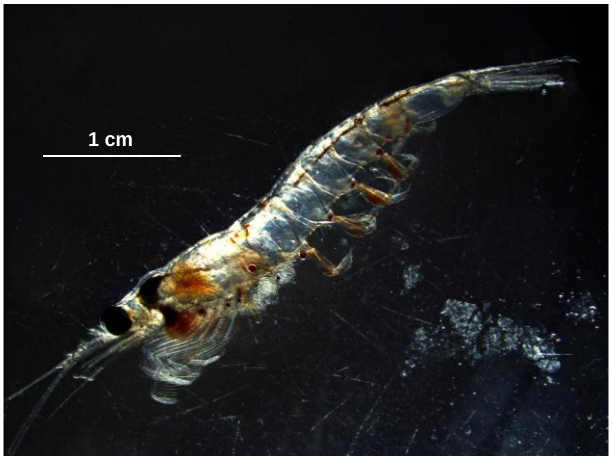


Figure 9-13: The euphausiid (krill) *Meganictyphanes norvegica* (M. Ringuette, DFO Maritimes, Ocean and Ecosystem Science Division).

As reported above, phytoplankton abundance was relatively low on the Scotian Shelf in the 1960s and 1970s and relatively high in the 1990s and 2000s (Figures 8 and 11). By contrast, abundances for the CPR copepod (zooplankton) taxa Calanus I-IV (mainly juvenile *C. finmarchicus*) and late stage C. *finmarchicus* (*C. finmarchicus* V-VI), which together dominate the mesozooplankton, were higher during the 1960s and 1970s than during the 1990s and 2000s (**Figure 9-14**, top panels). As well, the peak in *Calanus* I-IV abundance appeared earlier in the 1990s and 2000s than in previous decades, shifting from June-July to May-June (**Figure 9-11**) (Sameoto 2004, Head and Pepin 2010b). The abundances of three representative small copepods increased between the 1970s and 1990s (**Figure 9-14**, centre panels), while the abundance of euphausiids decreased and that of another taxon representative of macrozooplankton, hyperiid amphipods, increased (**Figure 9-14**, bottom panels).

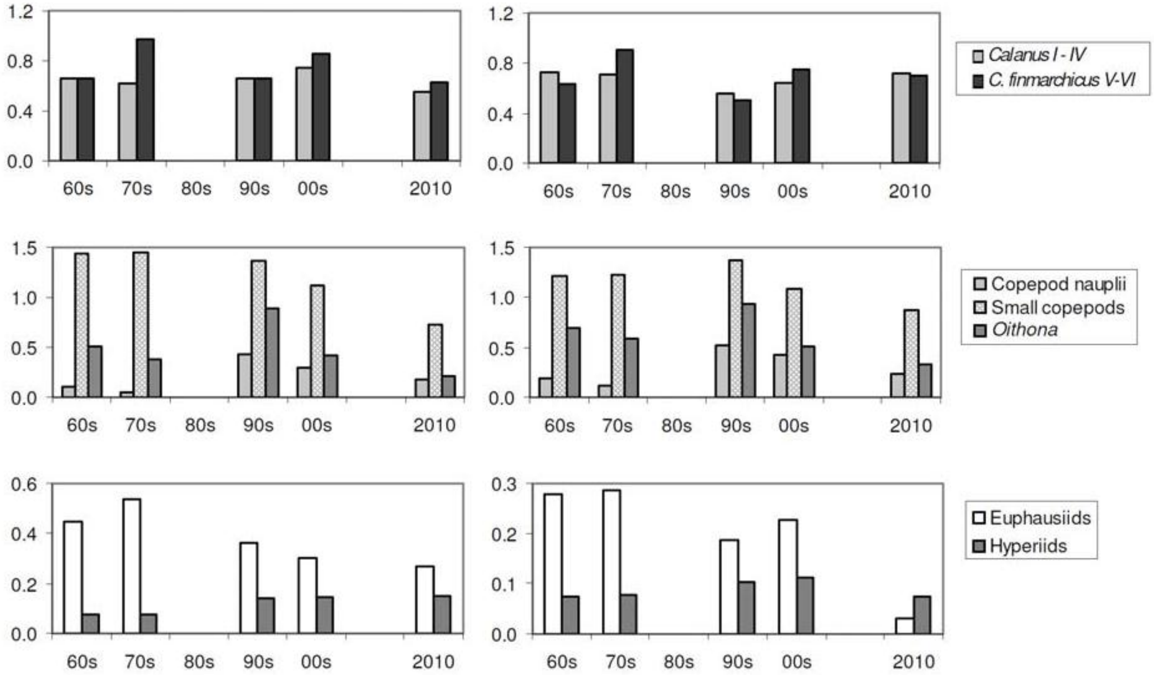


Figure 9-14: Annual average abundances by decade and in 2010 for selected zooplankton taxa on the Western (left hand column) and Eastern (right hand column) Scotian Shelf (Johnson et al. 2012b).

Food (phytoplankton) availability and other environmental variables (e.g., temperature) are likely the most important factors regulating al. 2012b). zooplankton abundance. For *Calanus* I-IV, their earlier appearance after 1990 may be linked to the earlier occurrence of the spring bloom, and their reduced annual abundance to the "mis-match" (see section 9.4.1) that has arisen between the seasonal cycles of growth and production for phytoplankton and *C. finmarchicus* (Head and Pepin 2010b). The short-lived smaller taxa appear to have been able to respond to increased phytoplankton (food) levels, although increasing near-surface temperatures (Hebert et al. 2012) may also have contributed to higher growth rates. The causes of the changes in abundance of euphausiids and hyperiid amphipods are not obvious, although it should be noted that the CPR does not sample these taxa very effectively due to their large size and their ability to avoid capture. In addition, it should be noted that the Scotian Shelf is an advective system (flowing and dynamic), where changes in the abundance of long-lived zooplankton species (e.g., *Calanus*) may be influenced by larger climate processes, such as circulation variability related to the North Atlantic Oscillation (NAO) (e.g., Greene and Pershing 2000) and inter-annual variations in the influx of water from the Gulf of St. Lawrence.

8.3.2.2 Composition: The composition of the zooplankton community has been studied in greater detail than that of the phytoplankton (e.g., Breeze et al. 2002). One species, the copepod *Calanus finmarchicus*, sometimes contributes >70% of the total copepod biomass (**Figure 9-15**) (Zwanenburg et al. 2006), and has been the subject of numerous studies, including investigations of its distribution and ecology (e.g., Head et al. 1999, Head et al. 2005, Johnson et al. 2008, Plourde et al. 2009). Despite the dominance of *C. finmarchicus*, the Scotian Shelf has a relatively high diversity of copepod species compared to neighbouring regions (**Figure 9-15**). The abundances of individual species may change from season to season and from year to year, but no strong trends are obvious for the 1999-2011 period (Johnson et al. 2012b).

Figure 9-15: The average annual abundances of the most common copepods at fixed stations in the northwest Atlantic, ordered from southwest to northeast. The seven stations were: NS (western coastal Gulf of Maine) sampled in 2003–2005 and 2007, WB2 (nearshore western Gulf of Maine) sampled in 2003–2007, WB7 (offshore western Gulf of Maine) sampled in 2005–2007, and P5 (Bay of Fundy), Sh (Shediac, western Gulf of St. Lawrence), HL2 (Scotian Shelf), and S27 (Newfoundland Shelf) all sampled in AZMP in 1999–2007 (from Johnson et al. 2010).

9.4 IMPACTS

9.4.1 Changes in Ecosystem Events (Match-Mismatch)

The Scotian Shelf ecosystem is a dynamic and productive system characterized by high seasonal variability. Phytoplankton and zooplankton production support ocean ecosystems and global fisheries, and climate change is expected to have important impacts on mechanisms regulating productivity. For example, shifts in the timing of seasonal events, such as the spring bloom, could influence trophic interactions on the Scotian Shelf, since they could disrupt the life cycles and productivity of grazers, if the latter are no longer present at the same time as their prey (Durant et al. 2007). On the other hand, effects may not always be negative. For example, *C. finmarchicus* eggs and larvae are important food items for the larvae of spring-spawned cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) (Zwanenburg et al. 2006). In 1999, when the spring phytoplankton bloom occurred 4 weeks earlier than normal on the Scotian Shelf, *C. finmarchichus* and haddock responded by reproducing earlier than normal, and this was associated with increased survival of haddock larvae and increased recruitment to the fishery (Platt et al. 2003; Head et al. 2005). This "match-mismatch" concept is further discussed in the theme paper on *Climate Change and its Effects on Ecosystems, Habitats and Biota*.

9.4.2 Ecosystem Productivity

In principle, warmer temperatures and less severe weather conditions arising from climate change could stabilize the water column, decrease the supply of nutrients to surface waters, and therefore reduce the productivity of the system (Boyce et al. 2010). However, the situation is likely more complicated. Interannual variation in stratification is also responsive to yearly variation in salinity and it is not immediately clear if warmer temperatures will necessarily lead to less mixing of the Scotian Shelf water column. Recently, it has been the inflows of low temperature and low salinity waters that have driven interannual variability in water-column stability and mixed-layer depth on the Scotian Shelf, causing yearly changes in phytoplankton dynamics and seasonal cycles (Ji et al. 2007). Whether this situation will continue under long-term climate change is unclear, however. In any case, increased water-column stability will result in fewer nutrients reaching surface waters but will also mean phytoplankton spend more time closer to the surface and the sunlight they need for photosynthesis. These counter-effects may largely offset each other on an annual basis but these remain to be more fully examined.

9.4.3 Species Composition

The species composition of the zooplankton on the Scotian Shelf may be impacted by climate change effects, operating over large, or local, spatial scales, if there are changes in ocean currents. For example, increased inputs of fresh water from the Arctic during the 1990s and early 2000s apparently enhanced the influx of Arctic Calanus species (*C. glacialis* and *C. hyperboreus*) to the Labrador Shelf and hence, via the Gulf of St. Lawrence, to the Scotian Shelf (Head and Pepin 2010b). As well, varying numbers of warm-water zooplankton species are brought to the Shelf from the south on an annual basis (Johnson et al. 2010). At the local level, assuming climate change leads to warmer temperatures and high levels of stratification on the Scotian Shelf, it is probable that smaller forms will become more dominant in the phytoplankton community, and that this might also influence the structure of the zooplankton community. Ocean acidification, driven by climate change, could also influence the composition of phytoplankton and zooplankton communities directly by impacting those with calcified structures, and indirectly by impacting their predators (e.g., fish) (see *Climate Change and its Effects on Ecosystems, Habitats and Biota* and *Ocean Acidification*). Additionally, the introduction and establishment of invasive species also influences species composition; these impacts are further described in the theme paper on *Invasive Species*.

9.4.4 Eutrophication (Blooms)

Increased nutrient inputs to coastal regions (e.g., from farming and other land-use practices) can fuel phytoplankton and macro-algal blooms. As this plant material decays and sinks to the ocean floor, it is utilised by bacteria and other benthic organisms, which can lower the dissolved oxygen concentration in the water rendering it hypoxic (little dissolved oxygen) or anoxic (no dissolved oxygen). There is limited or little evidence that there have been any wide-spread hypoxic or anoxic events on the Scotian Shelf, although the deeper regions of Emerald Basin have reduced oxygen levels and those of the Laurentian Channel are generally regarded to be hypoxic. More study is required on the local and broad-scale effects of eutrophication on the Scotian Shelf (DFO 2012).

9.4.5 Trophic Structure

There has been a change in trophic structure, attributed to an ecological cascade, on the Eastern Scotian Shelf. Specifically, the phytoplankton biomass increase in the 1990s, described in Status and Trends (Section 9.3), was linked to the decrease in the abundance of zooplankton, large-bodied copepods such as *Calanus finmarchicus* in particular. This decrease in zooplankton was in turn attributed to higher predation from forage fishes, which were more abundant due to the apparent overfishing and decline of their large-bodied groundfish predators (Bundy 2005, Frank et al. 2005). Euphausiid (krill) abundance decreased along with the copepods. Euphausiids utilize phytoplankton as food exclusively in their earliest stages, playing an important role on the Scotian Shelf. Like copepods, euphausiids are also preyed upon by juvenile groundfish and pelagic fish (Zwanenburg et al. 2006). The cascade interpretation of the changes in trophic structure on the Scotian Shelf has not been accepted by all of the scientific community, however. Others have argued that while effects may cascade from top carnivores downwards to their immediate prey, any extended impacts on zooplankton, phytoplankton, and nutrients are minor or nonexistent. Instead, it is argued that climate-associated effects provide an alternative explanation to observed changes in the phytoplankton and zooplankton, in both the Gulf of Maine/Georges Bank region (Greene et al. 2008) and on the Scotian Shelf (Head and Pepin 2010b). The potential impact of climate change on the Eastern Scotian Shelf trophic structure and function remains to be further examined. Refer to the theme paper on *Trophic Structure* for a more detailed description.

9.5 ACTIONS AND RESPONSES

9.5.1 International Commitments

There is little legislation and policy that directly impacts primary and secondary productivity. A precautionary approach framework (DFO 2009c) has been developed by DFO and is being implemented in all fisheries. The goal of the framework is to estimate reference points and establish baselines for managed stocks. Phytoplankton and zooplankton are not managed stocks, unlike the commercially harvested species at higher trophic levels which are dependent upon primary and secondary productivity. An ecosystem-based management framework has been developed (DFO 2007), which aims to understand ecosystem productivity at the lower trophic levels and to bring this knowledge into policy and management. Fundamentally, minimizing the impacts of anthropogenic stressors on the Scotian Shelf in an effort to slow climate change driven factors, such as rising water temperatures, would be prudent. One example of how this could be done would be to implement changes in legislation and public policy to reduce greenhouse gas emissions. Relevant legislation and policy are further discussed in the theme paper on *Climate Change and its Effects on Ecosystems, Habitats and Biota*. Additionally, there is legislation to limit nutrient enhancement of the coastal zones as governed by the *Canadian Environmental Protection Act*, 1999, and supported by the *Fisheries Act*, 1985.

In 1995, DFO was considering a proposal to harvest 1000 tonnes of krill. The experimental fishery did not take place due to the important role krill plays in the Eastern Scotian Shelf ecosystem, particularly for herring and the endangered North Atlantic right whale (Harding 1996).

9.5.2 Monitoring and Research

It will be important to continue to monitor primary and secondary productivity using CPR, satellite imagery and *in situ* observations over the short and long-term. Additionally, in view of the importance of temperature and salinity in controlling water stratification and metabolic rates, trends in SST and larger climate processes (e.g., the NAO) will likely become more important as indicators of productivity over time. Further, oceanographic processes such as vertical mixing during late winter-early spring which determines the timing of the spring phytoplankton bloom (Zwanenburg et al. 2006) should also be considered.

Productivity, the foundation of the ecosystem, exhibits a recurrent annual cycle, and DFO's Atlantic Zone Monitoring Program (AZMP) was designed to enable researchers to understand, quantify, and predict ecosystem states. Using data collected at a series of fixed coastal sampling locations, during broad-scale oceanographic and trawl surveys, and via remote sensing, the AZMP has been monitoring and assessing the distribution and variability in temperature and salinity conditions, and concentrations of nutrients and the plankton that they support on an annual basis. There are several methods, with various levels of sophistication, that can be used to estimate the biomass of primary (**Table 9-2**) and zooplankton secondary (**Table 9-3**) producers.

The Bedford Institute of Oceanography has created a website where maps of ocean colour data (Chl-*a* mg m^{-3}) are displayed. Maps of sea surface temperatures, measured by remote sensing, are also displayed. Data are available upon request. Temperatures at the surface and throughout the water column are also measured by hydrographic buoys and during oceanographic and research trawl surveys. CPRs were towed during only a few months of the year over the 1960-1976 period, but sampling has been more regular (approximately monthly) for most years since 1991. Satellite observations of ocean colour are dependent on weather (i.e., cloud cover), but are displayed as two-week averages, which have good coverage for most of the region for much of the year. When viewed from space, true water colour (**Figure 9-3**, left) is less useful than false colour imagery computed from radiometry (**Figure 9-3**, right) as an indicator of phytoplankton biomass. To monitor changes in phytoplankton abundance, examining results from both the CPR and remote sensing together provides a more holistic picture (Head and Pepin 2010a).

Table 9-2: Common methods, data sources, and approximate time series lengths, for estimating primary producer biomass on the Scotian Shelf.

Method	Variable(s) measured	Information	Years
Remote sensing by satellite	Surface chlorophyll *a* concentration, limited information on species composition and size structure	Satellites - CZCS, SeaWiFS, MODIS, MERIS Data sources NASA - http://oceandata.sci.gsfc.nasa.gov/ DFO - http://www.bio.gc.ca/science/newtech-technouvelles/sensing-teledetection/index-eng.php	1978-1986, 1997-present (AZMP)
Continuous plankton recorder (CPR)	Phytoplankton Colour Index (PCI) semi-quantitative abundances of phytoplankton by species or higher taxonomic order	Recorder towed by sea-going vessels at approximately monthly intervals. Data reside at SAHFOS http://www.sahfos.ac.uk/	1960-1976 intermittently, 1991-present (AZMP)
Secchi disk	Water transparency	Visual estimate using a black and white disk lowered into the water.	approximately 1900 to present
In situ methods	Chlorophyll *a*, biomass, species composition	Chlorophyll *a* measured on extracts of filters. Direct microscope counts of cells in water samples. Monthly at fixed coastal stations, 4 times per year shelf-wide. Date resides in BIOCHEM (DFO database)	1999-present (AZMP)

Table 9-3: Common methods, data sources, and approximate time series lengths, for estimating zooplankton secondary producer biomass on the Scotian Shelf.

Method	Variable(s) measured	Information	Years
Plankton tows	Species composition and abundance	Oblique plankton net tows (333 micron mesh) year-round. Sampling was on DFO research cruises in the SSIP (Scotian Shelf Ichthyoplankton Programme). Data reside in BIOCHEM.	1978-1981
Plankton tows	Species composition and abundance + bulk biomass	Vertically towed plankton nets (200 micron mesh). Sampling is at fixed coastal stations (monthly) and shelf-wide on DFO oceanographic (spring and fall) or research trawl (winter and summer) surveys. Data reside in BIOCHEM (DFO database)	Intermittent pre-1999, regular 1999-present (AZMP)
Continuous Plankton Recorder (CPR)	Semi-quantitative abundances of zooplankton by species or higher taxonomic order	Recorder is towed by sea-going vessels at approximately monthly intervals. Data reside at http://www.sahfos.ac.uk/	1960-1976 intermittent, 1991-present regular (AZMP)
Acoustic surveys	Krill abundance	DFO volume backscattering (200kHz). Data are collected during DFO shelf-wide oceanographic surveys in spring and summer	1984-present

9.6 INDICATOR SUMMARY

Indicator	**DPSIR Element**	**Status**	**Trend**
Climate change	Driving force	Unknown – There have been small, but measurable, changes, yet it is not presently clear what the short-term impacts may be.	Unknown/Worsening - In the long-term, overall impacts are expected to be negative, i.e., increased SST, however this has yet to be observed or confirmed.
Ocean acidification	Pressure	Fair/Unknown – The Scotian Shelf has become slightly more acidic however it is not presently known if there has been an impact.	Unknown/Worsening - Though pH has decreased this does not necessarily mean that productivity and ecosystem health are negatively affected. It is expected that if current trends continue, some species and ecosystem health will experience declines.
Changes in sea surface temperature	Pressure	Good – Sea surface temperatures support primary productivity.	Unknown/Worsening – If present warming trends continue, it is likely that species and ecosystem health will be influenced.
Timing of phytoplankton blooms	State	Fair – The Scotian Shelf is productive, though the timing of the spring bloom has become earlier.	Unknown – The timing of the spring phytoplankton bloom is earlier, which may eventually have negative implications for the state of the Scotian Shelf.
Chlorophyll *a* concentration	State	Good – Phytoplankton have been abundant in recent decades.	No trend – Generally speaking, the trend indicates ongoing abundance.
Zooplankton biomass (*Calanus* spp.)	State	Good – Zooplankton have been less abundant in recent decades however there is no indication that they are not supporting the food web.	No trend – Generally speaking, the trend indicates ongoing abundance.
Match-mismatch	Impact	Fair – Indications that blooms continue to support larvae and sustain adults.	Unknown/Worsening – Impacts will depend on whether the fish larvae are also early (or late), however being out of phase is typically reported to be negative for fisheries.

Categories for Status: Unknown, Poor, Fair, Good.
Categories for Trend: Unknown, No trend, Worsening, Improving.

Data Confidence:

- Measures of phytoplankton, zooplankton, and temperature are robust. Primary and secondary productivity is variable on the Eastern Scotian Shelf, with decadal trends. While monitoring is necessary as the climate is in flux, there have been subtle changes but no indication of alarm in the short-term.

Data Gaps:

- Canada is in the beginning stages of evaluating the short and long-term impacts of climate change on the marine environment.

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10. TROPHIC STRUCTURE[19]

Nancy Shackell, Fisheries and Oceans Canada, Ecosystem Research Division, Dartmouth, NS

10.1 ISSUE IN BRIEF

Trophic structure refers to the way in which organisms use food resources to get their energy for growth and reproduction, and is often referred to in simple terms as the "food web" or "food chain". A healthy marine ecosystem consists of trophic levels that have complex linkages to form a food web. A food web can be as complex as the connections of the world-wide web, but the concept can be understood if portrayed as a pyramid, with phytoplankton at the base of the pyramid, converting the sun's energy into food for organisms in the upper levels. The physical oceanography and climate are the natural drivers of these trophic dynamics (**Figure 10-1**). Regions with higher phytoplankton and zooplankton abundance at the base of the food chain, may have more productive (i.e., increased abundance and size) predator species and higher fishery yields (Ware 2005; Chassot et al. 2010). On the rich Scotian Shelf, over-fishing of large, dominant predatory fish (such as cod) has upset this balance because, in the absence of predators, their prey (e.g., shrimp, herring and sandlance) have increased, resulting in a trophic imbalance in the ecosystem (Worm and Myers 2003; Bundy 2005; Frank et al. 2005). A reduction in predator size on the Scotian Shelf may have also influenced the trophic structure, because smaller predators cannot regulate their prey as efficiently (Shackell et al. 2010). The focus of this paper is the groundfish collapse as it has altered the Scotian Shelf trophic structure. By 1992/1993 all fishing regions were declared under moratorium for cod, haddock and pollock, except for the most southerly warmest area in Atlantic Canada, the Western Scotian Shelf. Groundfish recovery and trophic balance since the moratorium on the Eastern Scotian Shelf has been slower than expected partly because herring and sandlance eat groundfish eggs and larvae, and the average groundfish is almost 50% smaller. Lately, some species such as haddock and cod (to a lesser extent) have recovered somewhat, but the fish are still small. The ecological impacts include a restructuring of the ecosystem due to loss of groundfish productivity, which has led to socioeconomic impacts including a decline in the health of coastal communities.

Linkages

This theme paper also links to the following theme papers:
- Marine Habitats and Communities
- Incidental Mortality
- Species at Risk
- Primary and Secondary Productivity
- Fish Stock Status and Commercial Fisheries
- Climate Change and its Effects on Ecosystems, Habitats and Biota

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[19] Completed June 2011.

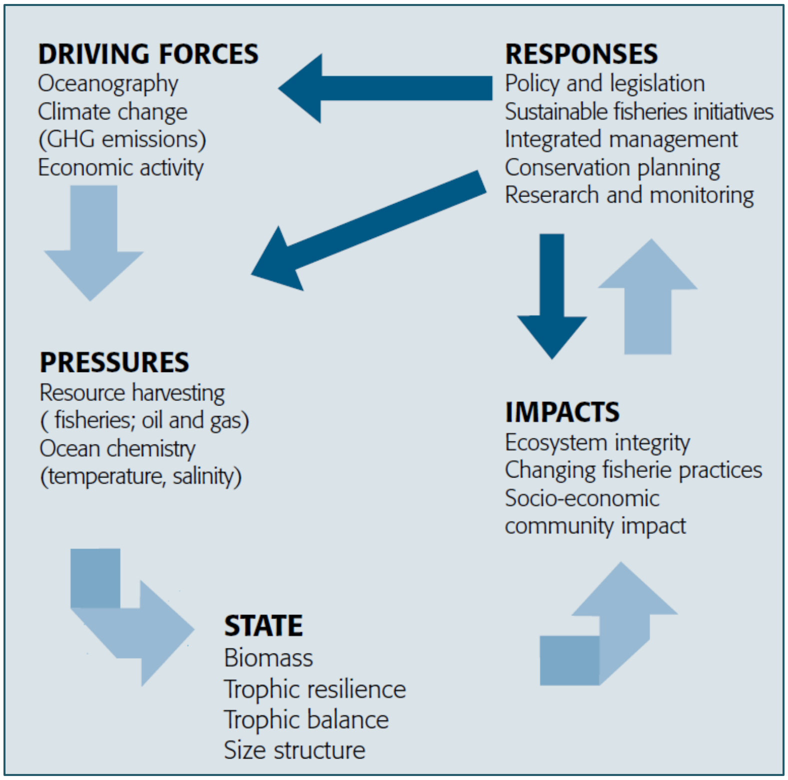


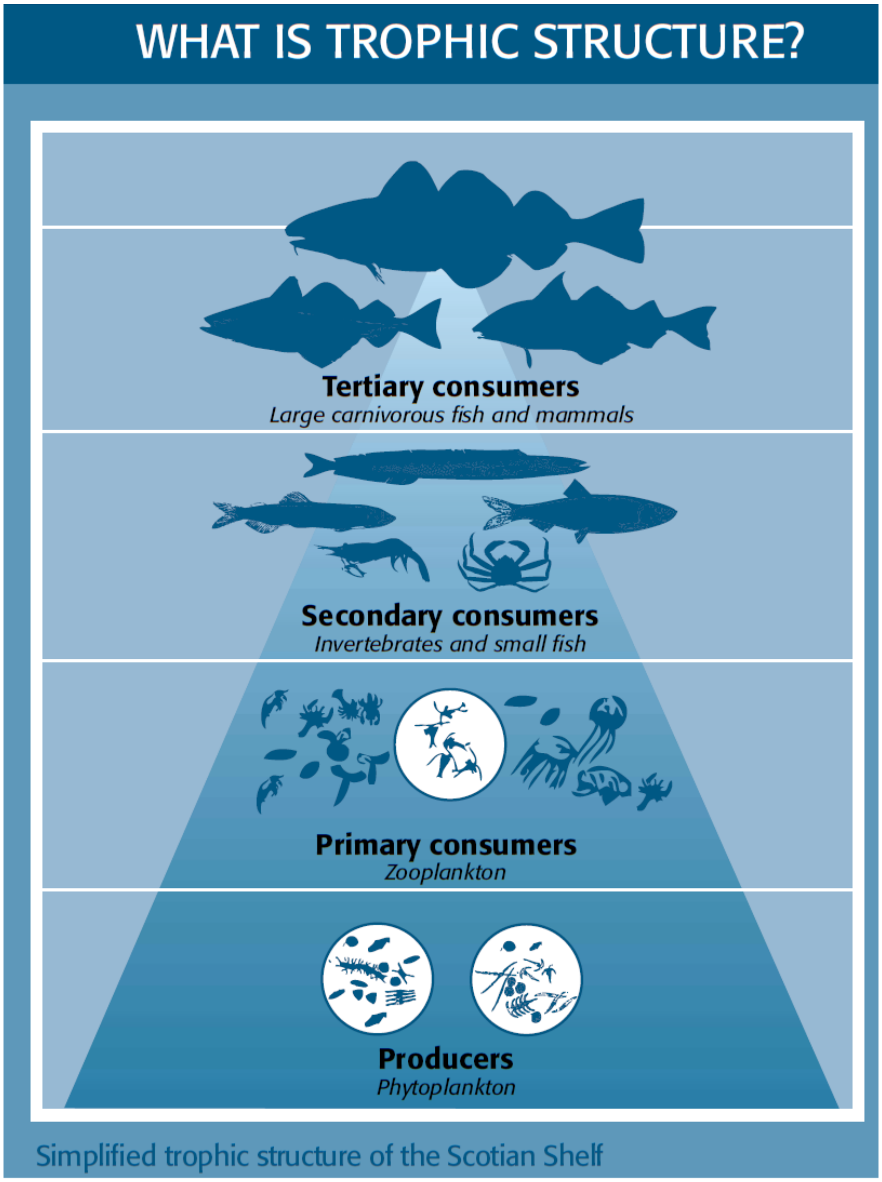
Figure10-1: Driving forces, pressures, state, impacts and responses (DPSIR) to trophic structure of the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human well-being, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements

10.2 DRIVING FORCES AND PRESSURES

Every ecosystem experiences natural and anthropogenic forcing, which alters its state, and has a varying impact on both the ecological integrity and resource use. Natural drivers include the natural oceanographic conditions and climate. Anthropogenic drivers include resource use and extraction, which are influenced by increasing populations and expanding economies. In our region, the main activity affecting trophic structure is fishing (resource harvesting). Although other activities (aquaculture, industry, oil and gas) place pressure on the environment (e.g. contamination) so that cumulative changes occur, currently the dominant pressure is fishing.

10.2.1 Oceanography

The physical oceanography of the Scotian Shelf is described in The Scotian Shelf in Context. The Scotian Shelf ocean climate is determined largely by ocean currents. The cold, low-salinity Labrador Current flows past the Grand Banks of Newfoundland and influences the Scotian Shelf. Fresher water also flows in from the Gulf of St. Lawrence. The western part of the Scotian shelf is influenced by the Gulf Stream, which flows north along the edge of the Continental Shelf. The Scotian Shelf is generally divided into two bio-geographical regions, the warmer Western Scotian Shelf, and the colder Eastern Scotian Shelf (**Figure 10-2**).



Simplified trophic structure of the Scotian Shelf

The word trophic means "to feed." The trophic structure in a community is the feeding relationships between species. It determines how energy is passed from organism to organism, like from plants to herbivores to carnivores. Trophic structure is organized in levels. The organisms of the first trophic level are called producers. They exist at the very bottom of the trophic structure and they support all other trophic levels. In the marine environment, these are the phytoplankton (algae). The organisms of all the levels after producers are called consumers, meaning they eat other organisms. The first trophic level after the producers is the primary consumer. These organisms are herbivores that eat plants, algae, or bacteria. The next trophic level is composed of secondary consumers, which include invertebrates (e.g., crabs) and small fish. The next level is composed of tertiary consumers, which are larger carnivorous fish and mammals. Detritivores, or organisms that derive energy from dead material like animal wastes, plant litter, or dead organisms, fit in at the very bottom of the trophic structure, but in reality, the food web is far more complex. Consumers at one level can eat at multiple levels and even the prey of one consumer can eat the eggs and larvae of their predators. The pyramid is a useful concept to think about how trophic interactions work, but reality is always more complex.

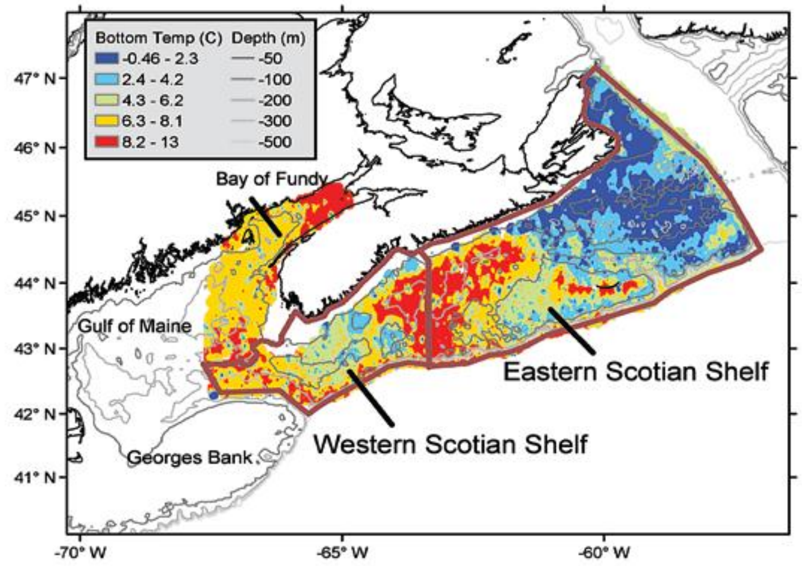


Figure 10-2: Bottom summer temperature on the Scotian Shelf, delineated into the Eastern Scotian Shelf and the Western Scotian Shelf. These generally correspond to NAFO divisions 4VW and 4X, which are used to compile statistics and regulate fisheries in the Northwest Atlantic.

10.2.2 Anthropogenic and Natural Climate Change

Anthropogenic climate change, principally global warming, due to greenhouse gas (GHG) emissions, is evident at the global scale from ocean circulation models (IPCC 2007a,b,c). These global-scale patterns are modified at the local scale by natural variability, which on the Scotian Shelf is very pronounced due to the strong seasonal cycle and the variable strength of prevailing large scale circulation and atmospheric forcing (e.g. the North Atlantic Oscillation) On shorter time scales (decades), natural variability will be the dominant pressure on shorter time scales (5-10 years), but it is the combined effect of natural variability and anthropogenic climate change that will lead to pronounced ecosystem change (J Loder, DFO, pers. comm., 2010).

Temperature heavily influences ecosystems through its effects on physiological processes (growth), timing of migration and population dynamics, all of which influence species distribution. Whether the sea surface temperature (SST) is warming or not depends on the time window. When measured from the early part of the century, SST on the Scotian Shelf as measured near Halifax has shown no long-term increase, but there has been a change of 1 °C of SST per century as measured at St. Andrew's, New Brunswick in the Bay of Fundy (**Figure 10-3**). In other words, there are effects of global warming but the natural variability still dominates

Anomalies

Anomalies are used often for time series in oceanography and refer to how much an observation deviates from its long-term mean. This is useful when comparing data from different sources. For temperature, data are scaled to have a mean of zero. If the SST is shown as 1ºC above the mean, it was a warmer year. Anomalies can also be standardized so as to have a standard deviation of 1. When every data set is scaled to have a mean of zero, and a standard deviation of 1, it is easy to compare how much each series varied over time. For example, if an indicator varied around 0 for the length of the time series, it did not vary much. If an indicator was 3 units above the mean in the earlier part of the time series, and is currently 3 units below, then that indicator has declined well below its long-term mean.

near Halifax with regards to SST. In both areas, there are distinct naturally derived warm and cold periods that would have affected productivity at all levels.

Recent work documents a decrease in salinity or "freshening" of the Scotian Shelf and Gulf of Maine (Drinkwater and Gilbert 2004; Greene et al. 2008). One of the main reasons for this is the melting of Arctic sea ice. This melting will increase the global input of freshwater resulting in changes in salinity and circulation in the ocean system. As sea ice melts, a large pulse of freshwater increases the strength of the southward flowing Labrador Current and reduces sea surface salinity.

Other expected long-term changes on the Scotian Shelf, due to climate change and GHG emissions, include decreasing oxygen levels in harbours and populated coastal areas (William Li, DFO, pers. comm., 2010) and ocean acidification (see *Climate Change and its Effect on Ecosystems, Habitats and Biota*, and *Ocean Acidification*).

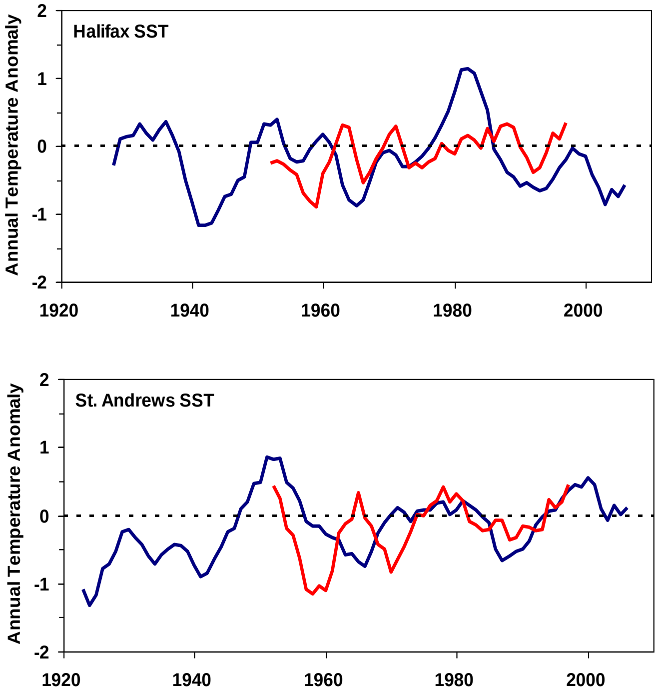


Figure 10-3: SST as measured at a station called the Halifax line, due to its origin from Halifax, Nova Scotia to the edge of the continental shelf (top panel), and St Andrews, New Brunswick (bottom panel). Units are expressed as anomalies, where the average is set to 0. The blue line indicates a 5-year running mean based on observations. Red line indicates 5-year running mean based on predictive model (see Petrie et al. 2009a; plot courtesy of Brian Petrie, DFO).

10.2.3 Commercial Fishing

The main economic activity on the Scotian shelf that affects trophic structure is fishing. The Scotian Shelf has always supported vibrant fishing communities (Lotze and Milewski 2004; see also *The Scotian Shelf in Context*). Originally these ecosystems were characterised by productive groundfish such as cod, haddock, pollock and silver hake. European exploitation began around 1560 (Kurlansky 1997). Nova Scotia exports in 1709 of primary target species were about 10,000 t of cod and 4,000 t of mackerel and herring per year, but by 1973, total fish landings were in excess of 750,000 t (Zwanenburg et al. 2006). The majority of the landings were groundfish both on the Eastern Scotian Shelf and Western Scotian Shelf (**Figure 10-4**). Invertebrates became increasing dominant in the landings during the 1990s.

Cod was once a principal fishery on the Scotian Shelf but was overfished. From 1974-1992, the annual rate of depletion on the Scotian Shelf averaged 49% on the Western Scotian Shelf and 53% on the Eastern Scotian Shelf (Petrie et al. 2009b). The depletion rate increased significantly on the eastern Scotian Shelf spawning stock biomass in the late 1980's, at the same time as certain spawning populations disappeared (Frank et al. 1994). By 1992, a little more than 80% of the available spawning stock biomass on the Eastern Scotian Shelf was being removed.

Since the groundfish collapses in the early 1990s on the eastern Scotian Shelf, the fishery has been dominated by crustaceans such as shrimp, snow crab and lobster (Bundy 2005; Frank et al. 2005). In general, fisheries on lower trophic level marine invertebrates and plant species expanded (Pauly et al. 2001; Anderson et al. 2008). This resulted in a decline in the mean trophic level of catches starting in 1988 (**Figure 10-5**).

Fishing not only removes biomass, but can also negatively affect habitat, increase mortality of non-targeted species (bycatch), and selectively target large older fish. In Atlantic Canada, trawling is currently the most widely used method to capture fish and is considered by Atlantic marine professionals (fishermen, scientists, marine conservation professionals, and fisheries managers) to have the greatest ecological impact (Fuller et al. 2008). Trawling will also tend to capture species that co-occur with the target species. For example Thorny skate is not a commercial species but co-occurs with cod and winter skate. The steady decline of thorny skate may be because it was continuously caught as bycatch during the height of the cod fishery (Shackell et al. 2005; see theme paper on *Incidental Mortality*).

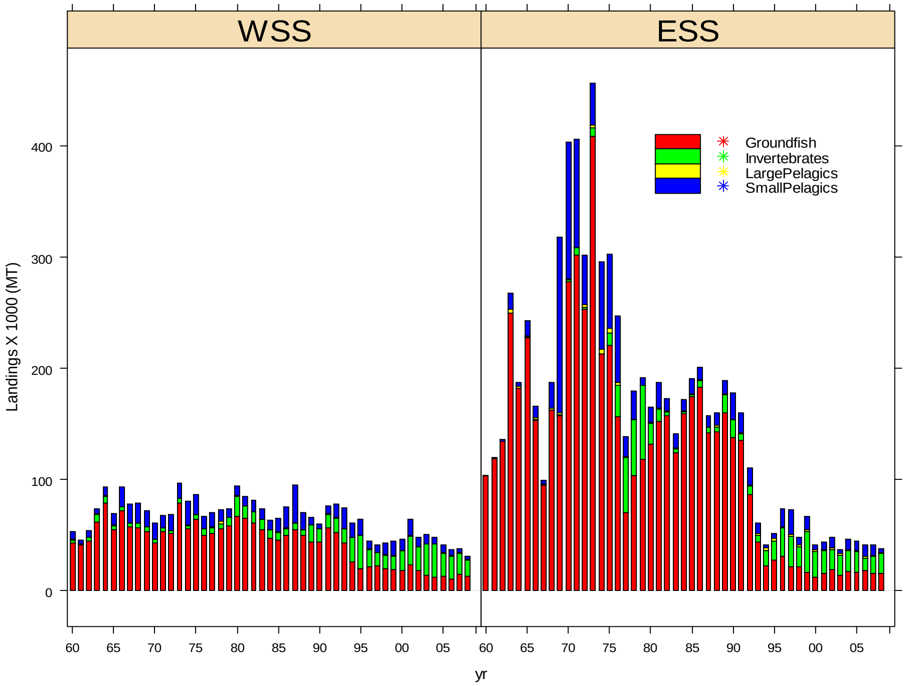


Figure 10-4: Commercial fisheries landings on the western and eastern Scotian Shelf from 1960-2008.

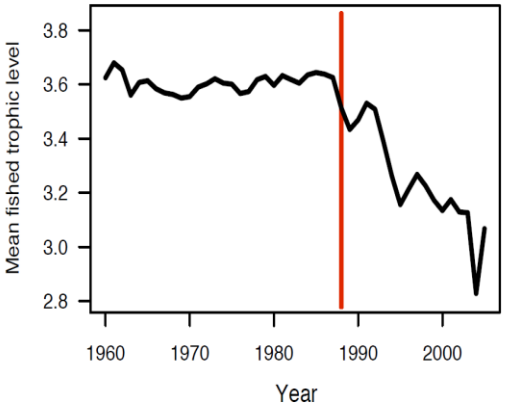


Figure 10-5: Commercial fisheries landings on the western and eastern Scotian Shelf from 1960-2008. The red line represents when the trophic level started to decline rapidly in 1988 and was used partly to designate fisheries as established, developing or emerging (adapted from Anderson et al. 2008).

10.3 STATUS AND TRENDS

The current state of the trophic structure of the Scotian Shelf is an altered structure dominated by the collapse of the traditional groundfish fisheries throughout the Northwest Atlantic. By 1992/1993 all fishing regions were declared under moratoria for cod, haddock and pollock, except for the most southerly warmest area in Atlantic Canada, the Western Scotian Shelf.

10.3.1 Biomass of the Main Trophic Levels

When the groundfish moratorium was declared in the early 1990s on the Eastern Scotian Shelf, it became clear that the decline in groundfish was principally due to overfishing, exacerbated by a cold period in the mid-1980's. Importantly, any effect of environmental forcing was dwarfed by the effect of fishing (Bundy 2005; Frank et al. 2005).

Over-exploitation of top predators can create an imbalance between top predator and forage fish prey abundances. Because there are fewer predators, their prey start to increase. If those more numerous forage fish start depleting their main source of food (zooplankton), there will be fewer zooplankton to eat phytoplankton, and phytoplankton will increase. This is referred to as a trophic cascade because removal of top predators can indirectly affect the dynamics of all the lower trophic levels. Globally, there was strong evidence that a decline in groundfish may cause a trophic cascade through the ecosystem. (Daskalov et al. 2007; Casini et al. 2008, 2009). The decline in groundfish on the Eastern Scotian Shelf initiated an increase in many of their prey species (**Figure 10-6**). Even the increase in lobster in the Gulf of Maine is likely due to the absence of large cod and other large fish predators (Steneck 1994; Boudreau et al. 2010). In the absence of a strong predation pressure, invertebrates, including shrimp, lobster and forage fish increased (Worm and Myers 2003; Choi et al. 2005). The increased abundance of forage fish put more predation pressure on zooplankton, and large copepods started to decline in the early 1990s. Since the zooplankton had declined, this allowed the phytoplankton to increase. Thus, the effects of over-fishing the top predatory groundfish have "cascaded" through the ecosystem on the Eastern Scotian Shelf (Bundy 2005; Frank et al. 2005).

As well as a decline in predator biomass leading to an increase in prey, there may also have been other factors affected the changes in the trophic structure on the Eastern Scotian Shelf. For instance, the decline in salinity may have caused the phytoplankton increase from the 1960s to the 1990s. Lower salinity causes increased stratification that traps nutrients in the upper layer of the water column where sunlight is available, resulting in an increase in phytoplankton production (Greene et al. 2008). While the cause of increased phytoplankton throughout the Northwest Atlantic has been questioned (see Head and Sameoto 2007; Greene et al. 2008), it is clear that the ecosystem has changed.

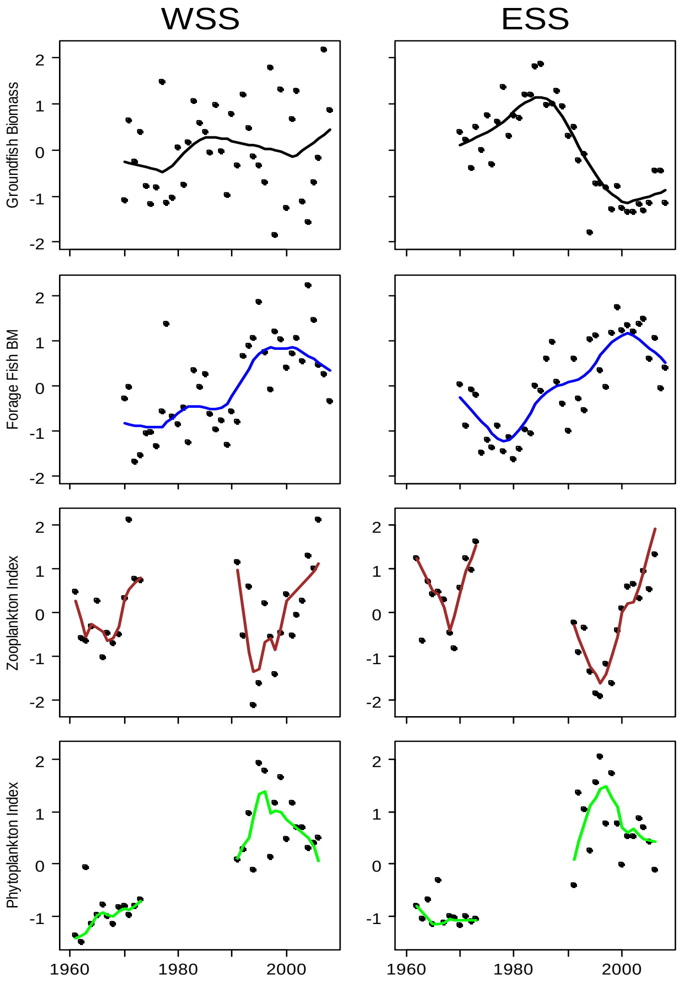


Figure 10-6: Trophic trends on the Western Scotian Shelf (WSS) and Eastern Scotian Shelf (ESS). From bottom to top panel : phytoplankton (green line); large copepods (brown line); forage fish such as herring, sandlance, argentine and mackerel (blue line), predatory groundfish including cod, haddock, pollock, dogfish, white hake, silver hake redfish etc. (purple line). All units area as anomalies.

On the adjacent Western Scotian Shelf, the trend in trophic patterns was similar to those on the Eastern Scotian Shelf except for one important difference- biomass of large groundfish. In both areas but to a greater extent in the east, there was an increase in phytoplankton from the 1960s early 1970s to the early 1990s, a decline in large copepods, and an increase in the biomass of forage fish up until the late 1990s (Choi et al. 2005; Frank et al. 2005; Shackell et al. 2010). The major dissimilarity between the two areas was largely in the response of the biomass of large groundfish (**see Figure 10-6**); not all species declined in the west and when dominant commercial species declined, other species increased (Shackell et al. 2007). The Western Scotian

Shelf showed signs of a weak cascade, but the predation pressure by top predators in terms of biomass, had not declined.

10.3.2 Size Structure

In marine systems size is important, with larger fish eating smaller fish, which eat smaller fish and so on. Fishing targets and removes the larger, older fish, leaving the smaller, younger and often less fit fish to reproduce (Bianchi et al. 2000; Olsen et al. 2004; Shin et al. 2005; Swain et al. 2007; Darimont et al. 2009). Declining fish sizes have been observed world-wide (Fisher et al. 2010a, b) and specifically on the Scotian Shelf (**Figure 10-7**; Shackell and Frank 2007; Shackell et al. 2010). Selection pressure of marine harvesting on large fish can be up to 300% higher than natural rates (Darimont 2009). Setting minimum size limits (e.g., 43 cm in cod, haddock, pollock fishery), can exacerbate the problem because the fishing pressure is then concentrated on larger fish.

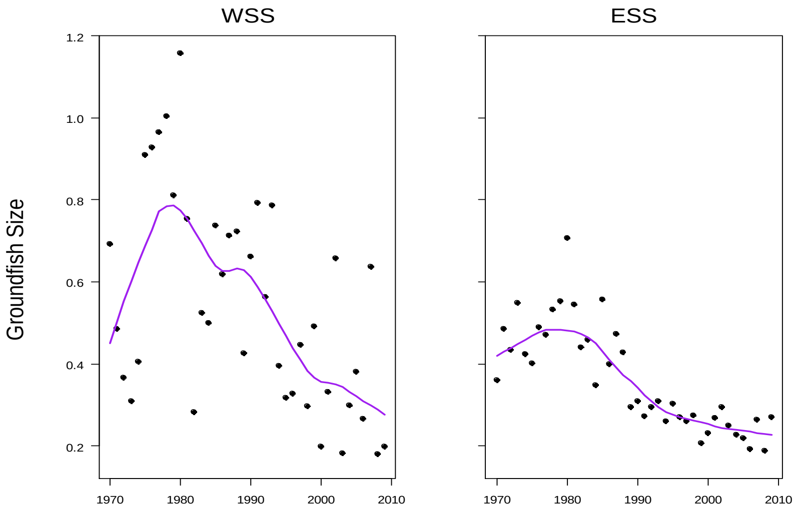


Figure 10-7: Groundfish size (kg) on the Western Scotian Shelf (WSS) and the Eastern Scotian Shelf (ESS) from 1970-2008 (Shackell et al. 2010).

Given the strong decline in predator size worldwide, it is possible that trophic structure is influenced by size. Larger predators are better hunters and have stronger per capita effects on prey because they need more food to survive. As well, they keep eating smaller prey but also eat larger prey as they get larger (Scharf et al. 2000). Larger hunters are more successful at capturing prey, because they can swim longer and faster, and possess higher visual acuity (Sornes and Aksnes 2004). Finally, larger fish can eat more prey per unit time than smaller predators. As larger fish chase a school of prey, they are able to consume more before that school of prey is able to scatter and escape. Indeed, the diminution of large predator attributes as their size declines would result in a weakening of top predation pressure, and are thought to be responsible for the increase in prey biomass and associated trophic changes observed on the Western Scotian Shelf (Shackell et al. 2010). Size-selective harvesting can occur either because fishers are taking the largest fish or because fish do not grow old enough to be large. Under changing climatic conditions, the decline in body size has initiated a trophic restructuring of the food chain on the Scotian Shelf, the effects of which may have influenced three trophic levels.

The temperature difference between the warmer west and the colder east accounts for the less extreme response in several of the biological indicators. On the Eastern Scotian Shelf, the response of lower trophic levels can be primarily attributed to the absolute loss of biomass of large fish (Frank et al. 2005). On the Western Scotian Shelf, the decline in body size of large fish may have led to different predator/prey dynamics. In other words, the indirect effects of size-selective fishing can result in a similar, but less extreme, trophic response as the direct removal of biomass of top predators.

10.3.3 Trophic Resilience

On the Eastern Scotian Shelf, the entire groundfish community declined, but has recently showed signs of recovering. On the Western Scotian, the total groundfish biomass did not collapse because species such as dogfish increased while cod, white hake, cusk and pollock declined (Shackell and Frank 2007). The resilience of a region to overfishing is directly related to its climate regime (Frank et al. 2007). The eastern and western Scotian Shelf share similar species composition and several populations exhibit coherent trends (Shackell and Frank, 2007). However, the "collapsed" Eastern Scotian Shelf is, on average, 2 ºC cooler than the adjacent Western Scotian Shelf where the cod fishery is still extant. In warmer regions, demographic rates are higher and the targeted stocks can withstand fishing better even though they can experience similar exploitation rates (Shackell and Frank 2007).

10.4 IMPACTS

Changes in trophic structure can have impacts on the ecosystem and socio-economics. **Table 10-1** provides a summary of likely impacts of changing trophic structure on the Scotian Shelf.

10.4.1 Cultivation Effect or Predator Pit Hypothesis

There are signs of partial recovery of groundfish stocks on the Scotian Shelf (Frank et al. 2007), but not to the extent hoped for. The climate, while unfavourable on the Eastern Scotian Shelf for a brief period, is not the dominant factor the lack of recovery (Choi et al. 2005). In the early 2000s, there were roughly 40 inter-related hypotheses as to why cod were so slow to recover in Atlantic Canada (DFO 2003). Ironically, part of the answer may be that the increase in forage fish such as herring and mackerel delayed groundfish recovery. Herring and mackerel, and likely other forage fish, not only eat groundfish eggs, their young compete with juvenile groundfish for food (Swain and Sinclair 2000). The sustainable abundance of predatory groundfish depends on what has been referred to as the "cultivation effect". When groundfish are abundant, they control the forage fish through predation and so limit their predation on groundfish eggs, and the competition between forage fish and juvenile groundfish. Once groundfish decline, the forage fish can become so abundant that they consume eggs, compete with juvenile groundfish, and suppress recovery. In such conditions, there would be a lagged recovery of groundfish (Walters and Kitchell 2001) and this may have contributed to the lack of groundfish recovery in the Gulf of St. Lawrence as well as other North Atlantic regions (Swain and Sinclair 2000; Walters and Kitchell 2001; Petrie et al. 2009).

Seals have long been suspected of negatively impacting cod populations in Atlantic Canada. On the ESS, grey seals numbered 5000 in 1970 and grew to 64 000 in 1994 but their consumption of cod was not a significant factor in the decline of cod (Mohn and Bowen 1996). The current debate is whether seals are impeding recovery of cod through their sheer abundance.

There is no consensus on the role of seals on cod recovery (see http://www.dfo-mpo.gc.ca/science/Publications/article/2008/16-09-2008-eng.htm) but if the forage fish are having a greater impact on juvenile cod, then culling the abundant seals, who are predators of forage fish as well (Beck et al. 2007) will further hamper recovery (Swain and Sinclair 2000). When forage fish become far too abundant given their food supply, their rate of population increase slows down, as has happened on both the eastern and western Scotian Shelf in recent years. This decline in forage fish may be beneficial to groundfish recovery (Frank et al., in review)

Table 10-1: Biophysical and socio-economic impacts of trophic imbalance on the Scotian Shelf

Element	Impacts
Biophysical Impacts	
Trophic Balance	• Predatory groundfish decline in biomass or size leads to an increase in their forage fish prey • Forage fish, in turn, may suppress groundfish recovery by eating their eggs and competing with their juveniles
Average Size	• Loss of potential accumulation of biomass to beget larger fish, the preferred choice of fisherman • Faster generation times • Lower diversity of size classes • Reduced predatory abilities
Species and ecosystems	• Reduced diversity within species and populations which reduces stability (Portfolio effect) • Transfer of fishing effort to alternate species with unknown consequences due to lack of knowledge of new species being fished (Anderson et al. 2008) • Some of these new species are being fished using gear that destroys habitat or have high rates of bycatch (Fuller et al. 2008)
Socio-Economic Impacts	
Commercial Fishery Employment	• In Atlantic Canada, the current invertebrate fisheries are more lucrative, but employ fewer people (Fuller et al. 2008; Charles et al. 2009)
Commercial Groundfishery	• Value has declined reflecting “depreciation of capital” (Charles et al. 2009)
Commercial Invertebrate Fishery	• Effort was transferred to invertebrate fisheries as major groundfisheries were closed. Their sustainability is not predictable. Lobster landings increased through the 2000s but in 2007, were 30% lower than the previous year (Charles et al. 2009) • Transfer of fishing effort to alternate species with unknown consequences due to lack of knowledge of new species being fished (Anderson et al. 2008) • Some of new species are being fished using gear that destroys habitat or have high rates of bycatch (Fuller et al. 2008)

10.4.2 Size Effect

Another part of the answer to delayed groundfish recovery, is the size and condition of the formerly large-bodied community. The average size of groundfish has declined on the Scotian Shelf (Shackell et al. 2010) as has their condition (an index of how fat they are at a given size) (Shackell and Frank 2007). A smaller fish, of the same species, contributes less to the next generation. Younger, smaller, first-time spawning cod are not as successful as second-time spawning cod. “They breed for a shorter period, produce fewer egg batches, exhibit lower fecundity, and produce smaller eggs with lower fertilization and hatching rates; moreover, their larvae are less likely to hatch in environmental conditions favourable for survival….” (Trippel 1994; 1998). This means that an age-truncated population of the same size does not have the same reproductive potential as an older population. Smaller females of a large-bodied species, in general, produce fewer eggs. When the entire population is smaller, the production potential is reduced (Brander 2007). However, fishery-induced size changes may be reversible (Conover et al. 2009) and the predatory groundfish of the Scotian Shelf may yet regain their former predatory role.

10.4.3 Portfolio Effect

The “portfolio effect” refers to the concept that diversity contributes to stability. Species diversity is one aspect that contributes to ecosystem stability, and likewise diversity within species allows for more stable population dynamics and more resilient populations (Schindler et al. 2010) and within populations (Trippel, 1994). When sub-populations of a species start to disappear, e.g. cod on the Eastern Scotian Shelf (Frank et al. 1994), the entire stability of the population is lower. When a population has reduced age/size/phenotype diversity, its stability is reduced. If many ages/sizes are able to contribute their genes to the next generation, the odds that their offspring survive are greater because they come from a diverse set of spawners; this is referred to as a “bet-hedging life history strategy” and is a reflection of the gambling approach to life in a highly variable environment. Consider the hypothetical example that in the 1970s, the environment was overly harsh in the early part of the spawning season, when small, young spawners spawn, and few offspring survived. That was not detrimental to the population as the environment favoured offspring that were spawned later in the season by larger fish. In the 2000s, during a similar regime, the odds of high rates of survival would be lower because the population no longer has as many large fish that spawn later in the season.

Diversified Ecosystems

“One of the most pervasive themes in ecology is that biological diversity stabilizes ecosystem processes and the services they provide to society, a concept that has become a common argument for biodiversity conservation.” (Schindler et al. 2010)

10.4.4 Economic Impacts

10.4.4.1 Harvesting Patterns: The change in the Scotian Shelf ecosystem has caused a fundamental change in the structure of the commercial fisheries in Atlantic Canada. In particular, there has been a decrease in the traditional groundfish fisheries and an increase in developing and emerging fisheries, particularly invertebrates (**Figure 10-8**).

On the Eastern Scotian Shelf, the principal fisheries are now invertebrate fisheries including lobster, scallop, soft-shelled clam and snow crab (Frank et al. 2005). The snow crab fishery is highly lucrative and there is some question as to whether there is any economic benefit if the groundfish predators resume their ecological role in trophic dynamics. In the long term, however, a biologically diverse system, including healthy invertebrates and groundfish populations is more resilient, would be better able to withstand climate change, and importantly, provides a more diverse option for fisheries. While the current invertebrate fisheries have a higher value than former groundfish, they do not employ as many people in the community (Fuller et al. 2008). As well, invertebrate fisheries are not inexhaustible. Lobster landings increased through the 2000s but in 2007, were 30% lower than the previous year (Charles et al.

2009). Notably, the total value of exports (accounting for 95% of total landings in 2006) peaked at CDN$1.2 billion dollars in 2002, but declined to CDN$ 975 million by 2006 (Pinfold 2007).

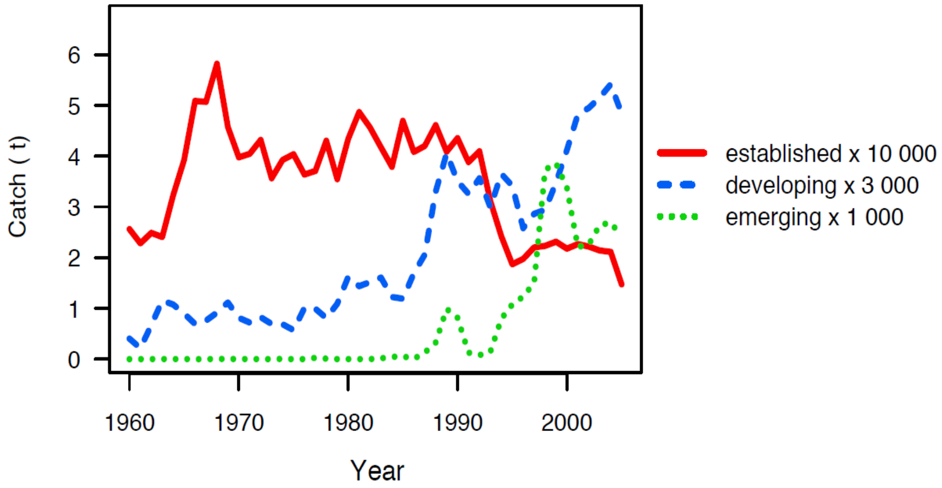


Figure 10-8: Mean annual catch of fisheries divided into those that are: 1) established: cod, haddock, halibut, redfish, yellowtail flounder, herring; 2) developing: dogfish, lobster, snow crab, shrimp, scallop, periwinkles, rockweed, and 3) emerging: red crab, rock crab, Jonah crab, quahog, Arctic surf clam, Atlantic surf clam, sea urchin, sea cucumber (adapted from Anderson et al. 2008).

10.4.4.2 Coastal Communities: With the downturn in the lucrative groundfishery, the economic activity and demographics of many coastal communities has changed. In 2006, 223 licensed fish processing plants were operating. Of those, only 105 were significantly active in actual processing while the remainder was inactive or involved in just shipping, buying, or selling. Of those extant plants, only 50% operated year round while the rest were seasonal. Assuming that the 400-odd plants in the early 1990s were actively processing, there was a 74% decline in the number of fish processing plants in Nova Scotia in 2006 (Pinfold 2007). This has obvious implications for job opportunities in the surrounding communities.

In the early to mid-1990s, the federal government began divesting in public ports, including small craft harbours where 90% of the fish are currently landed. These fishing ports have either been sold or transferred to municipal or provincial governments and private industry, or are maintained by the Small Craft Harbours Branch of DFO. The effect of changes in working waterfronts was addressed in the Nova Scotia State of the Coast Report (http://www.gov.ns.ca/coast/state-of-the-coast.htm; Nova Scotia 2009). A classification scheme of 93 rural coastal communities in Nova Scotia linked to working waterfronts was used to designate whether communities were healthy, transitional or declining. From 1991-2006, the number of healthy communities increased from 28% to 33%, while the number of declining communities increased from 42% to 65%.

Diversified Fishery

"From the human perspective in the fishery, reduced reliance on single fisheries and single fish stocks means not only a more diverse set of fisher livelihood options, thus greater resilience within fisher communities, but also potential insurance against a downturn in fish landings of a particular species". (Charles et al. 2009)

10.5 ACTIONS AND RESPONSES

The change in the ecosystem on the Scotian Shelf after the cod fishery collapse and the resultant impacts to fishing communities around Nova Scotia have heightened people's awareness of the need for conserving ecosystems as a whole, including the trophic structure. The Canadian government has made significant strides to create a framework, through legislation, policy and program initiatives, for sustainable resource use. As well, there are now numerous fisheries-led initiatives to maintain and conserve trophic resources on the Scotian Shelf. Several key aspects are highlighted below.

Although it is recognised that climate change is a key factor in driving changes in trophic structure, the actions and responses associated with climate change are outlined in the theme paper on *Climate Change and its Effect on Ecosystems, Habitats and Biota* and are not discussed here.

10.5.1 Legislation

There are several pieces of legislation that impact the conservation of species on the Scotian Shelf (see **Table 10-2**; see also the theme paper on *At Risk Species*). Key federal legislation includes the *Fisheries Act*, the *Oceans Act* and the *Species at Risk Act*. Under the Fisheries Act, fishing of Atlantic cod has been under moratorium since 1992.

Table 10-2: Key legislation that is applicable to managing species at risk on the Scotian Shelf.

Legislative Instrument	Purpose	Comments
Fisheries Act - 1985	Provides fishing regulations for management of commercial species and also habitat protection.	Managed by Fisheries and Oceans Canada. http://laws.justice.gc.ca/en/F-14/index.html
Oceans Act - 1996	Provides for the management and conservation of marine areas including the establishment of marine protected areas.	Managed by Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/oceans/oceans-eng.htm
Species at Risk Act - 2002	Provides for the recovery and protection of species that are endangered or at risk.	Coordinated by Environment Canada in collaboration with Fisheries and Oceans Canada, and Parks Canada. Activities include a Species at Risk Public Registry and Habitat Stewardship Program. DFO is responsible for aquatic species. http://www.dfo-mpo.gc.ca/species-especes/index-eng.htm
Canada National Marine Conservation Areas Act - 2002	Allows for the establishment of marine conservation areas within the exclusive economic zone	Managed by Parks Canada http://www.pc.gc.ca/eng/progs/amnc-nmca/pr-sp/index.aspx
The Coastal Fisheries Protection Act C-33	Protects coastal fisheries and migratory fish stocks in Canadian ocean waters.	Managed by Fisheries and Oceans Canada http://laws.justice.gc.ca/eng/C-33/page-1.html
Fisheries Development Act (R.S., 1985, c. F-21)	Provides for the efficient exploitation of fishery resources and for the exploration for and development of new fishery resources and technology.	Managed by Fisheries and Oceans Canada http://www.dfo-mpo.gc.ca/reports-rapports/fda/fda2001-eng.htm

10.5.2 Sustainable Fisheries Initiatives

There are currently several initiatives underway initiated by the Canadian Government, private industry and NGOs that address sustainable fisheries. Although these initiatives are not focused on trophic structure per se, by ensuring sustainable fisheries, the trophic structure of the Scotian Shelf and the healthy functioning of the ecosystem will be conserved.

10.5.2.1 Sustainable Fisheries Framework: DFO has initiated the Sustainable Fisheries Framework (http://www.dfo-mpo.gc.ca/fmgp/peches-fisheries/fish-ren-peche/sff-cpd/overview-cadre-eng.htm), which is an ecosystem approach to fisheries management focusing on sustainable resource use. Under this framework, DFO works together with the fishing industry to develop fisheries-specific integrated fisheries management plans (IFMPs). These identify goals related to conservation, management, enforcement, and science for individual fisheries; and they describe access and allocations among various fish harvesters and fleet areas. The plans also incorporate biological and socio-economic considerations that are factored into harvest decisions. IFMPs have been developed for the Maritimes Region for Atlantic Mackerel (2007), Bluefin Tuna (2007, 2008), and Atlantic Swordfish and other tunas (2004-06) (see http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm).

10.5.2.2 Industry-Based Initiative: There are several industry-led initiatives for sustainable fisheries. These include:

- Participation in the certification program of the Marine Stewardship Council – The Marine Stewardship Council is an international organization that provides certification of sustainable fisheries and ecolabelling for marketing purposes (http://www.msc.org/). Information on certified fisheries on the Scotian Shelf is provided at: http://www.msc.org/track-a-fishery/certified/north-west-atlantic.
- Canadian Code of Conduct for Responsible Fishing Operations – The Food and Agriculture Organisation (FAO) Code of Conduct for Responsible Fisheries has been adopted by 80 countries, including Canada in 1995. In response, the Canadian fishing industry has adopted the Canadian Code of Conduct for Responsible Fishing Operations, which outlines general principles and guidelines for all commercial fishing operations to ensure sustainable fisheries (available at: http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/cccrfo-cccppr-eng.htm).

10.5.2.3 Community Based Initiatives There are several community-led initiatives for sustainable fisheries. In general, these include:

- Community-Based Management in Integrated Coastal and Ocean Management in Canada. In the wake of the cod collapse, the Canadian government recognized that increased participatory governance of coastal communities, those with the highest stakes in the fishing industry, would be necessary to ensure sustainable fisheries. The extent of decision-making by coastal community management committees varies across the province. In the mid-1990s DFO worked with the some members of the fishing community on the Scotian Shelf to introduce community quota management (Fanning 2007). During this time, policies were adopted to move away from a top-down approach to fisheries management to a more participatory approach (DF0 2004).

- Development of fishing co-operatives - A recent initiative in Nova Scotia includes a joint effort by Ecology Action Centre and Fishers to connect consumers to small-scale hook and line fishers in the Bay of Fundy (see http://www.offthehookcsf.ca/). If this is successful, it may be expanded to other fisheries. The benefit to the fishers is that they sell directly to the consumer, bypassing the costs of middle man. The benefit to the consumer is the option to buy fish that are caught with gear that has relatively less impact on the benthic habitat.

10.5.3. Integrated Oceans Management

Integrated oceans management includes a variety of activities to manage the oceans in a holistic manner for the future sustainability of its resources. Some key initiatives include the development of integrated management plans, conservation planning and implementation of ecosystem approach to management.

10.5.3.1 Integrated Management Plans: Under the *Oceans Act*, the Eastern Scotian Shelf has been designated as a large ocean management area. The Eastern Scotian Shelf Integrated Management (ESSIM) Initiative is a collaborative ocean management and planning process being led and facilitated by DFO. The Eastern Scotian Shelf Integrated Ocean Management Plan (see http://www.dfo-mpo.gc.ca/Library/333115.pdf) has been developed as a blueprint for action for this area. Nothing similar is available for the Western Scotian Shelf. One of the major implementation tools for the ESSIM Plan is marine spatial planning (see Ehler and Douvere 2009). Currently work is being done on the authority required for marine spatial planning on the shelf and the information and tools that will be required for its implementation.

10.5.3.2 Marine Protected Areas and Conservation Planning: Designation of fisheries closures and marine conservation areas are accepted methods to limit the impact of anthropogenic activities on marine organisms. Fisheries closure can be found at: http://www2.mar.dfo-mpo.gc.ca/fishmgmt/vo/search/index.asp. Conservation areas on the Scotian Shelf and slope include the Lophelia Coral Conservation Area, The Gully Marine Protected Area and Roseway Basin Whale Sanctuary. Another marine protected area is currently being designated on the Eastern Scotian Shelf. DFO Maritimes region is actively involved in a larger project to develop a Canadian network of marine protected areas

10.5.3.3 Ecosystem Approach to Management: Ecosystem approach to management is an environmental management approach that recognizes the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation (Christensen et al. 1996, McLeod et al. 2005). In order to practically implement ecosystem-based management in the Maritimes Region, the DFO is currently developing an ecosystem approach to management through an Ecosystem Approach to Management (EAM) Framework (Fisheries and Oceans 2010). The EAM framework identifies key strategies for ecosystem management and critical thresholds or limits for indicators associated with these strategies. Pilot implementations were due to begin in 2010.

10.5.3 Ecosystem Monitoring

Developing an understanding of the ecosystem is key to managing it in an integrated and holistic manner. Research is an ongoing mandate for DFO Science Branch. Of particular interest is that, in response to the downturn in the cod fishery, the DFO established the Atlantic Zonal Monitoring Program (AZMP) in 1999 (http://www.bio.gc.ca/monitoring-monitorage/azmp-pmza/index-eng.htm). The main objectives of AZMP are to collect and analyse biological, chemical, and physical data to characterise and understand the causes of oceanic variability at different time scales; and to provide the multidisciplinary data sets that can be used to establish relationships among the biological, chemical, and physical components, including the various trophic levels.

10.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR*	Assessment	Trend
Climate Change				
SST	Global warming is occurring, but no direct indication on Eastern Scotian Shelf yet, but we are currently in a warm period	Pressure	Good	/
Salinity	Salinity is decreasing due to freshwater from melting Arctic ice, may enhance/disrupt regular patterns of plankton growth.	Pressure	Fair	-
Fishing				
Trophic Level of Landings	Fishing lower down the food chain is considered unsustainable because fishing options have been reduced.	Pressure	Poor	/
Trophic Balance	Trophic balance can be upset by overfishing one trophic	State	Fair	+
Fish Body Size	Size-selective fishing can cause decrease in long- term average size of fish.	State	Poor	/
Coastal Communities				
Fishery jobs	Employment levels in fishing industry	Impact	Poor	/
Health of Coastal Communities	Economic vibrancy and well-being	Impact	Poor	-
Fish Plants	Number of operational fish plants has declined	Impact	Poor	/
Fisheries Management				
Policy and legislation	All relevant policy and legislation are in place	Response	Fair	/
Practice	Implementation of policy is lagging	Response	Poor	/

Key:
Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?
*see more about the DPSIR framework at http://coinatlantic.ca/index.php/state-of-the-scotian-shelf/217

Data Confidence

- Good data are available for climate indicators and upper trophic levels of fish. There is a gap of information for lower trophic levels, phytoplankton and zooplankton and for invertebrates. Good data for all trophic levels, from phytoplankton to predatory groundfish is ideal to study trophic dynamics.

Data Gaps

- Since the start of the AZMP (Atlantic Zonal Monitoring Program) in 1998 (http://www.bio.gc.ca/monitoring-monitorage/azmp-pmza/index-eng.htm), researchers have had access to region-wide data on lower trophic levels and climate. To investigate trophic structure before 1998, researchers have had to patch together lower trophic level data from the CPR program (http://www.sahfos.org), and have only scant information on regional abundance and distribution of macroinvertebrates. However, data on upper trophic levels, including forage fish and their predatory ground fish has been available since 1970 from the Canadian Department of Fisheries and Oceans (DFO) annual, scientific research vessel (RV) surveys. Integrated management is difficult under the current governance.
- Some data on impact of cod fish collapse on fishing communities is available in Chapter 5 of http://www.gov.ns.ca/coast/state-of-the-coast.htm

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11. FISH STOCK STATUS AND COMMERCIAL FISHERIES[20]

Robert O'Boyle, Beta Scientific Consulting Inc., Bedford, NS

11.1 ISSUE IN BRIEF

The status of the commercial fisheries of the Scotian Shelf is impacted by driving forces and pressures, which influence the long-term productivity of the ecosystem as well as the demand for ocean uses (**Figure 11-1**). Changes in the region's oceanography (as measured by sea surface temperature) due to the effects of climate change will likely lead to changes in ecosystem productivity and thus aggregate fisheries yield. Global and regional demands for seafood due to growing population size will continue to apply pressure on the stocks while competition for ocean space from other ocean industries such as aquaculture and energy extraction will have both direct effects on fishing and indirect effects on the stocks. Fishing effort, as measured by exploitation rate, which applies pressure to the stocks, is currently under control. The impacts on stock status of these driving forces and pressures are likely to be different for each of the major species groups (see box) occupying the Scotian Shelf. These pressures have implications for the profitability of the fishing and processing sectors. Stock productivity will be influenced by changes in species diversity, which will have long-term implications for the well-being of the local fishing communities.

There are three major species groups commercially fished on the Scotian Shelf. Groundfish, also known as demersal fish, live near the bottom for much of their adult life. They include important commercial species such as cod, haddock, pollock, redfish and flatfishes. Pelagic fish live in the water column and near the surface of the ocean, and include small schooling fish such as herring and capelin as well as large-bodied species such as swordfish, sharks and tunas. Shellfish are invertebrates with an external skeleton (shell), such as snow crab, lobster, scallop and shrimp.

The response of the management system to these changes is and has been multi-faceted and will need to be adaptive. A new Sustainable Fisheries Framework has been established which out-lines harvest control rules and offers promise that the management of the commercial fisheries of the Scotian Shelf will adapt to future driving forces and pressures. Both internationally and within Canada, there is a move towards an ecosystem approach to management which takes into consideration the broader effects of fishing on ecosystems. If consistently applied, this should lead to the recovery of many depleted species. Industry has responded with a suite of activities that are both complementary to these changes (i.e., providing fishery and stock monitoring) as well as being pro-active to meet the demands of the global market place (i.e., eco-certification).

Linkages

This theme paper also links to the following theme papers:

- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Primary and Secondary Productivity
- Marine Habitats and Communities
- Trophic Structure
- Species at Risk
- Incidental Mortality

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[20] Completed July 2012.

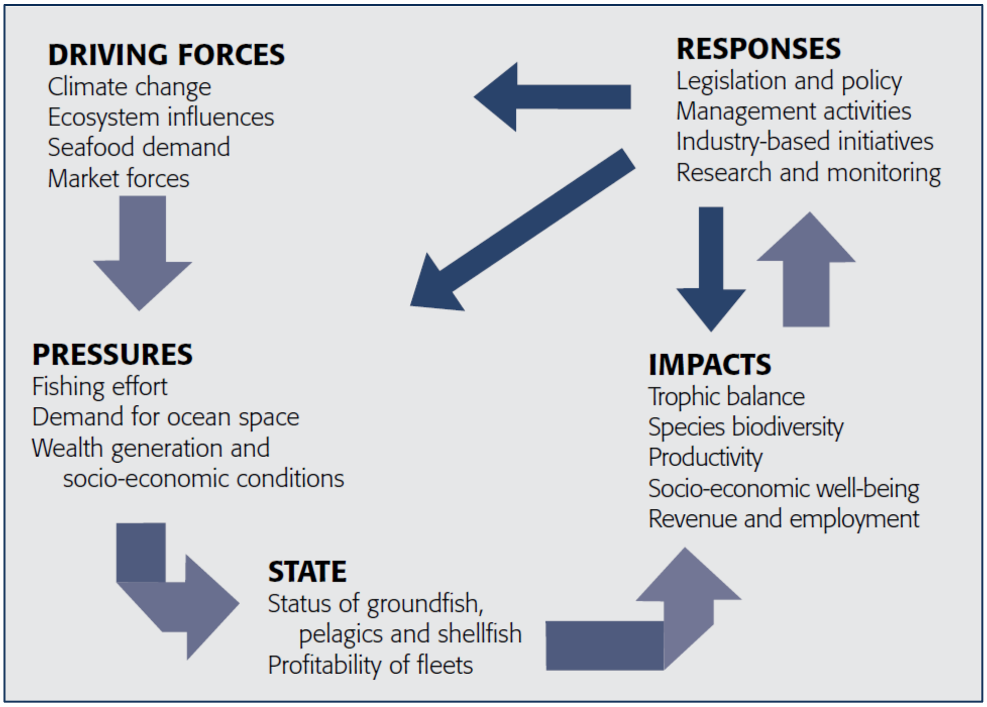

Figure 11-1: Driving forces, pressures, state, impacts and responses (DPSIR) implicated in the commercial fisheries of the Scotian Shelf. The DPSIR framework consists of the relation between the environment and humans. According to this framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the fisheries. This leads to impacts on ecosystems and human well-being, which elicit a societal or government response that feeds back on the other elements of the framework.

11.2 DRIVING FORCES AND PRESSURES

The fisheries of the Scotian Shelf are affected by forces and pressures that both change the productivity of the ecosystem, and thus the long-term expected yield of fisheries, and the demand for fish. Natural drivers include the oceanographic conditions of the Scotian Shelf which are in turn affected by climate change. Anthropogenic drivers include the demand for seafood, which is influenced by food markets both in the United States northeast as well as those in other parts of the world. Increasingly, other activities such as aquaculture and ocean energy development are competing with fishing for the use of the ocean.

11.2.1 Climate Change and Ecosystem Influences

The ocean conditions of the Scotian Shelf are determined largely by ocean currents[21]. The cold, low-salinity Labrador Current flows past the Grand Banks of Newfoundland and influences the whole Scotian Shelf. Fresher water also flows from the Gulf of St. Lawrence which primarily influences the eastern Scotian Shelf (ESS) while the Gulf Stream, which flows north along the edge of the Continental Shelf, primarily influences the western Scotian Shelf (WSS). Thus, while the Scotian Shelf is one ecosystem, within it are found distinct eastern and western components (**Figure 11-2**).

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[21] For more information on the geology, climate, oceanographic conditions and habitat of the Scotian Shelf, see *The Scotian Shelf in Context* (DFO 2012b).

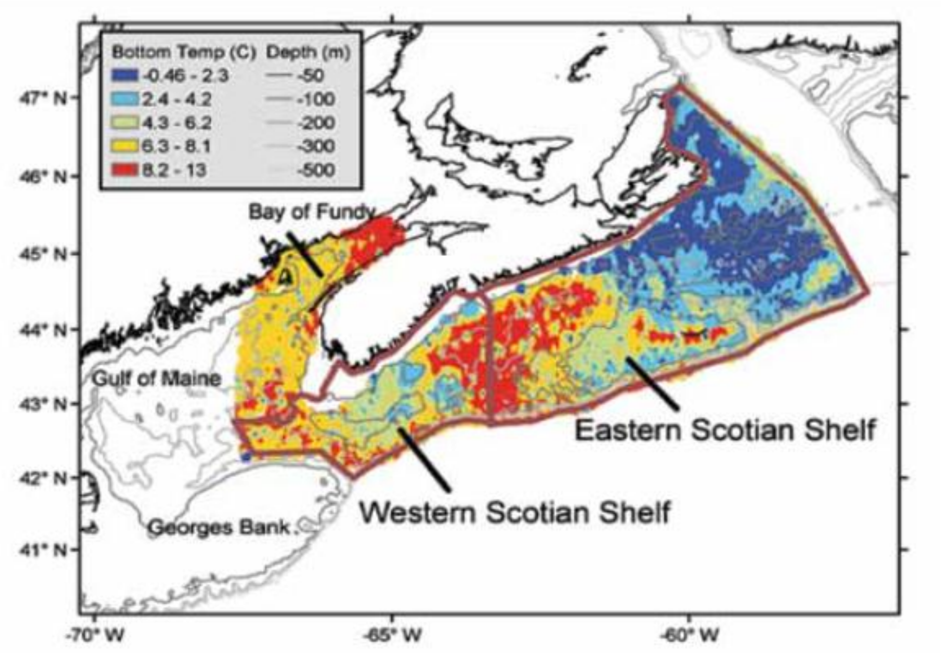


Figure 11-2: Bottom summer temperature of the Eastern and Western Scotian Shelf highlight its subdivision into eastern and western components (from Shackell 2011).

Anthropogenic climate change, principally global warming, due to greenhouse gas (GHG) emissions, is evident at the global scale from ocean circulation models (IPCC 2007a,b,c; see also the theme paper on *Climate Change and its Effects on Ecosystems, Habitats and Biota*). These global-scale patterns are modified at the local scale by natural variability, which on the Scotian Shelf is very pronounced due to the strong seasonal cycle, large scale circulation and atmospheric forcings (e.g., the North Atlantic Oscillation). Over the next 5–10 years, natural variability is expected to dominate but in the longer-term, the combined effect of natural variability and anthropogenic climate change is likely to lead to pronounced ecosystem change (Shackell 2011).

Temperature heavily influences the species inhabiting ecosystems through its effects on growth, feeding, migration and reproduction, any of which can lead to changes in a stock's productivity. Since the early part of the twentieth century, sea surface temperature (SST) measured near Halifax, an indicator of the local effects of climate change, has shown no long-term increase (Shackell 2011). On the other hand, since the 1960s, there has been a 1ºC increase of SST in the waters off St. Andrews, New Brunswick in the Bay of Fundy (**Figure 11-3**). In other words, natural variability still dominates the trend in SST off Halifax while the effects of climate change are becoming evident off St. Andrews (Shackell 2011). In general, the ESS and WSS are expected to respond differently to the effects of climate change. There has also been a decrease in salinity of the Scotian Shelf and Gulf of Maine (Greene et al. 2008) due primarily to the melting of Arctic sea ice. As sea ice melts, freshwater is added to the system. This large pulse of freshwater increases the strength of the southward flowing Labrador Current and reduces sea surface salinity.

Early speculation (Frank et al. 1988) on how commercial fisheries might be affected by climate change included a northward displacement of coldwater species, expansion of southerly warm water species from the Gulf of Maine, earlier arrival and later departure of pelagic migrants, a change in the overall fish community from groundfish to pelagics and an overall reduction in total fish production. Some of these predictions appear to have come true; however, whether or not climate change is involved is being debated (e.g. see Frank et al. 2011).

Since the 1960s, there have been changes along the full extent of the food chain on both the ESS and WSS, particularly in the former (**Figure 11-4**). In both areas, phytoplankton abundance increased from the 1960s to the mid-2000s (Shackell 2011). On the ESS, zooplankton decreased during this period while the biomass of pelagic and groundfish species increased and decreased respectively. There are differing hypotheses on the reasons for these changes. Frank et al. (2005; 2007) have argued that environmental influences are not primarily responsible and that overfishing of groundfish in the 1980s led to an imbalance in the ecosystem. With fewer groundfish predators, their prey (forage species) increased. The more numerous forage fish then depleted their main source of food (zooplankton), resulting in fewer zooplankton to eat phytoplankton, which in turn increased. This is referred to as a trophic cascade because removal of top predators can affect the dynamics of all lower trophic levels (Shackell 2011). Consistent with this theory is the hypothesis that an apex predator (grey seals) has inhibited the recovery of the ESS cod stock (O'Boyle and Sinclair 2012). More recently, there is some evidence to suggest that the Scotian Shelf ecosystem is reverting from one dominated by forage species to one dominated by groundfish (Frank et al. 2011).

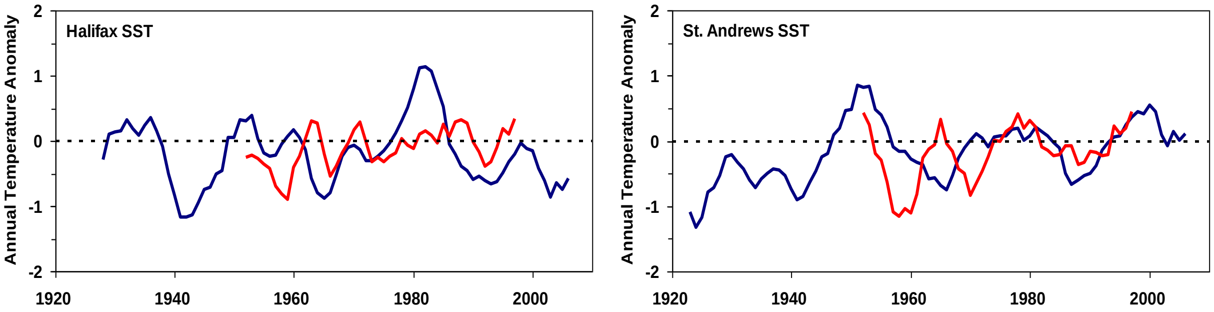


Figure 11-3: Sea surface temperature (SST) measured off Halifax (left panel), and St. Andrews, New Brunswick (right panel); units are expressed as differences above and below the long-term average. The blue line indicates the 5-year running mean based on observations while the red line indicates the 5-year running mean based on a predictive model (from B. Petrie, DFO, pers. comm. in Shackell 2011).

A competing hypothesis is that environmental forcings are indeed mainly responsible for changes in the Scotian Shelf ecosystem. Natural mortality for a large number of groundfish stocks has been high since the 1990s (Halliday and Pinhorn 2009), as evidenced in the WSS Atlantic cod stocks (**Figure 11-5**). Associated with this have been long-term reductions in the growth and condition of many of these stocks (**Figure 11-6**). These changes are coincident with increased strength of the North Atlantic Oscillation (NAO) leading to speculation that climate is playing an important role in the dynamics of the Scotian Shelf's fish stocks.

Whatever processes or combination of processes are responsible for changes in the Scotian Shelf ecosystem, they are having significant consequences for the productivity of the commercial fisheries. For instance, they have led to long-term declines in the productivity of some resources (e.g., ESS haddock, Mohn and Chouinard 2007; see section 11.4).

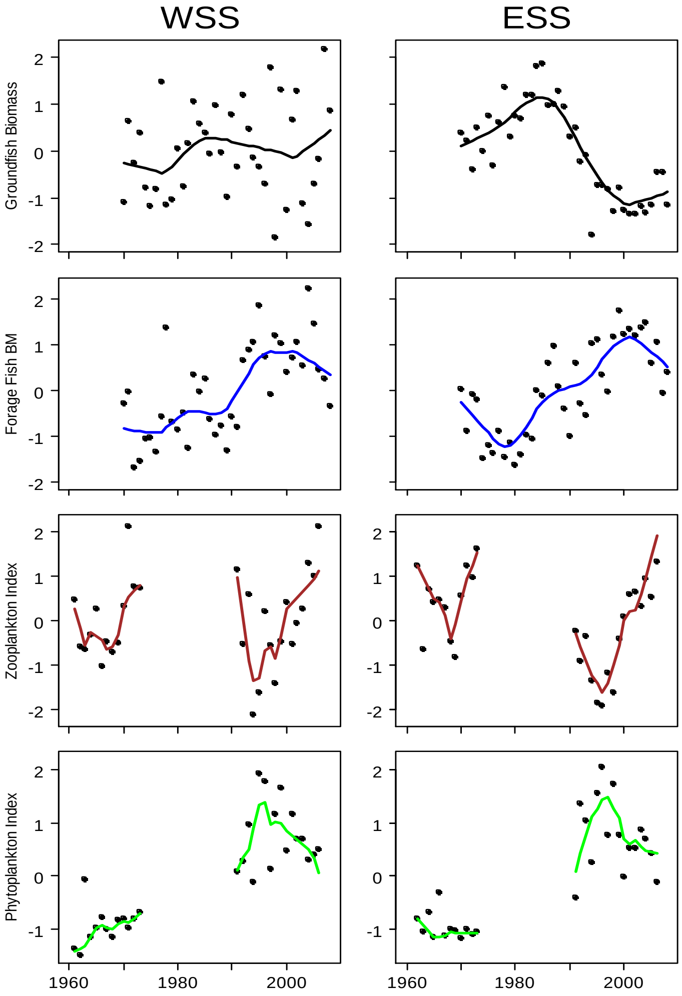


Figure 11-4: Abundance trends for different parts of the food chain on the Western Scotian Shelf (WSS) and Eastern Scotian Shelf (ESS); from bottom to top panel: phytoplankton (green line); large copepods (brown line); forage fish such as herring, sandlance, argentine and mackerel (blue line); predatory groundfish including cod, haddock, pollock, dogfish, white hake, silver hake, redfish, etc. (purple line); all units are as differences from long-term mean (Shackell 2011).

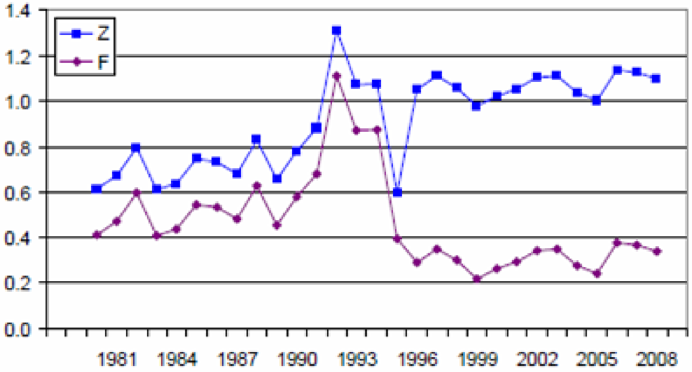


Figure 11-5: Total mortality (Z) and fishing mortality (F) of cod on the western Scotian Shelf and Bay of Fundy (NAFO Division 4X). The difference between Z and F is due to natural mortality (from DFO 2011f).

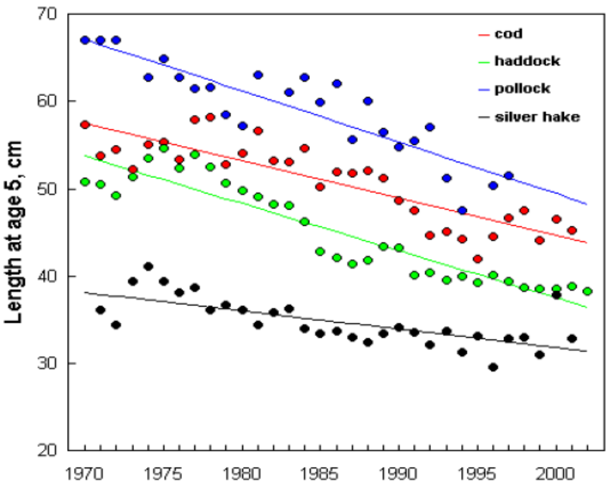
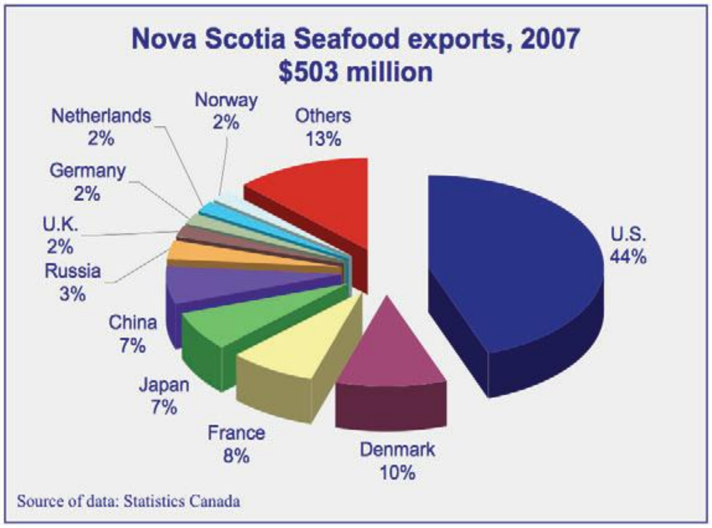


Figure 11-6: Length at five years of age for Scotian Shelf cod, haddock, pollock, and silver hake (DFO 2010c).

11.2.2 Seafood Demand and Market Forces

A major driving force of the Maritimes fisheries is the global and local demand for food. The current global population size is about seven billion, growing at a rate of about 1.1% per year (USCB 2012). This contrasts with the Nova Scotia population size of 945 000 in 2011 which has been growing at an average annual rate of 0.26% during 2002–2006 (Statistics Canada 2012). During this period, Nova Scotia seafood production averaged about $1.04 billion per year with 57% of this being from exports. Of these exports, 44% went to US markets, 29% to Europe, 14% to Asia and the remainder to other countries (**Figure 11-7**). There has been a 7% per year decline in revenue in recent years due to a strong Canadian dollar although the number of licensed fish plants and active plants has also declined due to difficulty in securing raw product and increasing consolidation in the processing industry (GPCE 2009).



Source of data: Statistics Canada

Figure 11-7: Percent global distribution of Nova Scotia seafood exports in 2007 (from GPCE 2009).

11.2.3 Socio-Economic Conditions

The social and cultural well-being of the Nova Scotia fishing communities that harvest the Scotian Shelf is tightly linked to ocean access. Of the 2006 Nova Scotia Gross Domestic Product (GDP) of $32 billion, 15.5% was of ocean industry origin, due to a number of industries including fisheries, aquaculture, fish processing, oil and gas, transport, tourism, shipbuilding and government related activities (e.g., national defence). In 2001, commercial fisheries were ranked number two in terms of GDP (GPCE 2005), but dropped to number three in 2006, or 17.6% of the ocean sector, behind oil and gas (**Figure 11-8**). Full-time employment in Nova Scotia's commercial fishery sector was 7121 in 2006, compared to 2778 and 517 in the oil and gas and aquaculture sectors respectively, both of which compete for ocean space with the fisheries. The oil and gas sector has leases to develop petroleum reserves primarily along the shelf edge off Nova Scotia (**Figure 11-9**) while aquaculture sites (321 in 2012) are located along the coast of Nova Scotia, where they would interact with coastal fisheries such as lobster.

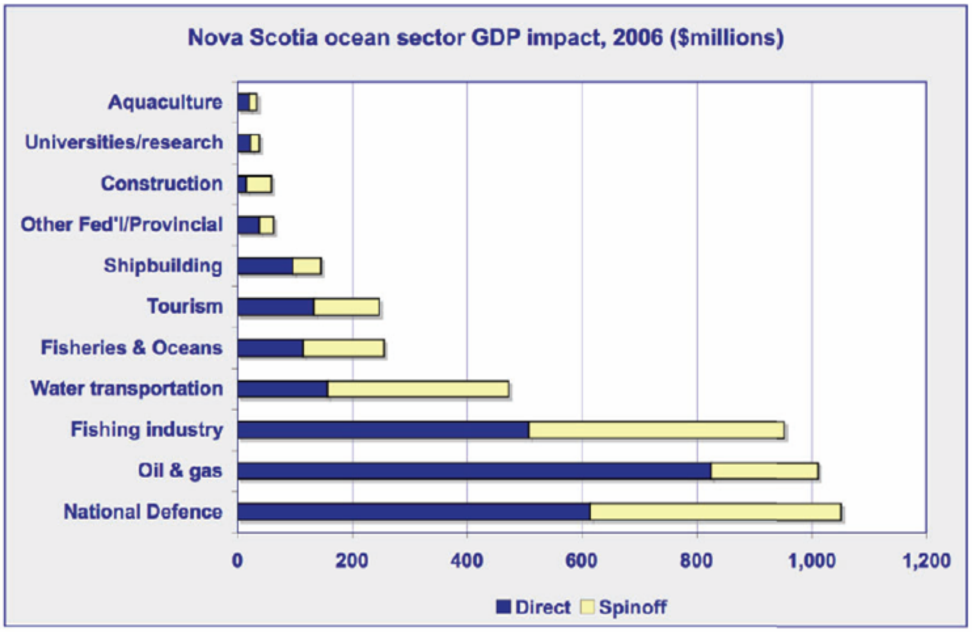


Figure 11-8: Distribution of Gross Domestic Product (GDP) 2006 impact ($ millions), both direct and spinoff by Nova Scotia ocean sector (from GPCE 2009).

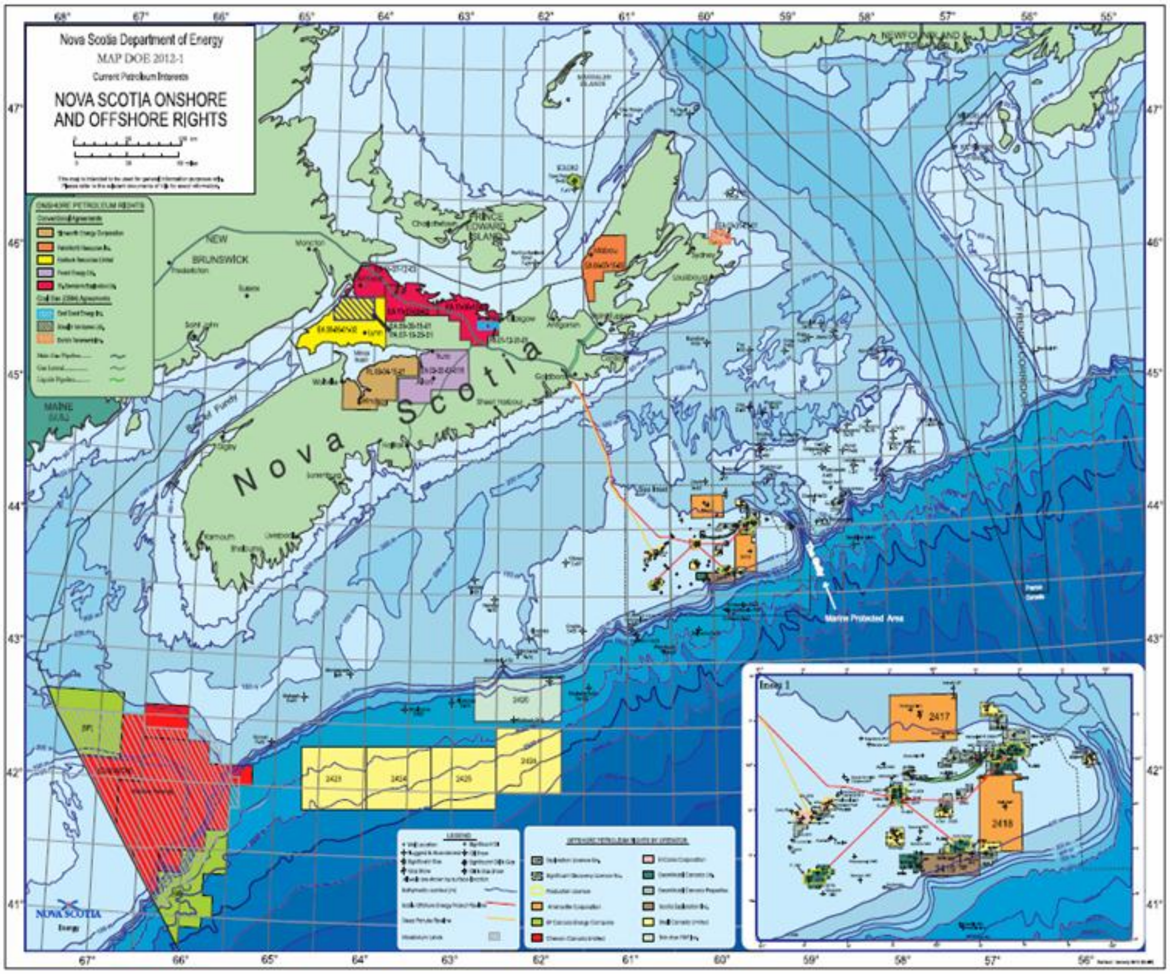


Figure 11-9: Nova Scotia onshore and offshore rights for petroleum exploration and development as of September 2012 (from http://www.gov.ns.ca/energy/resources/RA/maps/Onshore-Offshore-Rights.pdf).

11.2.4 Fishing Activity

The most immediate pressure applied to the stocks on which the Scotian Shelf fisheries depend is from fishing activity, as measured by the exploitation rate (% of biomass taken each year by fishing) experienced by each stock. The trend in exploitation rate varies markedly by groundfish (such as cod, haddock and pollock), pelagic (such as herring, mackerel and swordfish) and shellfish stocks (such as lobster, shrimp, and snow crab). Only a subset of the main species exploited is discussed here; these are intended to illustrate general trends.

Since 1993, most of the groundfish fishery on the ESS (including cod and haddock) has been closed and thus all stocks there have experienced low exploitation rates. On the WSS, the groundfish fishery has remained open. While the exploitation rate on WSS haddock has steadily declined since 1982, that on cod remained high until the early 1990s and then dropped in the mid-1990s to a relatively stable level (**Figure 11-10**). The exploitation rate on pollock was very high up until the mid-2000s after which it declined. Current exploitation rates are generally at or below their target (e.g., haddock and pollock harvest rates are 75% of their targets). However, for cod on the WSS, while exploitation is lower than what it was in the 1990s, overall mortality is still high due to unaccounted for high natural mortality (**Figure 11-5**).

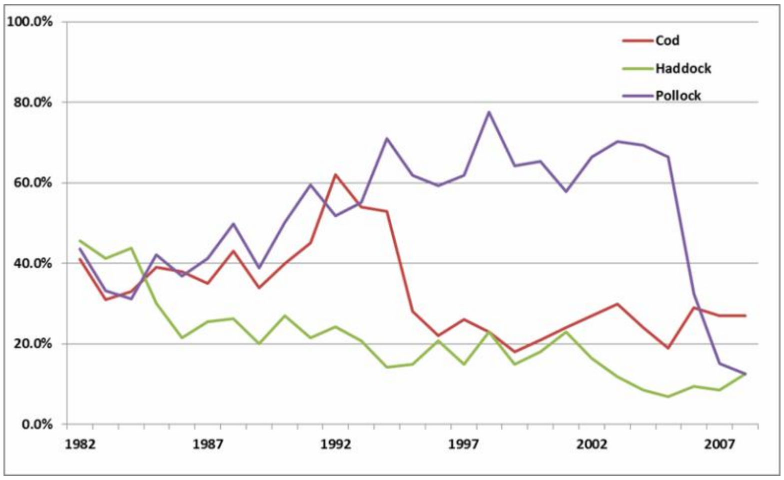


Figure 11-10: Trends in exploitation rates of cod, haddock and pollock on the WSS, as percent of the biomass taken by fishing each year (data from Clark and Emberley 2009, Stone et al. 2009 and Mohn et al. 2010).

For the main shellfish stocks, the fishery has been executed throughout the Scotian Shelf, with shrimp and snow crab primarily caught on the ESS and lobster and scallop on the WSS. Exploitation rates for shrimp and snow crab have been close to target levels of 10–20% (**Figure 11-11**). Exploitation rates of the lobster stocks are currently very high (in the order of 70– 80%) but do not appear to be threatening the sustainability of any of the LFAs under current environmental conditions (DFO 2011d). The scallop fishery on the WSS is primarily exploited in SFA 29 just off the coast of Southwest Nova Scotia and on Browns Bank. Exploitation rates on these stocks have ranged from 1 to 40% (DFO 2010a; DFO 2011c).

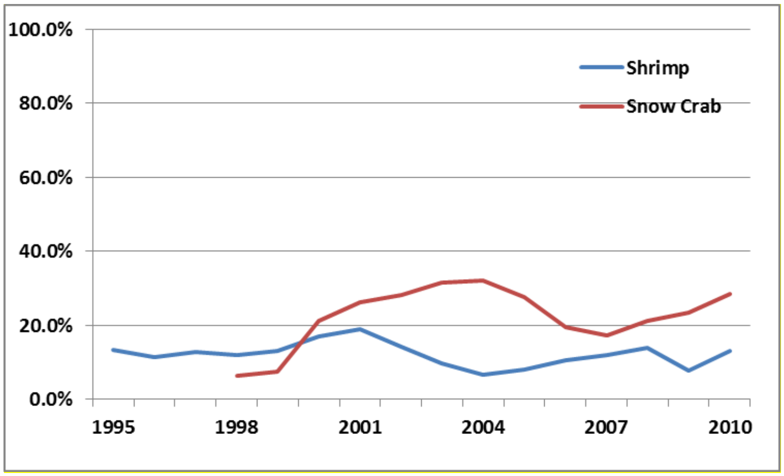


Figure 11-11. Trends in exploitation rates (percent biomass taken by fishing) of shrimp and snow crab on the ESS (data from Choi and Zisserson 2011 and Hardie et al. 2012).

The situation is more complicated with the pelagic species. While swordfish, bigeye tuna and blue shark are being exploited below their target exploitation rates, Atlantic mackerel and porbeagle shark are above theirs. Exploitation of herring off Southwest Nova Scotia has been relatively constant since the late 1990s but it is not clear whether or not it is high relative to the target level (DFO 2011a).

In response to the collapse of the traditional groundfish stocks, a number of new fisheries developed in the early 1990s. These include fisheries for monkfish, skates, dogfish, sea urchins, bloodworms and so on. Some of these fisheries prospered while others have not.

11.3 STATUS AND TRENDS

In the wake of the collapse of traditional groundfish stocks on the ESS (e.g. cod, flatfishes and pollock), shellfish stocks have grown significantly in their contribution to the revenue and profitability of the Scotian Shelf fishery. As well, other groundfish, such as Atlantic halibut and redfish, have grown in prominence. This situation is expected to continue until the groundfish stocks recover. The status of some of the more important stocks is described below followed by observations on their economic consequences.

11.3.1 Status of Stocks

As part of its Sustainable Fisheries Framework, DFO introduced biomass reference points (see box) to describe whether or not a stock was in a critical (below a Limit Reference Point or LRP), healthy (above an Upper Stock Reference point or USR), or cautious (between the LRP and USR) state (DFO 2012d). The section below on Responses describes this framework in more detail. Here, the biomass reference points are used to indicate stock status for those stocks for which biomass estimates from assessments are available and alternate reference points have not been formally established. In many cases, reference points have not been formally established. For stocks without estimates of assessed biomass, DFO summer survey trends are used to infer stock status.

Based on a sample of 48 of the management units on the Scotian Shelf, the majority of the shellfish stocks are in a healthy state (**Table 11-1**). The status of the pelagic stocks is split between the three states, with 47% in the critical state, 27% in the cautious state and 27% in a healthy state. Most of these stocks are part of the large pelagic fish community, such as swordfish, bluefin tuna and porbeagle shark. Of the groundfish stocks, over 50% are in a critical state, many of which reside on the ESS. Overall, the status of shellfish stocks is better than that of the groundfish.

Reference Points

Biomass reference points are particular values of indicators used to judge the status of a stock. For instance, spawning stock biomass is the total weight in tonnes of the mature female fish in a stock and is an indicator. When a stock is at the biomass which provides the Maximum Sustainable Yield (MSY), it is at the B_{MSY} reference point. When stock biomass is at or above 80% of B_{MSY}, it is at the Upper Stock Reference (USR) point. B_{MSY} is typically used as a biomass target in many fisheries. If stock biomass is below 40% of B_{MSY}, it is below the Limit Reference Point (LRP). This is typically a level below which biomass should not drop. As part of a Harvest Control Rule (HCR), managers take different regulatory actions (e.g. close or open fisheries) based on where biomass is in relation to these reference points (see section 5.1 for further discussion on reference points and HCRs).

Table 11-1: Status of Scotian Shelf commercially fished stocks; ESS – Eastern Scotian Shelf, WSS – Western Scotian Shelf, SS – Scotian Shelf.

Stock Group	**State**			
	Critical	**Cautious**	**Healthy**	**Total**
Invertebrate		1 (14%) SFA 29W scallop	6 (86%) snow crab, shrimp, inshore lobster, offshore lobster, surf clam, Browns Bank scallop	7
Pelagic	7 (47%) bluefin tuna, albacore tuna, shortfin mako, porbeagle shark, blue marlin, white marlin	3 (23%) mackerel, dogfish, basking shark	4 (27%) swordfish, bigeye tuna, yellowfin tuna, blue shark	15
Groundfish	14 (54%) ESS cod, ESS haddock, ESS pollock, ESS plaice, ESS sculpin, WSS cod, WSS witch flounder, SS silver hake, SS white hake, SS spotted wolfish, SS northern wolfish, SS cusk	5 (19%) ESS monkfish, WSS pollock, WSS monkfish, WSS skate, SS Atlantic wolffish	7 (27%) ESS witch flounder, ESS yellowtail flounder, WSS haddock, WSS winter flounder, WSS sculpin, SS halibut*, SS redfish*	26
Total	21	10	17	48

*****The halibut stock extends to the south coast of Newfoundland, the southern part of the Grand Banks and west of the Scotian Shelf to the U.S. boundary. The redfish stock (Unit 3) includes part of the eastern Scotian Shelf west into the Bay of Fundy

11.3.1.1 Shellfish:

Snow Crab: The snow crab fishery, which occurs primarily on the ESS, has been in existence since the 1970s. Annual landings rose significantly to above 10 000 t in the early 2000s, the majority of this from the southern area of the ESS. Since 2000, biomass first declined and then increased (**Figure 11-12**) and is now above 50 000 t, higher than the Sustainable Fisheries Framework reference points. The recent increase in biomass is due to a pulse of immature crab (recruitment) which was detected in the mid-2000s and will reach fishable sizes during 2011/2012. Positive signs of adolescent crab suggest continued good recruitment to the fishery for the next two–three years. The only recent negative sign was that egg production, which while above the historical average, is expected to decline due to a lack of immature female crabs. Overall, though, the stock is in a healthy state.

Shrimp: The shrimp fishery started on the ESS in the early 1980s and, after a decline in the late 1980s, dramatically rose in intensity in the early 1990s. Since then, annual landings reached a peak of 5500 t in 2000, declined to 3000 t in 2003, and subsequently increased again to range between 3500–4600 t annually. Stock biomass was below the LRP of 5000 t in the early 1980s but rose to above the USR of 14 558 t by 1998 and has been either at or above this level since then (**Figure 11-13**).

The increase in biomass during the 1990s was due to the maturation of strong year classes during 1993–1995 and 2001. More recently, the 2007 and 2008 year-classes also appear to be abundant and will enter the fishery during 2011–2013. There are, however, signs that recruitment of the 2010 and 2011 year-classes may be weak and the stock will start to decline (DFO 2012a).

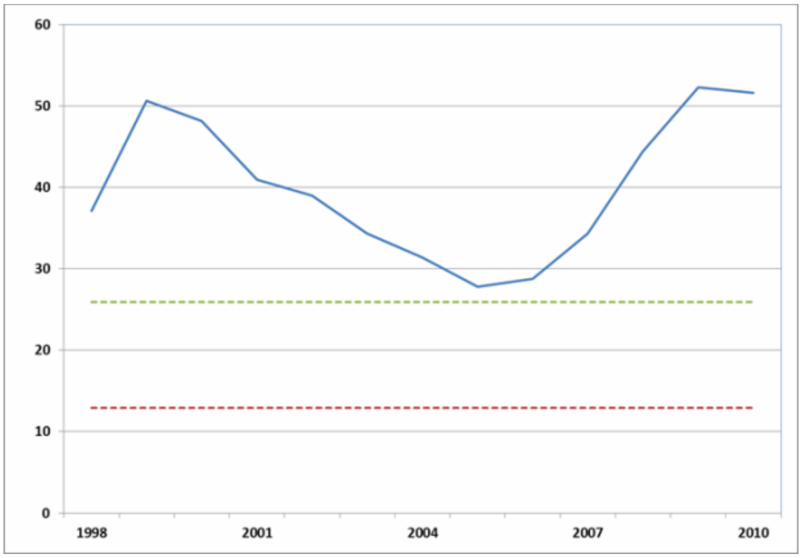


Figure 11-12: Trend in snow crab stock biomass in kilotonnes (kt) on the Scotian Shelf, 1998–2010; lower and upper dashed lines are the LRP and USR respectively (Choi and Zisserson 2011).

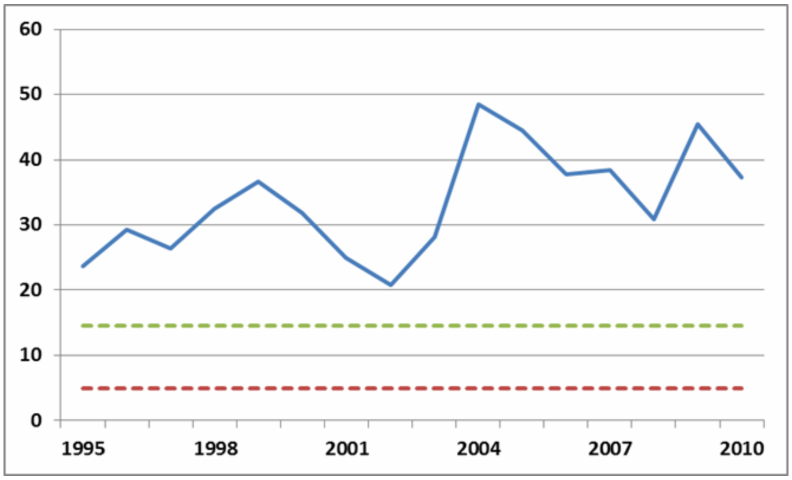


Figure 11-13: Trend in shrimp stock biomass (kt) on the ESS, 1982–2010; the lower and upper dashed lines indicate the LRP and USR respectively (DFO 2012a).

Lobster: The lobster fishery on the Scotian Shelf is managed according to six Lobster Fishing Areas (LFAs 27 - 33) along the coast of Nova Scotia and one for the offshore fishery that takes place on the WSS and Gulf of Maine (LFA 41). Landings from the coastal LFAs rose from below 2000 t in 1980 to about 7000 t in 1990, and dipped to below 4000 t in the late 1990s before increasing to above 10 000 t in 2009 (**Figure 11-14**). Landings are the only available proxy for lobster abundance over the long-term, with the 1985–2004 period being used to develop a lower (LRP) and upper (USR) biomass-related reference to determine stock status. Based upon these, the coastal stocks are healthy. As exploitation rates in this fishery have remained stable (DFO 2011d), increased landings are due to increased abundance which is in turn due to increased stock productivity.

Landings of the offshore LFA 41 have been fairly stable since the early 2000s, being about the Total Allowable Catch (TAC) of 720 t. Abundance indicators from the different subareas of LFA 41 suggest that biomass is either stable or has increased since 1999 (DFO 2009a). The stock is considered to be healthy.

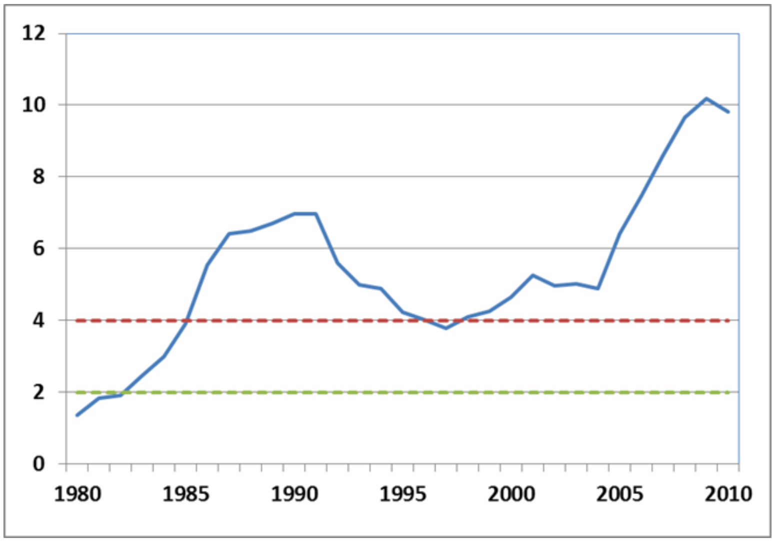


Figure 11-14: Trend in LFA 27–33 lobster landings (kt), 1980–2010; upper and lower dashed lines are the USR and LRP respectively (from DFO 2011d).

10.3.1.2 Pelagics:

Herring: The main herring stock (Southwest Nova Scotia/Bay of Fundy spawning component) annually migrates from the Scotian Shelf to its fall spawning grounds in the Bay of Fundy (DFO 2011a). Historically, annual landings were in the order of 100 000 t but since 2000, they have ranged from 50 000 to 70 000 t annually. Recently, there has been difficulty assessing the stock, although there is general consensus that the stock has declined over the past decade (**Figure 11-15**). There are a number of indications of declining stock status. There has been a recent declining trend in individual fish weight, consistent with unusual environmental conditions in 2010. Also, fish condition (plumpness of a herring) is at its lowest level since 1974. Fat content is also low. While the stock is not in a critical state, it is clearly in the cautious zone.

The status of the two other Scotian Shelf herring stocks (offshore Scotian Shelf Banks and Coastal Nova Scotia components) is uncertain (DFO 2011a).

Atlantic Mackerel: The Atlantic mackerel stock stretches along the whole Atlantic coast, from off New England to the north coast of Labrador. Long-term landings have averaged 53 744 t annually, about 50% of this being taken in American waters (Deroba et al. 2010). During 1999–2008, total annual landings were about 68 000 t, with just over half by Canada. Biomass was high in the 1970s, being over 1.3 million tonnes and declined to the 200 000– 400 000 t range during the 1980s (**Figure 11-16**). Recent assessments have estimated stock sizes ranging 71 710 t to 141 196 t. Recruitment to the stock is characterized by occasional large year-classes, especially those of 1967, 1982 and 1999. Recruitment during 1985–2009 has generally been low, which partly explains the relatively low level of current biomass. The stock is considered to be in the cautious state.

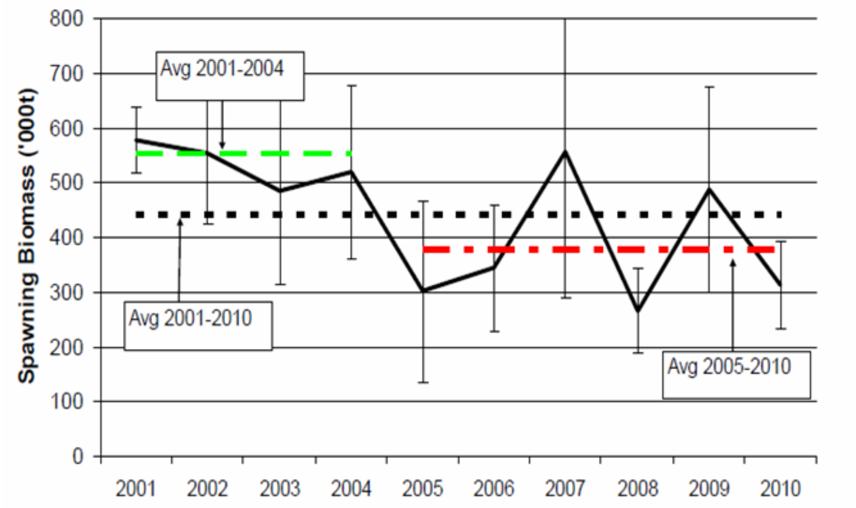


Figure 11-15: Trend in herring spawning biomass from acoustic surveys; recent average levels are indicated by the green (2001–2004), black (2001–2010) and red (2005– 2010) dotted lines (DFO 2011a).

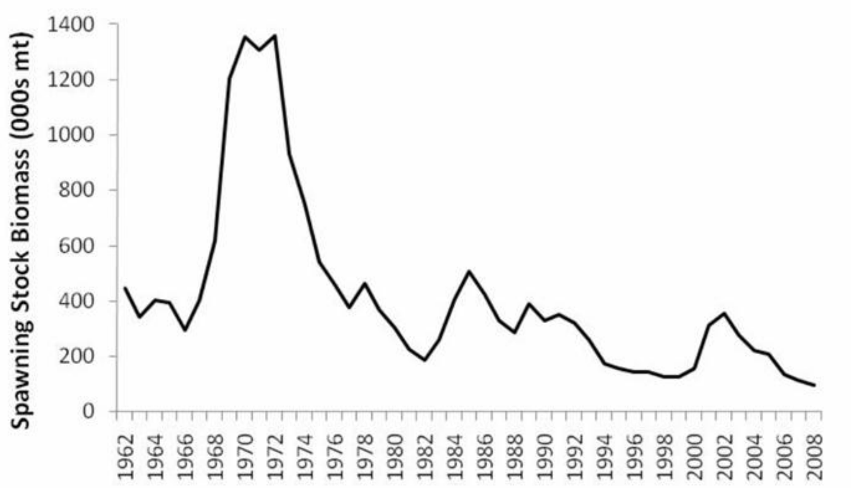


Figure 11-16: Trend in mature mackerel or spawning stock biomass (kt), 1962–2008 (Deroba et al. 2010).

Swordfish: Swordfish is one of the main large pelagic fish species found in the waters of the Scotian Shelf. Similar to other large pelagic species, swordfish migrate extensively throughout various regions of the Atlantic Ocean but frequent the waters off Atlantic Canada during the spring to fall. North Atlantic swordfish landings averaged almost 14 000 t during 1980–2008, of which the Canadian fleet, which operates almost exclusively off Nova Scotia, landed an average of almost 1200 t annually. Canadian landings were at a low of 500 t in the 1980s but have gradually increased since then, being in the order of 1300–1500 t annually since 2005.

Swordfish stock biomass was well above the B_{MSY} target of 61 860 t until the 1980s, at which time it decreased to its lowest point (43 870 t) in 1998 (**Figure 11-17**). Since then, it has increased and is currently just above B_{MSY}. Recruitment follows a similar trend to that of biomass, with strong recruiting year-classes in the 1980s, followed by a decline to a low in the late 1990s and an increase until the present. Overall, the stock is judged to be in a healthy state.

Other Pelagic Species: The other primary large pelagic species caught by the Canadian fleet include Bluefin tuna, bigeye tuna, yellowfin tuna, albacore, sharks such as porbeagle, shortfin mako and blue shark, and blue and white marlin. All of these species are highly migratory and three stocks (bigeye tuna, yellowfin tuna and blue shark) are in a healthy state, none are in the cautious state, and six stocks (bluefin tuna, albacore, shortfin mako, porbeagle, blue and white marlin) are in the critical state. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed bluefin tuna as endangered (COSEWIC 2011), shortfin mako as threatened (COSEWIC 2006) and porbeagle as endangered (COSEWIC 2004).

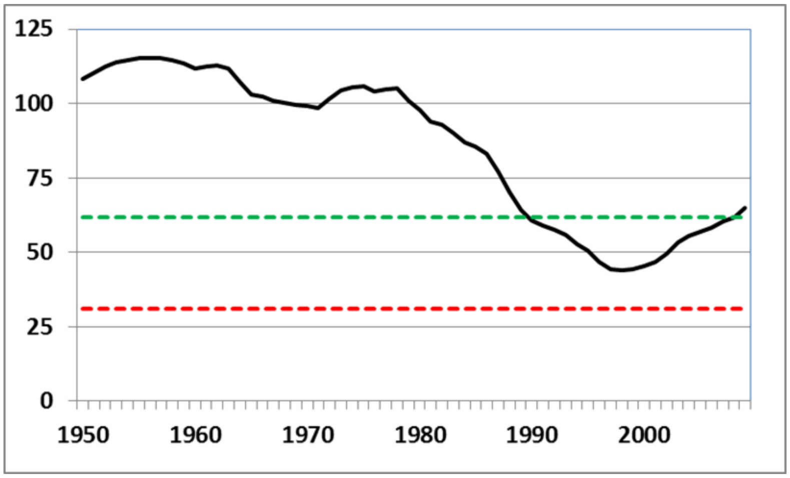


Figure 11-17: Trend in North Atlantic swordfish biomass (kt), 1950–2009; the International Commission for the Conservation of Atlantic Tunas (ICCAT) assesses and manages most of the large pelagic stocks fished in Canadian waters. The upper and lower dashed lines are B_{MSY} and 50% B_{MSY} respectively and are analogous to the USR and LRP used in Canadian fisheries (ICCAT 2009).

11.3.1.3 Groundfish:

Cod: There are two main cod stocks on the Scotian Shelf, one (4VsW) on the ESS and the other (4X) on the WSS and in the Bay of Fundy. There is a smaller stock resident off Cape Breton (4Vn) while the Gulf stock (4TVn) annually overwinters on the ESS. The annual landings of ESS cod ranged from 10 000–80 000 t during 1958– 1993 (Worcester et al. 2009). The directed fishery was closed in September 1993 with small amounts of bycatch (catch of species caught incidental to directed fishing) being the only source of landings since then (Gavaris et al. 2010; see also the theme paper on *Incidental Mortality*). Stock biomass declined during the 1980s and has remained at critically low levels (**Figure 11-18**). Recruitment declined during this period and has also remained low. Recent surveys show signs of recovery although further observations are needed to confirm this (O’Boyle and Sinclair 2012).

Landings of WSS/Bay of Fundy cod averaged 20 000 t annually over several decades but declined after 1990 to a range of 3000–5000 t since 2000 (Worcester et al. 2009). Biomass has steadily declined since 1980 such that it has been below the LRP of 24 000 t since 2002 (**Figure 11-19**) and, like ESS cod, this stock is in a critical state.

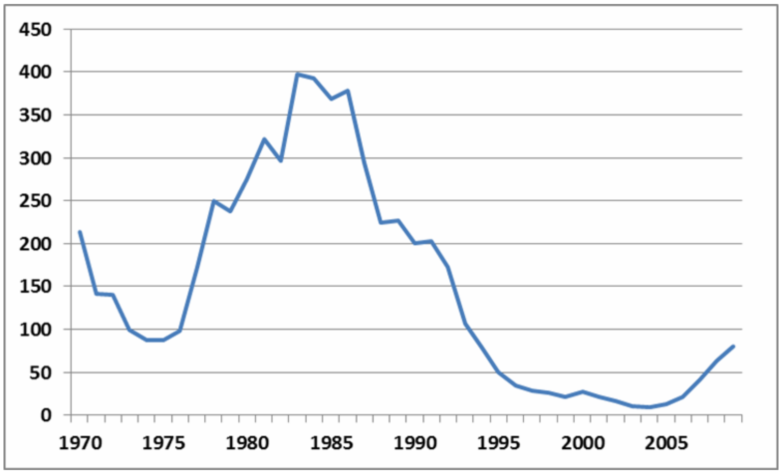


Figure 11-18: Trends in ESS cod mature biomass (kt), 1970–2009; note that Sustainable Fisheries Framework reference points have not been determined (data from O'Boyle and Sinclair 2012).

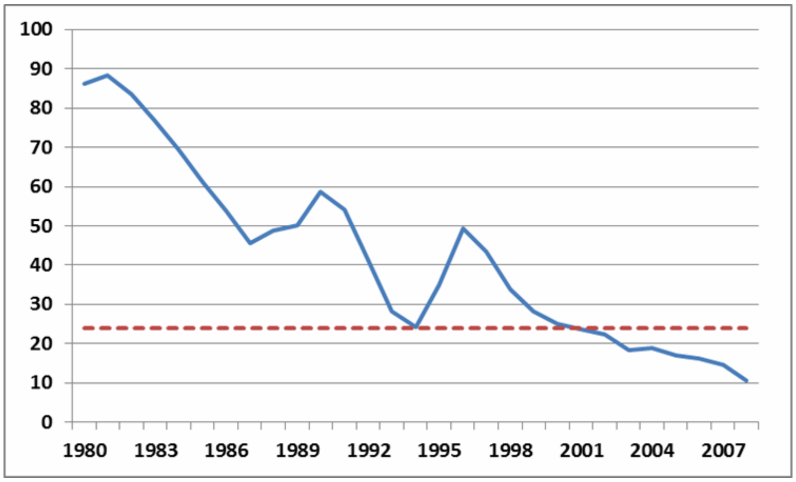


Figure 11-19: Trend in WSS/Bay of Fundy cod biomass (kt), 1980–2008; dashed line is LRP (from Clark et al. 2009; 2011).

Haddock: Two haddock stocks reside on the Scotian Shelf, one on the ESS and the other on the WSS and Bay of Fundy. The ESS stock has been closed since 1993 and is still depleted. On the WSS/Bay of Fundy, the fishery historically landed 10 000–20 000 t annually prior to the late 1980s but since then, landings have ranged from 5000–7000 t (DFO 2010b). Biomass over the long term has fluctuated around the USR of 35 000 t and has never fallen below the LRP of 17 000 t (**Figure 11-20**). Thus, this stock, contrary to that on the ESS, is considered healthy.

Pollock: Annual landings of the eastern and western components of pollock ranged from 30 000–40 000 t prior to 1990 but have only been 4000–5000 t, almost all from the western component, since 2005 (DFO 2009b). The eastern component of the resource is severely depleted. Biomass of the western component was relatively high in the 1980s, declined to its lowest level in 2000, and has subsequently increased due to improved recruitment (**Figure 11-21**). It has not returned to historical levels and is thus considered in the cautious state.

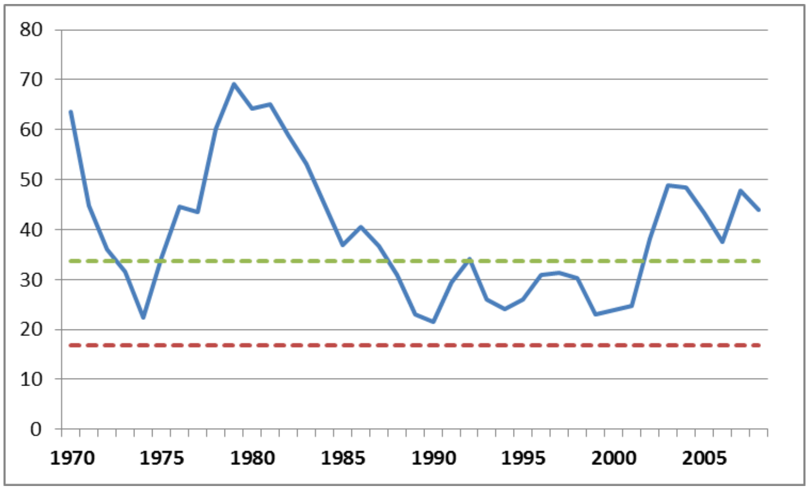


Figure 11-20: Trend in WSS/Bay of Fundy haddock biomass (kt), 1970–2009; the upper and lower dashed lines indicate the USR and LRP respectively (from DFO 2010b).

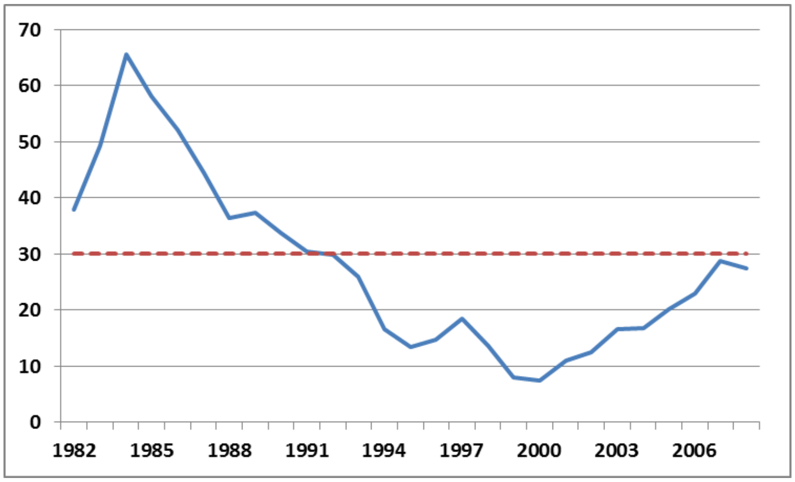


Figure 11-21: Trend in WSS pollock biomass (kt), 1980–2008; dashed line is the biomass reference point used in the fishery (from DFO 2009b).

Atlantic Halibut**:** The Atlantic halibut stock extends from the south coast of Newfoundland to the Canada– U.S. boundary. In the 1960s, annual landings averaged 2460 t but have dropped to an average of 1484 t in the 2000s (DFO 2011b). Spawning stock biomass was high in the 1970s, well above the USR of 3920 t, dropped below the LRP of 1960 t in the early 1990s and has steadily increased since to once again being above the USR (**Figure 11-22**; Trzcinski et al. 2011). The stock is currently in a healthy state.

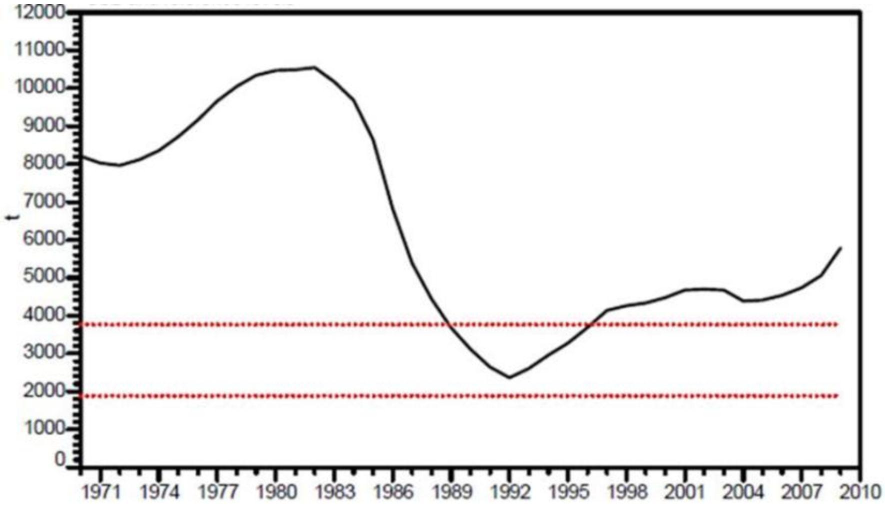


Figure 11-22: Trend in 3NOPs4VWX5Zc Atlantic Halibut biomass (t), 1970–2009; the upper and lower dashed lines indicate the USR and LRP respectively (from Trzcinski et al. 2011).

10.3.2 Status of the Fishery Sector

Landed value ($000), which represents gross revenue (before costs) from the fishery off Nova Scotia peaked in 2003 but has been declining since due to a strong Canadian dollar and the US recession (GPCE 2009; **Figure 11-23**). Groundfish landings dominated the Nova Scotia fishery up to the early 1990s, providing the main driver for the size of the processing sector and the economic strength of many dependent communities. Groundfish landings dropped by 80% between 1991 and 1995, undermining many of the plants dependent on this resource. The pelagic fisheries also declined over the years, with the tonnage landed gradually dropping to 50% of the level in the early 1990s. The rise in shellfish landings offset the impact of these declines to some extent, but with the exception of crab, shellfish does not generate significant onshore processing opportunities (GPCE 2007). Consequently, the number of fish plants has been reduced from over 400 in the early 1990s to 223 in 2006, most of these in Southwest Nova Scotia. With the exception of lobster holding and crab processing, there has been limited investment in new plants and equipment during the past 5–10 years. Overall, the financial position of many plants has deteriorated (GPCE 2007).

Regarding the profitability of the harvesting sector, DFO has conducted cost and earnings surveys since the mid-1980s, with the most recent one being in 2004 (DFO 2004a). Unfortunately, this survey provides only useful information on the profitability of the Scotian Shelf lobster fishery with limited sampling conducted on the other fisheries. The highest gross earnings were reported by the LFA 34 fleet. Notwithstanding this, the lobster fleets were left with less than half their earnings from fishing after taking into account costs. The latter have risen for all fisheries due to rising fuel and other costs after 2006. Though fuel costs dropped in mid-2008, gains were more than offset by a sharp drop in shore prices due to weak markets. The weak markets continue but are expected to improve as and if the US and other markets recover from the current recession (GPCE 2009). The economic crisis in Europe could however adversely affect market recovery.

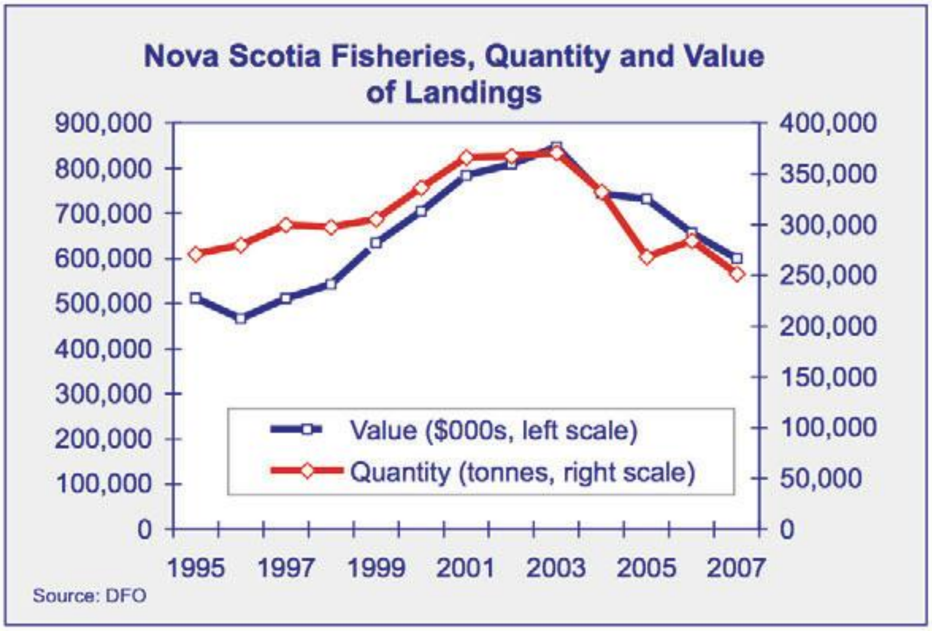


Figure 11-23: Trends in landings (t) and value ($000s) from 1995 to 2007 of the Nova Scotia commercial fisheries (from GPCE 2009).

11.4 IMPACTS

The changes in the stocks and their environment have impacted not only the structure and function of the Scotian Shelf ecosystem but also the social and economic well-being of the communities supported by the commercial fisheries.

11.4.1 Health of Ecosystems

The commercial fisheries have impacted the structure and functioning of the ESS and WSS ecosystems in a number of ways. The overexploitation of the groundfish stocks during the 1980s led to a severe decline in groundfish in both areas but most dramatically on the ESS (Zwanenburg et al. 2002). In this area, the entire groundfish community declined, only recently showing signs of recovery (Frank et al. 2011). While groundfish biomass did not decline to the same extent on the WSS, there was a change in the community structure with some species increasing (e.g., dogfish) and others decreasing (e.g., cod, white hake, pollock). This difference in impact has been attributed to colder environmental conditions (the ESS is, on average, 2°C colder than the WSS) and higher rates of natural mortality (Sinclair et al. 1997; Shackell 2011), suggesting that the ESS is less resilient to human impacts than the WSS. There is recent evidence to suggest that the shift to a pelagic species dominated system that occurred in the 1990s may be returning to a groundfish-dominated system (Frank et al. 2011).

These changes in biodiversity were also accompanied by severe declines in some species (termed “depleted species”), leading to their consideration for listing under Canada’s Species at Risk Act (SARA) (see theme paper on *At Risk Species* for a comprehensive summary of these species and their status). Some of these species may have been reduced to such low levels that predation from any source may be preventing recovery, termed a “predator pit.” Another process, termed the “cultivation effect,” suggests that a species, when abundant, keeps in check predators and/or food competitors of its early life stages (i.e., eggs and larvae). When depleted, these predators are released, decreasing survivorship of the early life stages of the depleted species, further causing a lack of recovery (see theme paper on *Trophic Structure* for further discussion). For instance, Frank et al. (2011) suggest that following the collapse of ESS cod, due to overfishing, forage species such as herring increased in abundance. The latter have inhibited the recovery of ESS cod through both competition with and predation on the early life history stages of cod. Declining forage species, who have now outstripped their own zooplankton food supply, have more recently allowed the cod stock to once again increase in biomass. This theory has been challenged (Swain and Mohn 2012) who suggest that the recent recovery of ESS is not due to declining forage species and is due to as yet unidentified other processes. Reductions in community biodiversity due to the irreversible loss of species components can have a ripple effect throughout the ecosystem and are a cause for concern.

Productivity changes are also a consequence of the impacts of fisheries. It has been shown that the multi-species aggregate surplus production of the Gulf of Maine ecosystem is lower (about 28%) than the summed production of the individual species (NEFSC 2008). This difference has been attributed to biological interactions such as predation and competition. In a highly stressed ecosystem, this difference may not be as great as in less stressed systems. This effect is modified by a change in the composition of the fish communities. As noted above, the Scotian Shelf ecosystem shifted from a groundfish-dominated system to one dominated by pelagic species. The latter species are typically shorter lived and faster growing than the former and consume prey at lower levels of the food chain. Their production dynamics are quite different, thus resulting in an overall change to the productivity of the ecosystem.

Despite the reduction in exploitation rates from the high levels observed in the 1980s, there have been fish size and age at maturity reductions over the long-term that have significantly reduced the productivity of primarily the groundfish stocks (Shackell 2011). This is evident in WSS haddock which has experienced a long-term decrease in the weight of a 50 cm fish since 1970 (DFO 2010b; **Figure 11-24**). One of the implications of this is that stock productivity, measured as Maximum Sustainable Yield (MSY) and the biomass at MSY, has declined over the long-term (**Figure 11-25**). For WSS haddock at least, it appears that fish size is currently on the increase and this stock productivity should once again increase.

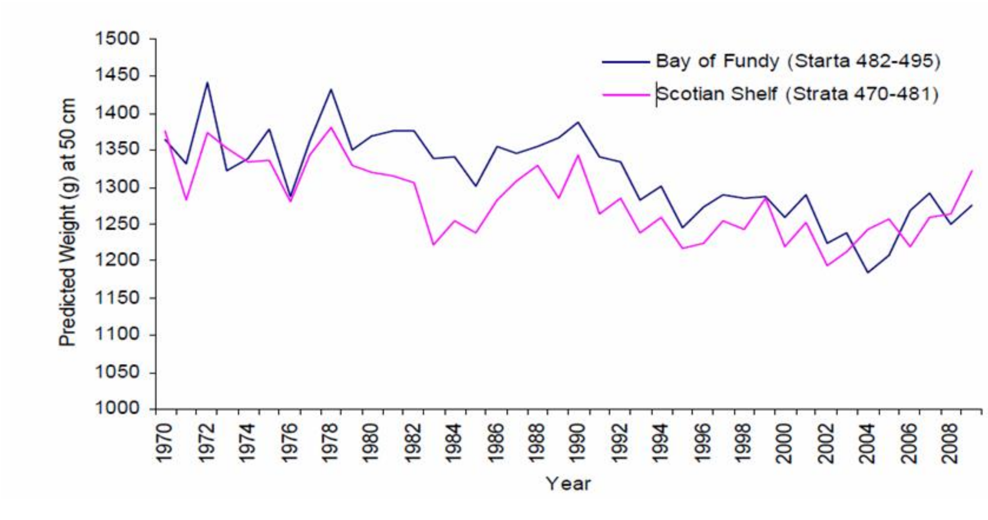


Figure 11-24: Trend in weight (g) of 50 cm WSS haddock from summer research trawl survey; blue and red lines refer to Bay of Fundy and Scotian Shelf areas respectively (from DFO 2010b).

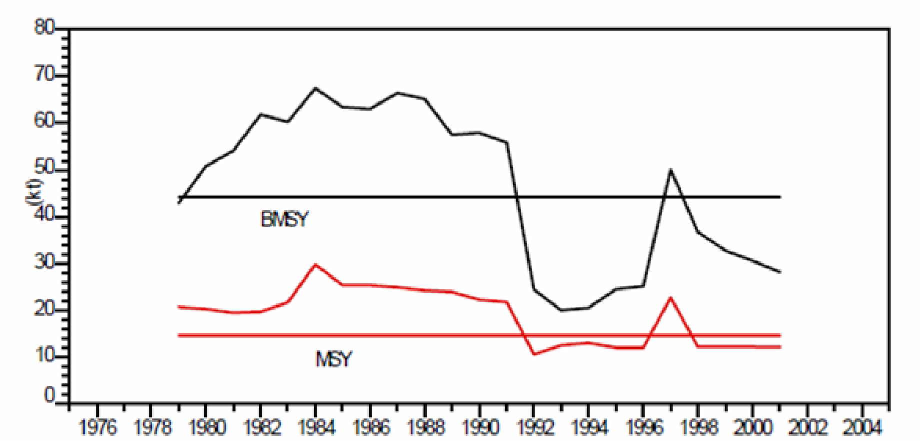


Figure 11-25: Trend in MSY and BMSY of WSS haddock, 1976–2004 (from DFO 2010b).

Fisheries also impact benthic habitat. For instance, it is known that trawlers and dredges can seriously impact sensitive habitats such as coral beds (DFO 2010e). However, the impact of bottom impacting gears is dependent on the sensitivity of the habitat being impacted (see theme paper on *Marine Habitats and Communities*). Highly naturally disturbed habitats are less sensitive to impacts than less disturbed ones. Also, the link between benthic habitat and fish productivity is not well understood.

11.4.2 Social and Cultural Well-being

Some of the biggest impacts of the fishery have been on employment in coastal communities. While full-time employment in the commercial fisheries of the Scotian Shelf was 7121 in 2006, there were an additional 6000 that were involved in spinoff industries. The fishing sector is ranked second in employment to national defence in Nova Scotia’s ocean sector (GPCE 2009; **Figure 11-26**). Compared to Canada, Nova Scotia has a low immigration rate. In 2006, immigrants made up 5% of the provincial population compared to 19.8% for Canada (Pilkey 2009). However, the overall provincial population has remained relatively stable, despite emigration from coastal communities. From 1991 to 2006, the population in the non-coastal regions of Halifax increased almost 19% while rural coastal areas experienced a 7% decline (Pilkey 2009; **Figure 11-27**). Much of this emigration was young people moving to western Canada, which has created challenges for the fishery to find and retain crews (GPCE 2009). This has in turn resulted in a shift, to older ages, of participants in the fishery.

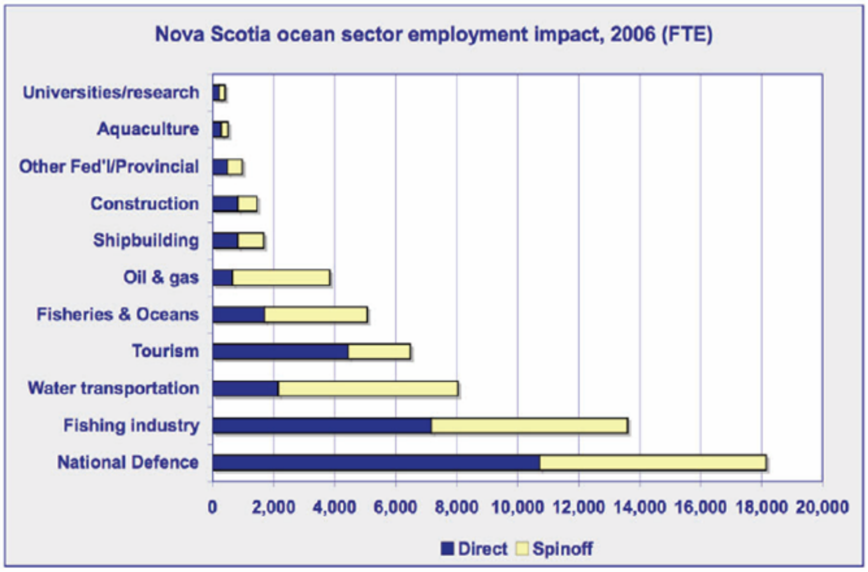


Figure 11-26: Nova Scotia ocean sector full-time employment impact in 2006 (from GPCE 2009).

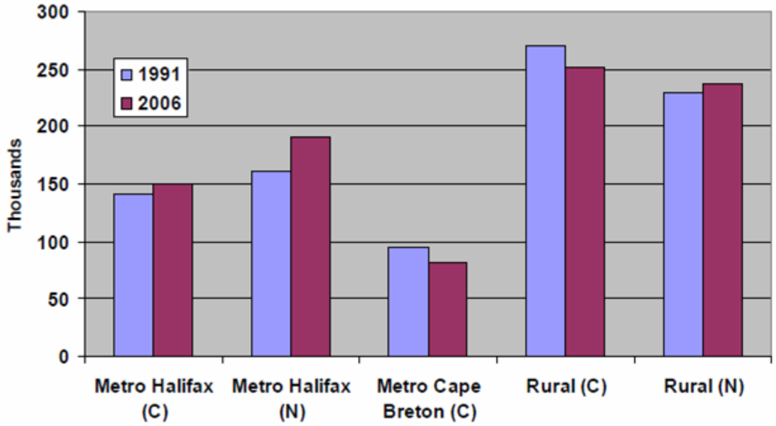


Figure 11-27: Change in Nova Scotia population size (000s), 1991–2006 by community; C and N indicate coastal and non-coastal communities respectively (from Pilkey 2009).

11.4.3 Economic Well-being

The trends in the fishery have also impacted the Nova Scotia fish processing sector which consists of just over 220 licensed enterprises with 182 in operation in 2006. Processors buy fish from some 5000 vessels, utilizing all 30 species landed in the province and producing a wide range of fresh, frozen and value-added products. Full Time Employment (FTE) varies seasonally with fishing activity and landings, ranging from a low of 2900 FTEs in winter to a peak of 4850 FTEs in summer. The value of production is estimated at $1.1 billion in 2006, with total exports of about $975 million. Processors have seen their competitive position eroded over the past 10-15 years due to declining resources (primarily groundfish which requires more on-shore processing than shellfish), competition from low-cost producers, rising raw material costs, increasing concentration of buying power in major markets, adverse exchange rate movements and the regulatory environment as it affects the terms and conditions of access to raw material (GPCE 2007).

Notwithstanding these trends, market conditions should improve as and if the United States and other markets recover from the current recession (GPCE 2007), although the economic crisis in Europe could adversely affect recovery. Whether the resource recovers to levels experienced in the 1980s is more difficult to say. What seems more certain is that there will continue to be structural change in the industry, with cost and earnings pressures likely to force further consolidations through concentration of quota and combining licenses. This will result in less capital in the industry and a decrease in the numbers employed. In the long-term, fisheries will continue to be one of Nova Scotia’s leading ocean industries.

11.5 RESPONSES

11.5.1 Legislation and Policy

In response to the *Oceans Act* (1997), DFO initiated the Eastern Scotian Shelf Integrated Management (ESSIM) Initiative, which developed a strategic plan (DFO 2007a) to achieve a suite of conservation and socio-economic objectives that apply to all human activities, including commercial fisheries, on the Eastern Scotian Shelf. The conservation objectives were developed nationally and included sub-objectives for the conservation of biodiversity, productivity and habitat (DFO 2004b). This plan has required development of operational objectives to achieve the conservation objectives. The fishing and other industries developed action plans to help implement the objectives. The initiative is currently (2012) in the evaluation stage and in the future will transition to a bioregional integrated ocean management process.

In 2009, DFO introduced the Sustainable Fisheries Framework which included a decision- making framework incorporating the Precautionary Approach (DFO 2012b). Once implementation is complete, it will provide the operational objectives for the Scotian Shelf fisheries. The key element of this framework is a Harvest Control Rule (HCR) by which biomass Limit Reference (LRP) and Upper Stock Reference (USR) points are used to set fishery removal or harvest rates (**Figure 11-28**).

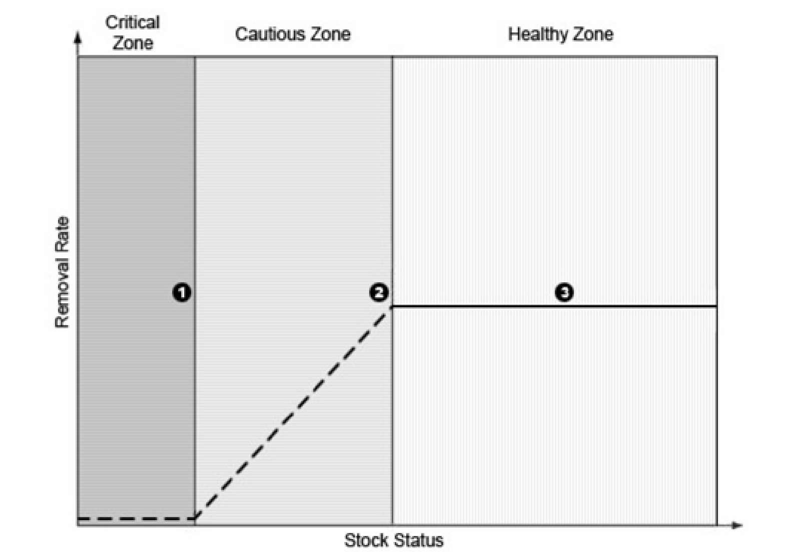


Figure 11-28: Harvest Control Rule (HCR) of DFO Sustainable Fisheries Framework; below the LRP (1), the removal rate is set as low as possible. Above the USR (2), removal rate is set at the target removal rate (3) and between the LRP and USR, removal rate is set proportional to stock size.

For the Scotian Shelf, the new HCR has been discussed with industry and implemented in 15 of the 40 main stocks commercially fished. As experience is gained with the HCR on these stocks, implementation will be undertaken in the remaining ones.

11.5.2 Management Activities

The management activities used to control the commercial fisheries of the Scotian Shelf are outlined in Integrated Fisheries Management (IFMP) and Conservation Harvesting (CHP) plans. These consist of catch controls such as annual quotas and effort regulations which stipulate seasonal and spatial restrictions as well as gear type, configuration and amount. The effectiveness of the regulatory package can be judged by comparing the realised fishing mortality (F) in the fishery to that established as a target.

Maximum Sustainable Yield (MSY) is commonly used to describe the maximum tonnage of fish that can be harvested on an ongoing basis from a stock. A stock, whose biomass is at B_{MSY} and is harvested at an exploitation rate of F_{MSY} produces a yield of MSY. MSY is a consequence of balancing processes such as recruitment and body growth with mortality, both fishing and natural.

The target is based upon both biological and socioeconomic considerations. Fishing mortality targets are typically a fraction (e.g. 75%) of F_{MSY} (**see box**). For shellfish stocks, except for lobster in LFAs 27–33, current fishing mortality is either at or below the target. In the case of lobster, while exploitation rates are high, they do not appear to be endangering the sustainability of the stocks. In the case of the pelagic fisheries, for some stocks (e.g., mackerel), exploitation has been in excess of the target but for most pelagic stocks, exploitation is either at or below the target or not known (herring). Regarding the groundfish stocks, those on the ESS such as cod and haddock are not prosecuted by directed fisheries and are only caught as bycatch while those on the WSS, such as pollock and Atlantic halibut are prosecuted by targeted fisheries. Where it has been assessed, exploitation rate is either at or below the target.

To achieve conservation objectives associated with biodiversity and habitat, DFO has either implemented or is in the process of implementing a number of spatial closures, most prominent of these being the Gully Marine Protected Area, St. Ann's Bank Area of Interest (a site that may become a marine protected area) and the Coral Conservation Areas (**Figure 11-29**). Monitoring programs have been established to measure the effectiveness of these closures (e.g., DFO 2010d for the Gully) but implementation is too recent to allow determination of outcomes.

Seventeen groundfish and pelagic stocks and species have been assessed by COSEWIC as special concern, threatened or endangered. Of these, three (Atlantic, northern and spotted wolfish) have been added to Schedule 1 of SARA. The two threatened species (northern and spotted wolffish) require recovery strategies, while the species of special concern (Atlantic wolffish) requires a management plan (Walmsley 2011). These have been drafted and implemented for all three species. The remaining species are managed under the *Fisheries Act* which stipulates special conditions within IFMPs for fisheries which encounter them. Any stock which is being considered for listing under SARA must undergo a Recovery Potential Assessment (DFO 2007b; 2011e) which assesses recent status, estimates the scope for management to facilitate recovery and considers scenarios for mitigation and alternative activities. So far, of the 17 stocks assessed by COSEWIC, 15 have undergone Recovery Potential Assessments, the results of which will inform recovery efforts (see for instance DFO 2011f).

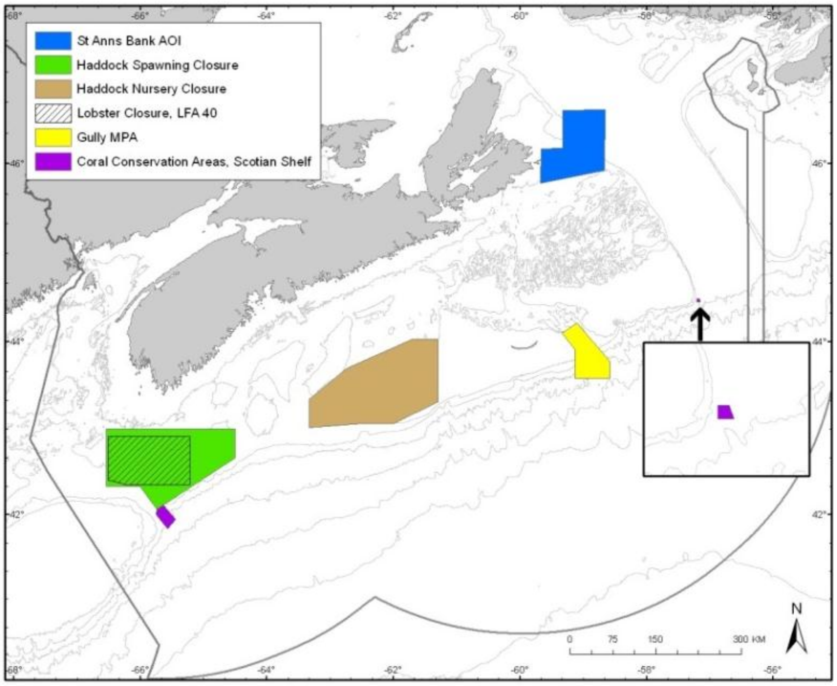


Figure 11-29: Spatial closures to achieve biodiversity and habitat conservation objectives. Grey line indicates Canada's Exclusive Economic Zone.

11.5.3 Industry-based Initiatives

The Canadian Code of Conduct for Responsible Fishing Operations (http://www.dfo-mpo.gc.ca/fm-gp/policies-politiques/cccrfo-cccppr-eng.htm) was developed by the fishing industry in 1998 to ensure sustainable harvesting. It outlines 36 guidelines to achieve the nine principles of the Code and aims to avoid the problems that caused the groundfish collapse of the early 1990s. As well, the Nova Scotia Swordfishermen's Association has developed a Code of Conduct for Responsible Sea Turtle Handling and Mitigation Measures. Initially, compliance with the Code of Conduct was optional but it is now a condition of licence.

Of 50 Scotian Shelf commercial fish stocks and fisheries, nine have either been or are in the process of being certified by the Marine Stewardship Council (see box), including ESS shrimp, snow crab, offshore scallop, offshore lobster, surf clam, swordfish, spiny dogfish, Atlantic halibut and WSS haddock. Increasingly, markets are requiring that eco-certification of the fisheries supplying the resources be undertaken. It is expected that the number of certified fisheries will increase in the future.

To control over-capacity in the inshore groundfish mobile gear fishery, Individual Transferable Quotas (ITQs) were implemented in 1991. The industry has adapted to this system, actively buying and selling quota shares. A similar system was introduced in the fixed gear fishery soon after this, with the unit of quota allocation being one of seven communities rather than the fishing licence (Fanning 2007). By 2002, ITQs were implemented in all groundfisheries on the Scotian Shelf. Currently, except for lobster, all major commercial fisheries are managed using either ITQs or community-based quotas. Overall, the program has provided more certainty in allocation for harvesters and has reduced harvest capacity (DFO 2004c; Gough 2007).

Addressing Consumers' Concerns:
Eco-certification, Community Supported Fisheries and Seafood Traceability

The Marine Stewardship Council (MSC) is the best-known fisheries eco-certification organization in this region. It has articulated and manages a set of standards against which fisheries are assessed. Increasingly, markets are requiring that fishery products are eco-certified to address consumer concerns about the sustainability of fisheries.

To help ensure stability of price, some fish harvesters have established consumer supported fishery groups, similar to the concept of community supported agriculture. Consumers pay a set price at the beginning of the fishing season for a share of the season's catch. By direct marketing to consumers, harvesters receive a greater share of the profits, while consumers receive fresher fish. Off the Hook was the first community supported fishery group formed in Atlantic Canada and was named runner-up in National Geographic's global contest, Turning the Tide for Coastal Fisheries Solutions (Off the Hook 2012).

An innovative seafood traceability program called "This Fish" allows consumers to find out who caught the fish they are eating. Participating fish harvesters tag their fish and enter information on how, when and where they caught it into an online database. After purchasing the fish, consumers can look up the tag number to find out more about the fish and the harvester that caught it. More than two hundred fish harvesters take part, mostly from Atlantic Canada, as do several Nova Scotia-based seafood companies (ThisFish 2012).

11.5.4 Research and Monitoring

Since the 1990s, the fishing industry has invested heavily in research and monitoring. While DFO manages the ITQ program, the monitoring costs, both at-sea observer and dockside, are borne by the industry. Industry-run surveys are now a critical element for assessing the WSS groundfish, Atlantic halibut, WSS herring, surf clam, ESS shrimp and snow crab stocks and represent almost 25% of the total DFO Science monitoring budget (R. Claytor, Fisheries and Oceans Canada, pers. comm. 2012). Indeed, the fishing industry has been proactive in a number of cases in not only undertaking monitoring but also in assisting DFO Science in identifying and funding research to fill essential knowledge gaps (e.g., O'Boyle 2004). Another example of this is the Fishermen and Scientists Research Society (http://www.fsrs.ns.ca/) which has played an invaluable role in facilitating the participation of inshore fishing groups in the monitoring, assessment and research of inshore lobster stocks.

There is increasing awareness of the need to undertake research and monitoring of depleted stocks. The annual surveys of DFO Science (Shackell 2011), which contribute to the Atlantic Zonal Monitoring Program (http://www.bio.gc.ca/monitoring-monitorage/azmp-pmza/indexeng.htm) are an essential element of efforts to monitor and assess long-term trends in biodiversity. Data collected by this program, along with that of the industry, are used in the Recovery Potential Assessments of depleted species (see section 11.4.1). These assessments also benefit from a number of specially designed bycatch studies which describe the "ecological footprint" of a fishery. Gavaris and others (2010) provide a description of the bycatch in the Scotian Shelf groundfish fisheries. Similar studies are being conducted on the scallop, snow crab, lobster and other fisheries. These are allowing managers and industry to mitigate the unintended bycatch of depleted species.

Research and monitoring is also being conducted on the impacts of commercial fisheries on benthic habitat (see theme paper on *Marine Habitats and Communities* for more details). One example of this is research to identify habitat where scallop and clams reside thus allowing fishing while avoiding the adverse effects of dredging. Multibeam imagery of large areas of the Scotian Shelf has been undertaken to characterize the benthic habitat. Using this imagery, Robert

(2001) found that scallops prefer gravel bottoms and when fishing is targeted on this habitat, the amount of bottom impacted by the dredges was reduced by 74%. This reduced footprint likely resulted in reduced impacts on the benthic communities. As well, fuel costs were reduced, which was a plus for the fishermen (**Table 11-2**). This study illustrated well the advantages of science-industry collaboration to both fishermen and the ecosystems of the Scotian Shelf.

Table 11-2: Advantages of identifying scallop-preferred benthic habitat through multi-beam imagery for a scallop quota of 13 640 kg (from Robert 2001).

	Without Imagery	With Imagery	Reduction
Time gear on bottom	162 hours	43 hours	73%
Area of bottom towed	1176 km^2	311 km^2	74%
Fuel usage	27 697 litres	17 545 litres	36%

11.6 INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT[1]	TREND[2]
Sea surface temperature (°C)	Global warming is occurring with some evidence on ESS	Driving Force	Unknown	/
Aggregate MSY	Many groundfish stocks have experienced low productivity since the early 1990s	Driving Force	Poor	/
Global population size (number)	Markets for N.S. exports remain strong due to global demand	Driving Force	Good	+
Export revenue ($M)	Export revenue has declined in recent years due to strong Canadian dollar and weak U.S. market	Driving Force	Fair	-
% Fisheries of GDP	Fisheries are increasingly competing for ocean space with other ocean industries	Pressure	Fair	-
Exploitation rate	Excessive exploitation due to high effort can cause overfishing	Pressure	Good	+
Shellfish stock group status ($B_{current}/B_{RP}$)	86% of the major shellfish stocks are healthy	State	Good	+
Pelagic stock group status ($B_{current}/B_{RP}$)	74% of the major pelagic stocks are in critical or cautious state	State	Poor	-
Groundfish stock group status ($B_{current}/B_{RP}$)	73% of the major groundfish stocks are in critical or cautious state	State	Poor	-
Landings value / revenue ($M)	Landed value has declined since 2003 due to weak U.S. markets and lack of groundfish recovery	State	Poor	-
Species diversity (number of depleted species)	Loss of species can lead to reduced ecosystem resilience	Impact	Poor	-
Productivity ($Yield_{current}$ / MSY)	Overfishing can lead to reduced stock productivity and lost yield	Impact	Fair	/
Coastal community population size	Fishing communities are having difficulty retaining youth	Impact	Poor	-
Processing sector employment	Lack of groundfish recovery is challenging processing sector	Impact	Poor	-
% Stocks with HCR	HCRs are an integral component of the DFO Sustainable Fisheries Framework	Response	Fair	+
% Fishing mortality of target	To ensure sustainability, F needs to be maintained at that determined by the HCR	Response	Good	+
% Depleted species that have undergone Recovery Potential Assessments	All stocks assessed as threatened, endangered or special concern by COSEWIC must undergo an RPA	Response	Good	+
% Fisheries eco-certified	Eco-certification provides industry standard of sustainability	Response	Good	+
% Stocks with dedicated monitoring	Monitoring is critical element of stock assessment	Response	Good	+

[1] Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.
[2] Trend: is the trend positive or negative in terms of implications for the state of the environment. It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Key: Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?

Data Confidence

- Good data are available for most of the main commercial stocks and the environment in which they reside.
- A large source of uncertainty is the high and unexplained natural mortality observed in many of the groundfish stocks.

Data Gaps

- There are gaps in the bycatch data although some work is being undertaken to resolve these.
- While knowledge and understanding of ecosystem dynamics is advancing, it is not clear whether or not recovery of many depleted species will occur and that the Scotian Shelf ecosystems will attain a state comparable to that before the groundfish collapse of the 1990s.
- Changes related to fishing effort—for example, changes in vessels, gear, technology used, and fishermen's knowledge—and their overall impacts on fish stocks are difficult to track.

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Marine Environmental Quality

12. WATER AND SEDIMENT QUALITY[22]

Christopher Burbidge, Environmental Consultant, Halifax, NS

GLOSSARY

bioaccumulation: The process by which a chemical or substance accumulates in an organism over time through the uptake of food, water, and air.

***biomagnification*:** The process by which a chemical or substance increases in concentration at each trophic level in the food web. Higher concentrations of chemicals and substances will therefore be observed in organisms at higher levels of the food web (i.e., top predators such as large pelagic fish and marine mammals).

DDT (Dichloro diphenyl trichloroethane; 2,2-Bis[p-chlorophenyl]-1,1,1-trichloroethane): DDT is an organochlorine compound that was used as a broad spectrum commercial pesticide before it was banned in the U.S. in the 1970s and Canada in the 1980s. DDT and its derivatives DDD (Dichloro diphenyl dichloroethane, 2,2-Bis [p chlorophenyl]-1,1-dichloroethane) and DDE (Dichloro diphenyl ethylene, 1,1-Dichloro-2,2-bis[p-chlorophenyl]-ethene) are referred to collectively as ΣDDT.

dioxins/furans: Organochlorine compounds present as trace contaminants in a variety of industrial chemicals and are produced as by-products from municipal waste incinerators, pulp and paper mills, petroleum refineries, wood burning, automotive emissions, electric power generation, and the combustion of PCBs.

halocarbons: Hydrocarbon compounds containing chlorine, bromine, fluorine, or iodine (the halogens).

hydrocarbons: Organic compounds comprised of hydrogen and carbon. Hydrocarbons are major components of petroleum.

methylmercury: The organic form of mercury. Methylmercury is formed by aquatic organisms from inorganic mercury through anaerobic processes, and is also produced in some industrial processes. Methylmercury is considered to be a persistent organic pollutant (POP).

organochlorine compounds: Hydrocarbon compounds containing chlorine. Many organochlorine compounds are considered to be persistent organic pollutants. Common uses of organochlorine compounds include pesticides and insulators.

organotin compounds: Organic compounds containing hydrocarbons and tin. Many organotin compounds are considered persistent organic pollutants and are commonly used as biocides.

PAHs (polycyclic aromatic hydrocarbons): Organic compounds found in many fossil fuels and produced as by-products during the combustion of fossil fuels. Some PAHs are synthesized by marine plants and zooplankton or derive from natural products and processes.

PBDEs (polybrominated diphenyl ethers): Organic compounds containing carbon and bromine. PBDEs are considered to be persistent organic pollutants (POPs) and are used as flame retardants in a wide variety of industrial and consumer products.

PCBs (polychlorinated biphenyls): Organochlorine compounds that were used for many years as insulation in electrical equipment and were found in a variety of common consumer products whose disposal was not controlled. PCBs are considered to be persistent organic pollutants (POPs).

PFCs (perfluorinated compounds): Organic compounds containing carbon and fluorine. PFCs are considered persistent organic pollutants (POPs) and are used in a variety of consumer products and food packaging.

POPs (persistent organic pollutants): Organic compounds that that persist in the environment for long periods of time tend to accumulate in fatty tissue of organisms, are subject to long-range transport in the environment, and cause adverse effects on human health and/or the environment.

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[22] Completed April 2012.

12.1 ISSUE IN BRIEF

Marine environmental quality is the condition of a particular marine environment measured in relation to each of its intended uses and functions (Wells and Côté 1988). The physical and chemical characteristics and conditions of the ocean bottom (i.e., sediments) and water column as well as the concentration of various contaminants influence the health and functioning of marine ecosystems. A contaminant is defined as any element or natural substance (e.g., trace metals) whose concentration locally exceeds the background concentration, or any substance that does not naturally occur within the environment (e.g., synthetic chemicals such as DDT) (DFO 2009a). This paper focuses on three broad categories of contaminants in the marine environment which can impact water and sediment quality in offshore areas[23] of the Scotian Shelf: (1) organochlorine compounds and other halocarbons; (2) hydrocarbons and polycyclic aromatic hydrocarbons (PAHs); and (3) metals. Nutrients, carbon dioxide, and pathogens are not addressed in this paper. For additional information on marine environmental quality on the Scotian Shelf, the reader is directed to the theme papers on *Ocean Noise, Waste and Debris,* and *Ocean Acidification*. The driving forces influencing marine environmental quality on the Scotian Shelf include changes in the economic, human and natural environments (**Figure 12-1**). The main pressure on water and sediment quality is the presence of contaminants in the marine environment from both natural sources (e.g., the weathering of the continents, forest fires, etc.) and anthropogenic sources (e.g., coastal development, industrial activities, marine shipping, offshore oil and gas, etc.).

Overall, available data indicate that levels of contaminants in the offshore waters and sediments of the Scotian Shelf are at or near background levels and very rarely exceed Canadian guidelines for water and sediment quality. There is a general lack of information about the biological effects of contaminants on marine biota, and the accumulation of certain organochlorine compounds and mercury in some higher trophic level organisms on the Scotian Shelf is a concern. However, in most instances, levels of contaminants in the offshore do not appear to be high enough to cause any obvious or acute toxic effects. Many emerging contaminants of concern (e.g., brominated flame retardants) have not been studied on the Scotian Shelf, and data on some conventional marine contaminants (e.g., DDT and PCBs) are largely outdated and may not reflect current conditions. A variety of management actions have been implemented to protect the marine environmental quality of the Scotian Shelf including legislation and policies, and scientific research and monitoring programs. The use and production of many toxic substances in Canada is strictly regulated or banned altogether.

Linkages

This theme paper also links to the following theme papers:

- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Fish Stock Status and Commercial Fisheries
- Marine Habitats and Communities
- Marine Waste and Debris
- Ocean Acidification
- Ocean Noise

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[23] Like other theme papers in the State of the Scotian Shelf report, the focus of this paper is the offshore. However, contaminants are more likely to be at levels of concern in inshore areas (see Box 1).

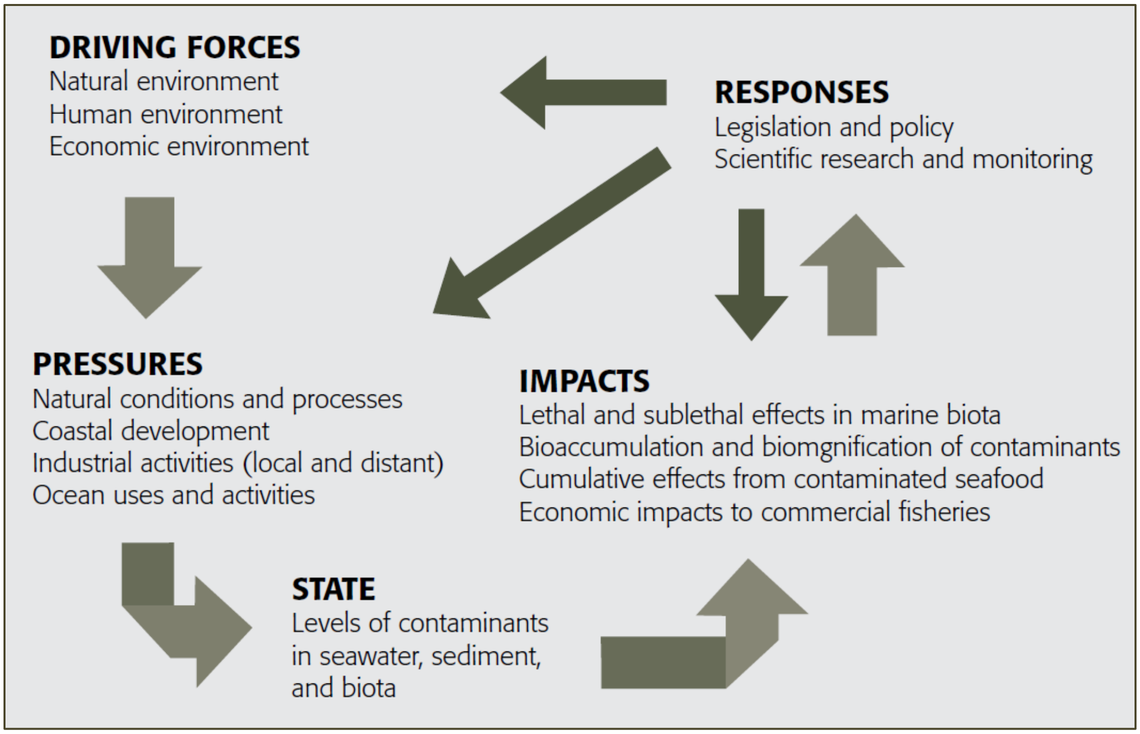


Figure 12-1: Driving forces, pressures, state, impacts and responses (DPSIR) for water and sediment quality on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and materials, which may elicit a societal or government response that feeds back on all the other elements.

12.2 Driving Forces and Pressures

The driving forces influencing marine environmental quality on the Scotian Shelf include changes in the economic, human and natural environments. Natural conditions and processes play an important role in the transport and distribution of substances and chemicals in the marine environment and therefore have a strong influence on marine environment quality. The natural conditions of the Scotian Shelf are described in detail in *The Scotian Shelf in Context*. The behaviour of a chemical in aquatic ecosystems is controlled by factors including the physical-chemical properties of the chemical; its sources, pathways, and sinks; and the physical, chemical and biological processes that all interact within aquatic ecosystems (Pierce et al. 1998). While certain potentially harmful substances and chemicals occur naturally in the marine environment, human activities release a wide variety of contaminants into the marine environment and thus represent a significant pressure on water and sediment quality. Coastal development, industrial activities (both local and distant), shipping, and offshore oil and gas activities are all significant anthropogenic sources of contamination on the Scotian Shelf. The main sources of natural and anthropogenic contaminants on the Scotian Shelf, in order of importance, include: (1) the Gulf of St. Lawrence outflow; (2) offshore exchange; (3) atmospheric deposition; (4) outflow from rivers in Nova Scotia; (5) leakage from industrialized areas including industrialized harbours and offshore oil and gas projects; and (6) marine shipping (Yeats 2000; see **Figure 12-2**).

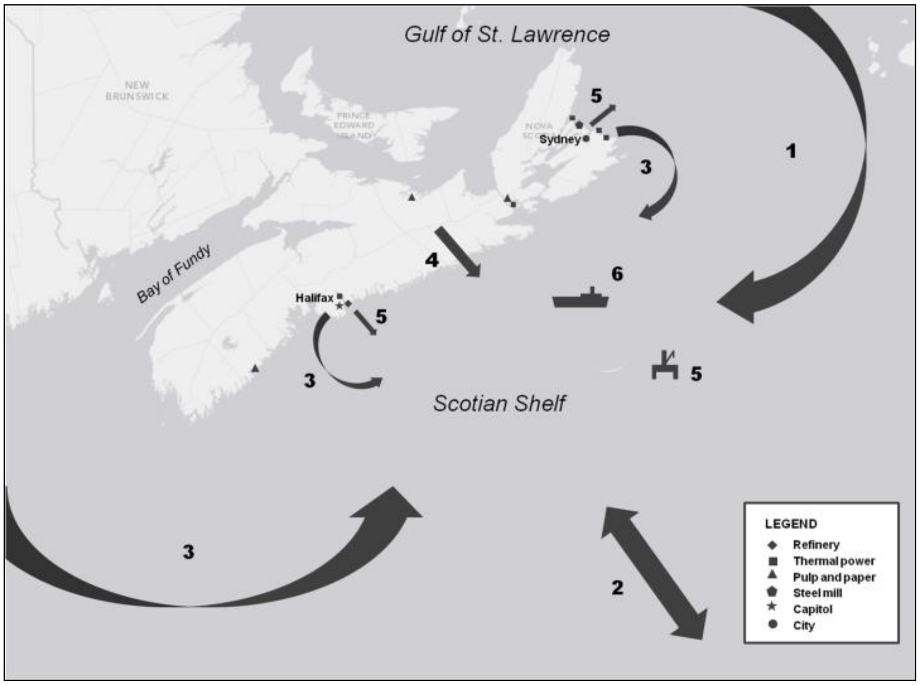


Figure 12-2: The main sources of natural and anthropogenic contaminants on the Scotian Shelf: (1) the Gulf of St. Lawrence outflow; (2) offshore exchange; (3) atmospheric deposition (long-distance and local); (4) Nova Scotia rivers; (5) leakage from industrialized areas, including industrialized harbours and offshore oil and gas projects; and (6) marine shipping (Source: Based on information in Yeats 2000 and Stewart and White 2001).

12.2.1 Natural Conditions and Processes

Weathering of the continents and the seabed generates material containing a variety of metals which can enter the ocean through runoff and river discharge; atmospheric suspension and deposition; and chemical changes in marine sediments. Some PAHs are synthesized by marine plants and zooplankton, or produced by natural processes (Kennish 1997; Stewart and White 2001). Natural processes can sometimes cause the concentration of chemicals in a localized area to be significantly higher than surrounding areas. For example, chemical interactions with sediments result in higher concentrations of manganese in suspended matter above the bottom in deep basins of the Scotian Shelf (Stewart and White 2001). In some regions, features known as “hydrocarbon seeps” release hydrocarbons from the seabed, leading to elevated levels of hydrocarbons in the vicinity. There is evidence of cold seeps in deep waters of the Laurentian Fan (Mayer et al. 1988). As well, pockmarks in Emerald Basin have been interpreted as being associated with natural release of hydrocarbons or water (Lewis and King 1970 cited in Stewart and White 2001). However, there are no confirmed hydrocarbon seeps on the Scotian Shelf.

12.2.1.1 Oceanographic Conditions: Oceanographic conditions play an important role in the transport and distribution of contaminants in the marine environment. Contaminants are transported horizontally by ocean currents and ocean mixing and vertically by advection, turbulent mixing and settling of particulate matter (Brandon and Yeats 1984). The Scotian Shelf is most strongly influenced by three currents: the Nova Scotia Current, the Labrador Current and the Gulf Stream (see *Scotian Shelf in Context*). The topography of the seafloor interacts with these currents and creates localized circulation patterns. These currents and circulation patterns actively transport and distribute dissolved and particulate contaminants around the marine environment. Physical mixing processes from wind, waves, tides, and upwelling also help to disperse chemical contaminants within the water column (Brandon and Yeats 1984). While the relative importance of different sources varies for each specific contaminant, the Gulf of St. Lawrence outflow is the main source for most natural and anthropogenic contaminants found on the Scotian Shelf (Stewart and White 2001; Yeats 2000). This outflow, which includes water from the St. Lawrence River, transports a variety of contaminants including PAHs, metals, and pesticides from heavily industrialized areas of the Great Lakes region.

The sediments covering the Scotian Shelf seafloor are an important structural and functional component of the marine ecosystem. Some contaminants including PCBs, organochlorine pesticides, PAHs, and some metals have a tendency to sorb to particulate matter and may be deposited into the bed sediments from the water column where they accumulate over time (Brandon and Yeats 1984; Pierce et al. 1998; CCME 1999). The incorporation of contaminants to settling particles is an important removal process of trace contaminants from the water column, and sediments may therefore act as long-term reservoirs of chemicals in the marine environment (Brandon and Yeats 1984; CCME 1999). Natural processes can change the stability of sediments after their deposition, resulting in the release of metals back into the water column. Contaminants can also be released into the water column following physical disturbances to bottom sediments caused by tides, storms, and benthic organisms.

12.2.1.2 Atmospheric Conditions: The atmosphere is a significant pathway for the transport of many natural and anthropogenic contaminants from the continents to the ocean (Duce et al. 1991). Many contaminants, including PAHs, DDT, PCBs, dioxins/furans and some metals, can be transported long distances in the atmosphere before being deposited in the marine environment. Atmospheric deposition at the ocean surface may be in the form of dry particles, through absorption of gaseous contaminants, or through wet precipitation of particulate matter (Brandon and Yeats 1984). The dominant storm tracks in the Northwest Atlantic pass through highly industrialized regions of North America, and subsequent precipitation from these storms introduces contaminants into the Scotian Shelf region (Brandon and Yeats 1984). Volcanic eruptions and forest fires also release a variety of chemicals (e.g., PAHs, dioxins/furans, and heavy metals) into the atmosphere that can be transported long distances before being deposited into the marine environment (Kennish 1997; CCME 1999). It is possible that climate change may alter oceanographic and atmospheric conditions on the Scotian Shelf, resulting in changes in the transport and distribution of contaminants in the marine environment (see *Climate Change and its Effects on Ecosystems, Habitats and Biota*).

12.2.1.3 Marine Organisms: Marine organisms can also influence the concentration and distribution of chemicals, as they take in and use chemicals in biological processes. For example, the uptake of metals by biota from surface waters, and their subsequent removal from the water column to the ocean floor by planktonic debris or fecal pellets, controls the distribution and transport of several trace metals including cadmium, zinc, nickel, chromium and selenium (Brandon and Yeats 1984).

12.2.2 Anthropogenic Contaminants

The water and sediment quality of the offshore Scotian Shelf is largely influenced by distant anthropogenic sources of contaminants, as the majority of contaminants come from heavily industrialized areas in Eastern Canada and the northeastern United States. Industrial activities release contaminants into the atmosphere and the St. Lawrence River before entering the Scotian Shelf region via the Gulf of St. Lawrence outflow and atmospheric deposition (Addison 1984b; Yeats 2000; Stewart and White 2001). Although less important than these distant sources, coastal development, local industrial activities, shipping, and offshore oil and gas activities are also significant sources of contaminants on the Scotian Shelf.

12.2.2.1 Coastal Development and Industrial Activities: Significant sources of marine pollution from coastal areas include domestic sewage and chemicals; surface runoff and river discharge containing hydrocarbons, metals, silt and persistent plastics; agriculture and forest sprays; dust and airborne emissions; industrial and manufacturing outputs (e.g., pulp and paper mills, refineries, smelters); power plants; and mining operations (Wells and Rolston 1991; Brandon and Yeats 1994; Stewart and White 2001). It is estimated that half of all major industrial effluents discharged in the Atlantic Provinces enter directly into estuaries or the sea (Wells and Rolston 1991). Industrialized harbours and urban centres adjacent to the Scotian Shelf such as Halifax and Sydney, Nova Scotia are important local sources of contaminants (Yeats 2000).

12.2.2.2 Atmospheric Pollution: Human activities release a variety of contaminants into the atmosphere including particulate soot, dust, aerosols, trace metals, organic compounds such as PCBs and PAHs, and radioactive materials (Wells and Rolston 1991; Stewart and White 2001). Atmospheric deposition is a significant source of volatile contaminants (e.g., volatile organic compounds and mercury) as well as some non-volatile contaminants (e.g., lead) on the Scotian Shelf (DFO 2009a). Some common sources of atmospheric pollution include stacks, vehicles and a variety of non-point sources. The widespread combustion of fossil fuels, particularly in heavy industry and thermal power generation, is a significant source of organic contaminants (such as PAHs) to the marine environment (Stewart and White 2001). Coal combustion for power generation is the single largest source of atmospheric mercury and an important source of PAHs (Eaton et al. 1984; Wells and Rolston 1991). There are four coal-fired power plants in Nova Scotia located in Sydney, Point Aconi, Point Tupper, and Trenton. Since areas of greatest annual deposition are usually within 5 to 30 km of power stations, most of the emissions from these plants will be transported over marine waters and enter the sea (Eaton et al. 1984).

12.2.2.3 Shipping: The strategic location of Nova Scotia on the Great Circle Route (i.e., shortest distance over the earth's surface) between eastern North America and Europe makes it important for international shipping (Coffen-Smout et al. 2001). Hydrocarbons are released from accidental and routine discharges from tankers, shipping accidents, tank and ballast water clearing and bilge operations, and passing ships (Stewart and White 2001). Except for occasional major spills, petroleum hydrocarbon contamination from shipping on the Scotian Shelf is not significant (Wells and Rolston 1991). Additional contaminants released from shipping include anti-corrosive metals, organotin compounds from anti-fouling paints, marine litter and garbage, chemicals, and ship debris and cargoes from ship accidents (Stewart and White 2001).

12.2.2.4 Oil and Gas Activity: Oil and gas activity is one of the main non-fishing industrial activities taking place on the continental shelf and slope, and is a major source of income and employment in Nova Scotia. As of 2004, over 300,000 km of seismic survey tracks had been recorded and 194 wells had been drilled, with the majority of wells concentrated on the eastern shelf near Sable Island (Coffen- Smout et al. 2001; Zwanenburg et al. 2006). To date, two petroleum production projects have operated on the Scotian Shelf near Sable Island including the Cohasset-Panuke Project (1992–1999) and the Sable Offshore Energy Project (1999–present) (CNSOPB 2011a). A third project, the Deep Panuke Offshore Gas Development Project is currently under development and is expected to start production in 2012.

Produced water (brine that is extracted from rock formations), drilling wastes, and accidental spills of hydrocarbons from offshore oil and gas activities are another significant source of contamination on the Scotian Shelf (Coffen-Smout et al. 2001; Zwanenburg et al. 2006). Drill cuttings and produced water comprise the largest volume of wastes discharged from typical exploratory drilling operations, while produced water accounts for the largest volume of waste released during hydrocarbon production phases (Stewart and White 2001). Drilling rig operations also release a variety of contaminants into the marine environment including human domestic sewage and deck drainage, cooling waters from machinery, particulates and gases from flaring, hydrocarbons from routine operations, and metals which may enter seawater from rig structures (Stewart and White 2001).

12.2.2.5 Commercial Fishing: Commercial fishing is a major source of income and employment in Nova Scotia and is widespread on the Scotian Shelf. However, the fishing industry does not contribute significantly to contaminant levels in the region (Stewart and White 2001). Minor sources of contaminants from the fishing industry and associated infrastructure (e.g., wharves, vessel maintenance and repair facilities, and fish processing operations) include organic waste from fish plants, hydrocarbon releases from fuels and lubricants, anti-fouling chemicals (e.g., TBT), and wood preservatives (e.g., creosote) (Stewart and White 2001). Bottom trawling and dragging can disturb bottom sediments and redistribute any contaminants that are present in the sediments (Messieh et al. 1991; Stewart and White 2001).

12.2.2.6 Other: There is growing concern over the effects of micro-plastic particles on marine environmental quality. These particles tend to accumulate and transport persistent, bioaccumulating and toxic contaminants such as PCBs and DDT, and have been shown to be ingested by a range of marine organisms (Bowmer and Kershaw 2010). For more information about marine waste and debris on the Scotian Shelf, the reader is directed to the theme paper on *Marine Waste and Debris*.

12.3 STATUS AND TRENDS

There are limited scientific data on contaminant levels and trends in the waters, sediments and biota on the Scotian Shelf, apart from that necessary to determine if "safe" levels of key contaminants occur in fish, shellfish and fish products (Stewart and White 2001). Data on conventional marine contaminants such as DDT and polychlorinated biphenyls (PCBs) are largely outdated and may not reflect current conditions in the Scotian Shelf region. Overall, available data indicate there are relatively low levels of organochlorine compounds, metals, hydrocarbons, and PAHs in offshore areas of the Scotian Shelf and these levels are at or near background levels (Addison 1984b; Wells and Rolston 1991; Yeats 2000; Stewart and White 2001; Yeats 2008). There are a number of possible explanations for this observation (Addison

1984b; Stewart and White 2001). First, the anthropogenic sources of contaminants are limited by the relatively low population density and few sources of industrial pollution along coasts of Atlantic Canada. Second, the Northwest Atlantic is a very dynamic environment, and contaminants tend to be dispersed rapidly and widely. Third, many contaminants do not reach offshore, but are instead absorbed by particles that are deposited near the source of contamination in standing water on land and in nearshore waters. Although offshore areas of the Scotian Shelf are relatively uncontaminated, sediment core records for the Emerald Basin show that deposition of many contaminants in recent decades significantly exceeded deposition over the preceding century (Yeats 2000).

Box 1. Marine water and sediment quality in inshore areas of the Scotian Shelf

As with offshore areas of the Scotian Shelf, much of the inshore waters around Nova Scotia are relatively uncontaminated, with levels of most contaminants at or near background levels (Stewart and White 2001). However, a number of industrialized harbours in the province, such as Sydney Harbour, are severely polluted with contaminants such as organic carbon, metals, PAHs, and PCBs from industrial activities (Stewart and White 2001; CBCL Ltd. 2009). One of the main sources of pollution in Sydney Harbour is the Sydney Tar Ponds—an area near the shore of the harbour where much of the contamination from a steel smelter and coke ovens accumulated (Stewart and White 2001). Efforts to clean-up the Tar Ponds have been underway since the 1980s and have yet to be completed. Some rural areas of Nova Scotia, such as Clam Harbour and Isaacs Harbour, have high concentrations of arsenic and mercury from historic gold mining activities (CBCL Ltd. 2009). Aquaculture operations along the coast Nova Scotia may be associated with a variety of chemical inputs into the marine environment including antibiotics, drugs and pesticides, metals such as copper and zinc, lime, disinfectants, and fungicides (Burridge et al. 2010). Monitoring of nutrient levels from 1996–2001 show a general increase in the amount of nutrients, particularly nitrogen, entering coastal waters from land-based sources (CBCL Ltd. 2009). As a result, coastal waters in many areas of the province are at a higher risk of algal blooms.

Poor coastal water quality in nearshore areas has resulted in economic impacts to the province. From 1985–2000, the number of shellfish closures in Nova Scotia doubled, representing the greatest increase in shellfish closures from contamination among the Atlantic provinces (CBCL Ltd. 2009). High levels of contaminants in the South Arm of Sydney Harbour led to the closure of an important commercial fishery for lobster (Stewart and White 2001). For information about water quality in nearshore areas of the Scotian Shelf, see *The State of Nova Scotia's Coast Report* (CBCL Ltd. 2009; and Stewart and White (2001).

In addition to the conventional marine contaminants discussed in this paper, there are a number of contaminants that are of growing scientific concern, but are not routinely monitored or assessed by regional or national programs. Concern over these "emerging contaminants" may arise from new information about previously identified compounds or from the discovery of new substances that may pose a risk to the environment and/or human health (Roose et al. 2011). Some emerging contaminants in the marine environment include brominated flame retardants, short- and medium-chain chlorinated paraffins, perfluorinated compounds (PFCs), antifouling booster biocides, pharmaceuticals and personal care products (PPCPs), and organophosphate esters (Roose et al. 2011). Despite the lack of information about these contaminants in the Scotian Shelf region, they have the potential to have a strong influence on water and sediment quality in the future and represent a major knowledge gap in marine environmental quality on the Shelf. The general status and trends of organochlorine compounds, hydrocarbons and PAHs, and metals on the Scotian Shelf are summarized below based on available published data. Although the focus of this paper is water and sediment quality, information on contaminants in marine biota are also included as an additional indicator of marine environmental quality. In order to provide some context to the specific contaminant concentrations described in this section, the reader may wish to refer to some of the more widely used standards and thresholds for contaminant concentrations in marine waters, sediments, and fish and fish products in Canada (see **Table 12-5** as well as CCME (1999); CFIA (2005); Health Canada (2011).

12.3.1 Organochlorine Compounds and Other Halocarbons

Halocarbons are hydrocarbon compounds containing chlorine, bromine, fluorine, or iodine (the halogens) (Kennish 1997). Chlorine halocarbons, known as organochlorine compounds, are the most common of the halocarbons and include chemicals such as DDT, PCBs, and polychlorinated dioxins and furans. Many organochlorine compounds are classified as persistent organic pollutants (POPs). POPs persist in the environment for long periods of time, tend to accumulate in fatty tissue of organisms (bioaccumulation), are subject to long-range transport in the environment, and cause adverse effects on human health and/or the environment (Environment Canada 2006a). Some of the most important halocarbon compounds found in the marine environment and the main sources of these contaminants are described here.

DDT: DDT was used as a broad spectrum commercial pesticide before it was banned in the U.S. in the 1970s and in Canada in the 1980s. Its main use in Eastern Canada was the New Brunswick forest spraying program from the early 1950s to the early 1960s (Addison 1984a). DDT and its derivatives DDD and DDE (referred to collectively as ΣDDT) are among the most well-known and ubiquitous examples of organochlorine compounds in the environment. DDE accounts for most of the ΣDDT in the ocean and 80% of that in marine organisms (Kennish 1997). Although DDT has not been applied in the marine environment, it enters the ocean via non-point source runoff from land, river discharge, direct disposal, and atmospheric deposition (Kennish 1997; CCME 1999).

PCBs: PCBs were used for many years as insulation in electrical equipment, but U.S. production ceased in 1977 (Kennish 1997). PCBs have had only a small-scale industrial application in Eastern Canada, but they were used in a variety of common consumer products whose disposal was not controlled (Addison 1984a). PCBs have become universally distributed in marine environments and occur in nearly all marine plant and animal species (Kennish 1997). Atmospheric deposition is the main source of PCBs in the marine environment, but river discharge is also an important source (Kennish 1997).

Dioxins/Furans: Dioxins and furans occur as trace contaminants in a variety of industrial chemicals and are produced as by-products from municipal waste incinerators, pulp and paper mills, petroleum refineries, wood burning, automotive emissions, electric power generation, and the combustion of PCBs (Kennish 1997; CCME 1999). The biggest source of dioxins and furans in Canada is the large-scale burning of municipal and medical waste (Health Canada 2005). Wastewater, stormwater runoff, and atmospheric deposition are all common sources of these chemicals in the marine environment (Kennish 1997).

Polybrominated diphenyl ethers (PBDEs): PBDEs are organobromine compounds used as flame retardants in a wide variety of products (Environment Canada 2011). PBDEs are not manufactured in Canada but are imported into Canada as commercial mixtures and added to various intermediate and finished products, such as computer housings, household appliances, furniture, automotive/aircraft seating and interiors, and a variety of electrical and electronic components (Environment Canada 2011). Recently, there has been growing concern over the rapid emergence of PBDEs in the marine environment, which have surpassed PCBs and DDT as the number one persistent contaminant (Ross et al. 2008). PBDEs enter the marine environment by sewage discharge and atmospheric deposition.

Overall, there is a lack of information about organochlorine compounds and other organic chemicals in the offshore waters and sediments of the Scotian Shelf. However, a variety of organochlorine compounds have been detected in a number of different marine organisms on the Scotian Shelf. Based on available information, the Scotian Shelf region appears relatively contaminated by ΣDDT and less so by PCBs. Data on concentrations of PCBs in marine biota indicate a declining trend, while data on ΣDDT in marine biota are conflicting (Addison and Stobo 2001; Hooker et al. 2008; DFO 2009a). There are no specific studies of PBDE ion the Scotian Shelf; however, PBDEs are found in all marine fish and marine mammals examined in Canada and their concentrations are increasing exponentially in fish and marine mammals in Canada's three oceans, and in some areas/species, are doubling every 3–4 years (Ross et al. 2008). It is important to note that many marine mammals are migratory; therefore, the levels of PBDEs observed in migratory populations are not a reliable indicator of local or regional marine environmental quality. Nevertheless, PBDEs are poised to overtake DDT and PCBs as the dominant persistent contaminant in Canadian aquatic food webs.

12.3.1.1 Marine Waters and Sediments: Since organic chemicals are generally only sparingly soluble in water and have a high affinity for suspended particulate material, organochlorine compounds are usually found in appreciably higher concentrations in sediments than in water (Pierce et al. 1998; Stewart and White 2001). However, no measurements of concentrations of organochlorine compounds in seawater or sediments are available for offshore areas of the Scotian Shelf (Addison 1984a; Stewart and White 2001). Typical concentrations in surface waters in the Northwest Atlantic (excluding the lipid-rich surface micro-layer) range from about 0.1 to 10 nanograms per litre (ng/L) for ΣDDT and 1 to 100 ng/L for PCBs (Addison 1984a). Concentrations of both residues in the surface micro-layer may be 5 times higher.

12.3.1.2 Marine Biota: Given the tendency of organochlorine compounds and other halocarbons to bioaccumulate in the fatty tissues of marine organisms, significant concentrations can occur in biota relative to other compartments of the environment (Stewart and White 2001). Therefore, studies measuring the levels of these contaminants in the tissues of marine organisms represent the best source of information about their status and trends on the Scotian Shelf. Fish and fishery products as well as some marine mammals in offshore areas of the Scotian Shelf have been sampled periodically to measure levels of organic chemicals (Stewart and White 2001). Most organochlorine measurements in marine organisms of the Scotian Shelf were carried out in the 1970s during the period of most concern about the effects of these contaminants. Information about the levels of organochlorine compounds in fish, shellfish, and marine mammals on the Scotian Shelf is summarized here.

Fish and shellfish: The International Council for the Exploration of the Sea (ICES) Baseline Monitoring Study conducted during the 1970s is among the most comprehensive studies measuring organochlorine compounds in marine organisms (ICES 1977). Cod liver samples taken from the Scotian Shelf as part of this study contained high levels of ΣDDT; similar to those found in the North Sea, and higher than levels found in Greenland or Spitzbergen, Norway (Addison 1984a). PCB levels in these samples were intermediate: higher than those found in Arctic samples, but lower than those found in the North Sea. Dieldrin levels in these samples were also relatively high.

A number of other studies have measured organochlorine compounds in fish, shellfish, and fish products from the Scotian Shelf. The concentration of several organochlorine compounds in the tissues of fish and shellfish collected from offshore areas of Nova Scotia is shown in **Table 12-1**. These studies suggest that levels of organochlorine pesticides and PCBs measured in fish and invertebrates during the 1970s were generally low, except for bluefin tuna which contained high concentrations (Zitko 1980; Stewart and White 2001; see **Table 12-1**). The pesticide chlordane and nonachlors (chlordane contaminants) were also detected at high concentrations above levels considered acceptable for human consumption by Health Canada in liver samples taken from bluefin tuna captured off Nova Scotia from 1976–78. The tuna samples also had elevated liver concentrations of a number of other organochlorine compounds as well, including dieldrin, hexachlorobenzene (HCB), chlordane and nonachlors, oxychlordane (a chlordane metabolite), toxaphene, DDT derivatives, mirex and octachlorostyrene. HCB was found in Atlantic herring from the Scotian Shelf in 1972, and toxaphene was found in herring caught off Halifax in the 1980s (Zitko et al. 1974; Musial and Uthe 1983; Stewart and White 2001).

A 2002 survey measured levels of dioxins/furans, PCBs and PBDEs in fish and seafood products sold at the retail level in Vancouver, Toronto and Halifax (Health Canada 2004a). PCB levels in the sampled fish and seafood products were quite low, with average values not exceeding 18 ppb; while PBDE levels in the samples did not exceed 5.5 ppb.

Marine mammals: Concentrations of ΣDDT in samples of blubber from grey seals collected from Sable Island declined from 12 to 0.5 micrograms per gram (μg/g) lipid between 1974 and 1994 (Addison and Stobo 2001; DFO 2009a). Concentrations of PCBs in these samples were stable between 1976 and 1985, but then declined between 1985 and 1994. These declines were likely the result of widespread reductions in the use of DDT and PCBs beginning in the early 1970s. A number of other organochlorine compounds have been detected in Sable Island grey seals. HCB, alpha-hexachlorocyclohexane (alpha-HCH), and trans-nonachlor were present in most tissue samples collected from grey seals between 1988 and 1991 (Addison and Stobo 1993). Concentrations of HCB and of trans-nonachlor showed no change between 1984 and 1994, but those of alpha-HCH showed some decline between 1984 and 1994, and oxychlordane began to decline after the early 1990s (Addison et al. 1998).

During the 1970s and early 1980s, organochlorine levels in grey seals from Sable Island were lower than in grey seals in the North Sea (Addison 1984a). PCB levels in the Sable Island samples were about half of those taken in the Farne Islands, U.K. and well below those taken in East Anglia, U.K. Similar levels of ΣDDT were found in the samples taken from these different regions. However, organochlorine levels in grey and harp seals in Eastern Canada were about one order of magnitude higher than those in ringed seals in the Canadian Western Arctic. In contrast to the declines in ΣDDT levels observed in Sable Island grey seals between 1974 and 1994, tissue samples taken from resident northern bottlenose whales in the Gully Marine Protected Area (MPA) indicated significant increases in DDE and trans-nonachlor from 1996/97 to 2002/03 (Hooker et al. 2008; DFO 2009a). Since 2003 was the final year of sampling, it is not known whether the increase was a single year event, or whether this trend may have continued (Hooker et al. 2008). The levels of organochlorine compounds were higher in the tissue samples taken from whales in the Gully than those from offshore areas of northern Labrador, but overall the concentrations were generally consistent with concentrations reported for other large toothed whales in the North Atlantic.

Table 12-1: Concentration of several organochlorine compounds in fish and invertebrate tissues collected in offshore areas of Nova Scotia. The Canadian Food Inspection Agency's Guidelines for Chemical Contaminants and Toxins in Fish and Fish Products specifies an action level of 5.0 micrograms per gram (µg/g) for DDT and DDE, and 2.0 µg/g for PCBs (edible weight). Source: Adapted from Stewart and White (2001).

Species or Type	Source	Year	Area	Tissue	Tissue Concentration (µg/g) (wet weight)		
					Total DDT	DDE	PCB
Groundfish (cod, hake, plaice & ocean perch)	Zitko (1971)	1970	NS banks	Muscle	-	< 0.02	< 0.02
Pelagic (Atlantic herring)	Zitko (1971)	1971	Chedabucto Bay	Muscle	43	24	54
Atlantic herring	Zitko et al. (1974)	1972	NS commercial catch	Muscle	20	11	64
Cod	Sims et al. (1975)	1971	Atlantic coast	Liver	4–14	-	-
Cod	Sims et al. (1975)	1971	Sydney Bight	Muscle	3	0.01	-
Bivalves (clams, mussels, oysters, scallops)	Sims et al. (1977)	1971–72	Atlantic coast	Edible parts	0.003–0.015	-	0.005–0.023
Crustaceans (lobster, queen crab, red crab, rock crab, shrimp)	Sims et al. (1977)	1971–72	Atlantic coast	Edible parts	0.0003-0.061	-	0.024–0.098
Groundfish (catfish, cod, grey sole, haddock, halibut, plaice, pollock, yellowtail, redfish)	Sims et al. (1977)	1971–72	Atlantic coast	Edible parts	0.004–0.24	-	0.01–0.27
Pelagic (alewives, capelin, dogfish, eels, herring, mackerel, salmon, sardines, smelt, striped bass, swordfish)	Sims et al. (1977)	1971–72	Atlantic coast	Edible parts	0.021–1.1	-	0.057–0.94
Bluefin tuna	Sims et al. (1977)	1971–72	Scotian Shelf	Edible parts	0.6–7.3	> 1	0.6–9.7
Bluefin tuna	Zitko (1980)	1976–78	Scotian Shelf	Liver	2.0–10.6	2.4–6.2	4.6–25.1
Cod	ICES (1977) from Zitko (1981)	1975	Browns Bank	Liver	-	-	145
Cod	ICES (1977) from Zitko (1981)	1975	LaHave Bank	Liver	-	-	205
Cod	ICES (1977) from Zitko (1981)	1975	Northeast of Cape Breton Island	Liver	-	-	19

Seabirds: Several perfluorinated compounds (PFCs) were detected in herring gull eggs collected from Sable Island in 2008 (Gebbink et al. 2011). The concentrations of PFCs in the eggs from Sable Island were higher than those measured from other colony sites in New Brunswick and Newfoundland, and concentrations of some PFCs in the Sable Island colony were comparable to colony sites close to urbanized areas in Ontario and Quebec. It is likely that the Sable Island gulls were exposed to PFCs through marine aquatic prey, but no information about the colony's dietary composition is available.

12.3.2 Hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAHs)

Hydrocarbons and PAHs are some of the dominant contaminants in the marine environment. Hydrocarbons are major components of petroleum and can occur in dissolved form and as particles ranging in size from microscopic to large tar balls (Wells and Rolston 1991; Stewart and White 2001). In the late 1990s, the estimated average annual inputs of oil entering the marine environment from ships and other sea-based activities was 1.2 million metric tonnes (GESAMP 2007; see **Table 12-2**). Anthropogenic sources of hydrocarbons in the marine environment include oil spills, discharges during marine transportation, ocean dumping, leakages from drilling operations, discharges from coastal refineries and marine terminals, industrial discharges and effluents, urban runoff, waste incineration, and combustion of fossil fuels (Kennish 1997). Hydrocarbon concentrations vary over time and space and depend upon inputs and oceanographic conditions (Levy 1984). PAH compounds are found in many fossil fuels and are some of the most ubiquitous organic contaminants found in marine organisms (Kennish 1997). PAHs are released into the environment from atmospheric emissions, especially the burning of fossil fuels. In the marine environment, PAHs generally adsorb to suspended matter or sediments where they persist; so sediments are the main environmental sink for these compounds (Kennish 1997). PAHs are now ubiquitous in terrestrial, atmospheric, and aquatic environments and are considered to be POPs (CCME 1999; Wells and Rolston 2001). Most PAH compounds released into the marine environment originate from anthropogenic activities such as industrial operations, fossil fuel combustion, waste incineration, oil spills and refinery effluents (Kennish 1997; CCME 1999). However, some PAHs are synthesized by marine plants and zooplankton or derive from natural products and processes such as coal and oil, grass and forest fires, marine seeps and volcanic eruptions (Kennish 1997; Stewart and White 2001).

Table 12-2: Estimated annual global input of oil into the marine environment (Source: GESAMP 2007).

Source	Input (tonnes/year)
Ships	457 000
Offshore exploration and production	20 000
Coastal facilities	115 000
Small craft activity	53 000
Natural seeps	600 000
Unknown (unidentified) sources	200
Total:	**1 245 200**

Data from the early 1980s indicate that concentrations of petroleum hydrocarbons and PAHs in the offshore waters and sediments of the Scotian Shelf are relatively low, near background levels (Levy 1984). Levels of these contaminants in marine biota also appear to be low (Zitko 1981; Hooker et al. 2008; DFO 2009a). Some data indicate a declining trend in levels of hydrocarbon contamination during the 1970s, while other data indicate an increasing trend from the early 1970s to 2000 (Levy 1984; Yeats 2000; DFO 2009a). Elevated levels of hydrocarbons have been observed in the vicinity of oil and gas activities, and short-term increases in hydrocarbon levels are often observed following spills and accidents.

Box 2. Oil spills and blowouts on the Scotian Shelf

Oil spills from ships and blowouts from oil and gas wells have the potential to result in widespread contamination of the marine environment. In 2010, an explosion on the *Deepwater Horizon* drilling rig in the Gulf of Mexico killed 11 workers and resulted in the release of millions of barrels of oil into the Gulf over a 3 month period. The incident was the largest accidental marine oil spill in the history of the petroleum industry. While an incident of this magnitude is unlikely to occur on the Scotian Shelf due to the types of hydrocarbons produced (natural gas and light condensate) and strict safety and environmental regulations, there have been a number of notable oil spills and blowouts in the region:

- On February 4, 1970, the Liberian oil tanker *Arrow* carrying 108 000 barrels of Bunker C fuel oil ran aground on Cerberus Rock in Chedabucto Bay, Nova Scotia during heavy rains and strong winds (Environment Canada 2006b). The ship suffered extensive damage and oil slicks, some miles in extent, were observed in the Bay. On February 8, the tanker broke in half spilling even more oil into the sea. An estimated 8000 tonnes of fuel were spilled, affecting over 300 km of shoreline (Beson 2001). The spill had major environmental and economic impacts. A variety of species were affected including shellfish, lobsters, fish, plankton, aquatic plants, and seabirds. Lobster Fishing Areas 29 and 30 were closed in 1970 because of the high concentrations of oil present in the area. By April 1971, levels of petroleum hydrocarbons in the waters of Chedabucto Bay returned those typically measured in the marine waters off Atlantic Canada, averaging 1.5 parts per billion (ppb) (Gordon Jr. and Michalik 1971).

- On March 15, 1979, the British oil tanker *Kurdistan* carrying 29 662 tonnes of Bunker C fuel oil was damaged during a powerful storm approximately 50 nautical miles northeast of Sydney, Nova Scotia (Environment Canada 2006b). The ship split in two, spilling 7000 tonnes of oil into the ocean. Oil from the spill washed ashore along the length of the eastern Nova Scotia shoreline and the southern coast of Newfoundland throughout the summer and early fall of 1979. Over 550 miles of coastline had to be cleaned, yielding close to one million bags and almost 1500 barrels of oily debris. It was estimated that 12 000 to 25 000 seabirds were killed and $800 000 worth of fishing gear was damaged as a result of the spill. Monitoring of oil pollution from the *Kurdistan* on the Scotian Shelf found that hydrocarbon concentrations returned to background concentrations within one year following the spill (Levy 1989).

- On February 22, 1984, 16.9 km northeast of Sable Island, the oil rig *Vinland* had a blowout resulting in the release of natural gas and light condensate over 13 days (Environment Canada 2006b). It is estimated that 75% of the condensate was lost by evaporation during the first 24 hours after release, while the remainder either formed a temporary surface slick or became entrained in the water column (Boudreau et al. 2001). The surface slick of condensate persisted for several days and was observed up to 10 km from the rig, while dissolved condensate in the water column presumably persisted longer and travelled further because of decreased evaporation. Measured hydrocarbon concentrations in the water column, detected to depths of at least 21 m, were usually under 100 ppb compared with background levels of about 1 ppb. Biological effects of the hydrocarbon contamination from the *Vinland* blowout were not observed or evaluated.

12.3.2.1 Marine Waters: The most recent assessment of dissolved and dispersed hydrocarbons on the Scotian Shelf conducted in the 1970s indicated a general decline in background levels between 1973 and 1975 (Levy 1984). Levy (1984) suggests that this decrease was the result of pollution control measures introduced in the late 1960s and early 1970s. Interestingly, the number of oiled seabirds in the region increased 3.2% annually between the early 1970s and 2000 (Yeats 2000; DFO 2009a). Therefore, the oiled seabird data do not support the previous findings by Levy (1984). In the early 1980s, levels of petroleum hydrocarbons in the water column of the Scotian Shelf were slightly elevated over those in the Gulf of St. Lawrence, but these levels were still considered to be relatively minor (Levy 1984; Wells and Rolston 1991).

Water quality assessments conducted as part of the Sable Offshore Energy Project (SOEP) Environmental Effects Monitoring (EEM) program in 1999 found no detectable concentrations of petroleum hydrocarbons outside the 500 m safety zone during the drilling phase, and a plume of flocculated drill waste was only observed once out to 500 m from the drilling platform (CNSOPB 2011b). From 2000 to 2008, discharges of produced water were found to have relatively low toxicity (CNSOPB 2011b). The toxicity of produced water increased from 2005 to 2008, but no toxic results were observed in water column samples collected adjacent to the platform and produced water was within the safe discharge criteria detailed in *the Offshore Waste Treatment Guidelines* (OWTG).

12.3.2.2 Marine Sediments: Keizer et al. (1978) analyzed the hydrocarbon content and composition of surface sediments from 20 stations on the Scotian Shelf on a transect from Halifax to Emerald Bank and around Sable Island. Levels of hydrocarbons in sediments were low around Sable Island and on the middle shelf, and elevated levels were found only at two sites on the Inner Shelf approximately 30 and 60 km off Halifax Harbour (Keizer et al. 1978; Stewart and White 2001). PAHs were not detected in sediment samples collected from feeder canyons to the Gully MPA on the Scotian Shelf in 2006, but the samples did contain low concentrations of total alkanes (C10-C35) ranging in concentrations from 966 to 6486 nanograms per gram (dry weight) (Yeats et al. 2008; DFO 2009a; see **Figure 12-3**). The composition and concentrations of these samples are consistent with observations of hydrocarbon concentrations in mostly uncontaminated sandy shelf sediments elsewhere, but also suggest an anthropogenic source is likely.

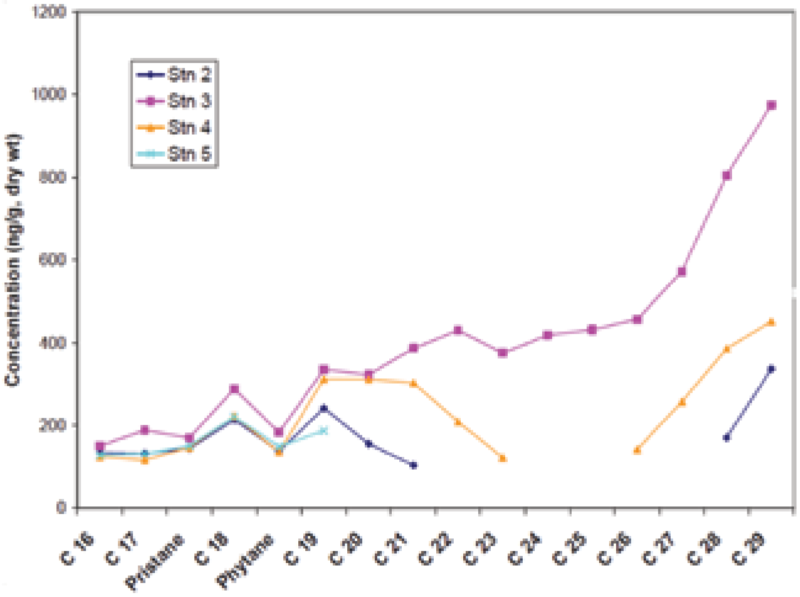


Figure 12-3: Concentration of various hydrocarbons (i.e., C16-C29, pristane, phytane) in sediment samples taken from the Gully MPA in 2006 (Source: Yeats et al. 2008).

Sediment quality monitoring and toxicity testing conducted as part of the SOEP EEM program in 1999 found the level of total petroleum hydrocarbon (TPH) to be above background levels at all platforms (CNSOPB 2011b). Since 1999 the spatial extent of contamination has decreased with none detected at the Venture platform from 2000 onward, and at the North Triumph platform from 2003 onward. Elevated concentrations of TPH at the Thebaud platform decreased more slowly, but no contamination has been detected since 2007. Sampling sites on the western boundary of The Gully MPA have shown no elevated concentrations of TPH since monitoring began in 1998. In 2001, amphipod mortality testing found sediments at the Thebaud platform's near-field 250 m sampling site to be toxic in the direction of the prevailing current, but no sediment toxicity has been observed at any site since 2003.

12.3.2.3 Marine Biota: A small sample of krill taken from the Gully MPA contained pristane, but no other detectable alkanes and very low concentrations of PAHs (DFO 2009a). Samples taken from northern bottlenose whales in the Gully MPA between 1996–1997 and 2002–2003 showed generally low levels of CYP1A1 protein expression (an indicator for exposure to PAHs), but a significant increase in these levels was recorded in 2003 (Hooker et al. 2008). These increased levels suggest that the whales may have been exposed to hydrocarbon contamination. Hooker et al. (2008) note that during the same period, there were several spills of kerosene and streamer fluids during seismic survey work on the Scotian Shelf. Data on PAHs in marine biota are limited and outdated, but indicate that there is little PAH contamination in finfish in offshore areas of the Scotian Shelf (Zitko 1981). Hydrocarbons have been detected in moored mussels and natural scallop beds within 500 m of the SOEP platform, but the observed concentrations were within natural variations (CNSOPB 2011b).

12.3.3 Metals

Heavy metals are natural constituents of the marine environment and normally occur at low concentrations (Ray and Bewers 1984). Many metals are used by marine organisms in biological processes. However, these metals may become toxic to marine organisms at high concentrations, while other metals such as lead, cadmium, arsenic and mercury have no biological role and may be toxic even at low concentrations (Ray and Bewers 1984; Kennish 1997).

Metals primarily enter the marine environment via river discharge, atmospheric deposition, mixing of water masses and a wide range of anthropogenic activities (Kennish 1997). A large quantity of the metals in river discharge originate from the weathering of rocks and leaching of soils, but these natural sources are often augmented by anthropogenic sources in rivers that flow through urban or industrialized areas (Kennish 1997). Some metals such as lead and mercury primarily enter the ocean through atmospheric deposition. Organotin compounds such as tributyltin (TBT) have been identified as important contaminants in the marine environment. TBT is a biocide used as antifouling agents applied to the hulls of ships, small boats and even lobster traps to protect against an accumulation of organisms on underwater surfaces (Matheson 1984).

By far the largest source of anthropogenic and naturally occurring metals on the Scotian Shelf are the waters exiting the Gulf of St. Lawrence and the Labrador Current (Yeats 1993). Estimates of the magnitude of known transport vectors and the predicted input of three metals onto the Eastern Scotian Shelf are shown in **Table 12-3**.

Table 12-3: Estimates of the magnitude of known transport vectors and the predicted input of three metals onto the Eastern Scotian Shelf (Source: DFO 2009a).

Transport Vector	Copper (tonnes/year)	Lead (tonnes/year)	Zinc (tonnes/year)
Gulf of St. Lawrence	4 390	258	7 750
Oceanic water	279	37	409
Rainfall	90	90	270
Nova Scotia Rivers	32	30	97
Sewage	5	3	11
Produced water from oil and gas operations	<1	23	157

Concentrations of metals throughout the marine waters of the Northwest Atlantic do not vary widely (Ray and Bewers 1984). Lead and cadmium are considered to be the major metal contaminants in all the world's oceans, including the Northwest Atlantic (Ray and Bewers 1984). Overall, the concentrations of trace metals in offshore areas of the Scotian Shelf are generally low compared to other coastal waters of the world (Yeats et al. 1978). The present pattern of metal distribution and abundance in the waters, sediments and biota of the Scotian Shelf appears to reflect the natural metal regime, with the exception of cadmium, where human activities have increased the amounts entering the western North Atlantic (Yeats and Bewers 1983; Ray and Bewers 1984; Stewart and White 2001; DFO 2009a). Levels of dissolved lead and zinc show a decreasing trend between 1985 and 2005, while levels of dissolved copper remained relatively constant (DFO 2009a).

While there have been no studies on the levels of TBT in offshore areas of the Scotian Shelf, levels of TBT have been monitored in a variety of inshore areas across Canada. The most recent assessment of TBT in Canada's marine sediments and waters by Chau et al. (1997) found that despite the introduction of regulations restricting the use of TBT in Canada in 1989, TBT was found more frequently in marine waters and sediments in 1994 than it was in previous surveys conducted between 1982 and 1985, and in every case its concentration exceeded acute and chronic toxicity limits in water. About half of the sediment samples exceeded the limits (Chau et al. 1997; Maguire 2000). Based on conservative estimates of the rate of release from known sources between 1994 and 2000, Environment Canada (2009) concluded that the concentrations of TBT in water and sediments would be high enough to potentially harm organisms.

12.3.3.1 Marine Waters: Concentrations of many trace metals including iron, aluminum, manganese, cobalt, copper, cadmium, zinc and nickel vary with depth and between water masses on the Scotian Shelf (Bewers et al. 1976; Stoffyn 1984). Zinc, nickel, copper, cadmium and aluminum have low levels in the upper 30 m of the water column because they are incorporated into surface phytoplankton; and higher levels at 30 to 100 m depth where they are released from decomposing phytoplankton, and other organic matter (Ray and Bewers 1984; Stoffyn 1984; Stewart and White 2001). In general, metal concentrations in surface waters decrease east-to-west and north-to-south over the Scotian Shelf, as the Gulf of St. Lawrence and Labrador Current waters are diluted through mixing with other water masses (Stewart and White 2001). Surface waters of the Scotian Shelf having elevated primary productivity, such as the surface slope water that lies off the shelf edge, are likely to have lower metal concentrations because a greater quantity of metals are incorporated into biomass (Bewers et al. 1976; Stewart and White 2001).

Continental runoff does not appear to have much influence upon the distributions of trace metals on the Scotian Shelf, except for manganese which has increased concentrations nearshore (Bewers et al. 1976; Stewart and White 2001). The distributions of iron and manganese on the Scotian Shelf are strongly related to the distribution of suspended particulate matter, and their concentrations extracted from suspended matter are considerably higher than those in some underlying sediments (Bewers et al. 1976). Manganese is released into the water column as the result of chemical processes in offshore sediments, resulting in higher levels of particulate manganese in bottom waters than shallower waters (Bewers et al. 1976; Yeats and Bewers 1983; Stewart and White 2001).

Concentrations of trace metals in the water column have only been measured in specific locations of the Scotian Shelf, such as the Gully MPA (Stewart and White 2001). **Figure 12-4** shows the levels of dissolved copper, lead and zinc in the water column of the Scotian Shelf between 1985 and 2005. Levels of dissolved lead and zinc show a decreasing trend over this period, while levels of dissolved copper remained relatively constant (DFO 2009a). According to Fisheries and Oceans Canada (DFO 2009a), the decreases in dissolved lead across the Scotian Shelf are associated with a reduction in anthropogenic releases of lead into the atmosphere, including the elimination of lead from gasoline. Decreases in the industrial discharge of zinc into rivers are likely responsible for the decreasing trend in dissolved zinc.

The initial baseline survey for the SOEP measured particulate barium at five sites at the edge of Sable Island Bank adjacent to the Gully at levels below detections limits for the methods used (Yeats et al. 2008). A study of particulate trace metals (including aluminum, iron, manganese, lead, copper, vanadium and cobalt) on the Scotian Shelf found lower concentrations in all particle sizes in the upper 250 m of slope waters than in shelf waters (Weinstein and Moran 2004). The higher particulate metal concentrations in shelf waters are likely the result of an increased supply of these trace metals from continental sources. Levels of mercury measured at two sites on the Scotian Shelf in the early 1990s were similar to the levels found at two deep water sites in adjacent waters of the Northwest Atlantic (Dalziel 1992).

Breeze and Horsman (2005) prepared maps showing the average concentrations of dissolved cadmium and copper in surface waters of the Scotian Shelf in fall (**Figure 12-5**). Cadmium concentrations decrease with increasing salinity and increase with increasing phosphate concentration. Copper concentrations are high in fresh waters from both natural and anthropogenic sources and decrease in coastal waters with increasing salinity. At the northeastern end of the shelf, the maps show the influence of the input of cadmium and copper from the Gulf of St. Lawrence in the low salinity Nova Scotia Current. Local discharges along the Nova Scotia coastline also contribute to the increased levels of copper in this area. Copper concentrations on the eastern shelf are noticeably higher than those on the western shelf because of the magnitude of the Gulf of St. Lawrence freshwater discharge. Offshore concentrations of cadmium in the surface layer are very low because of the removal of phosphate and cadmium from oceanic surface waters by the growth and subsequent death and sinking of phytoplankton. No temporal trends in the concentration of cadmium or copper on the Scotian Shelf have been observed. The highest concentrations of cadmium observed on the shelf are less than half of the CCME guidelines for the protection of aquatic life (0.12 micrograms per litre). There are no CCME guidelines for dissolved copper at present.

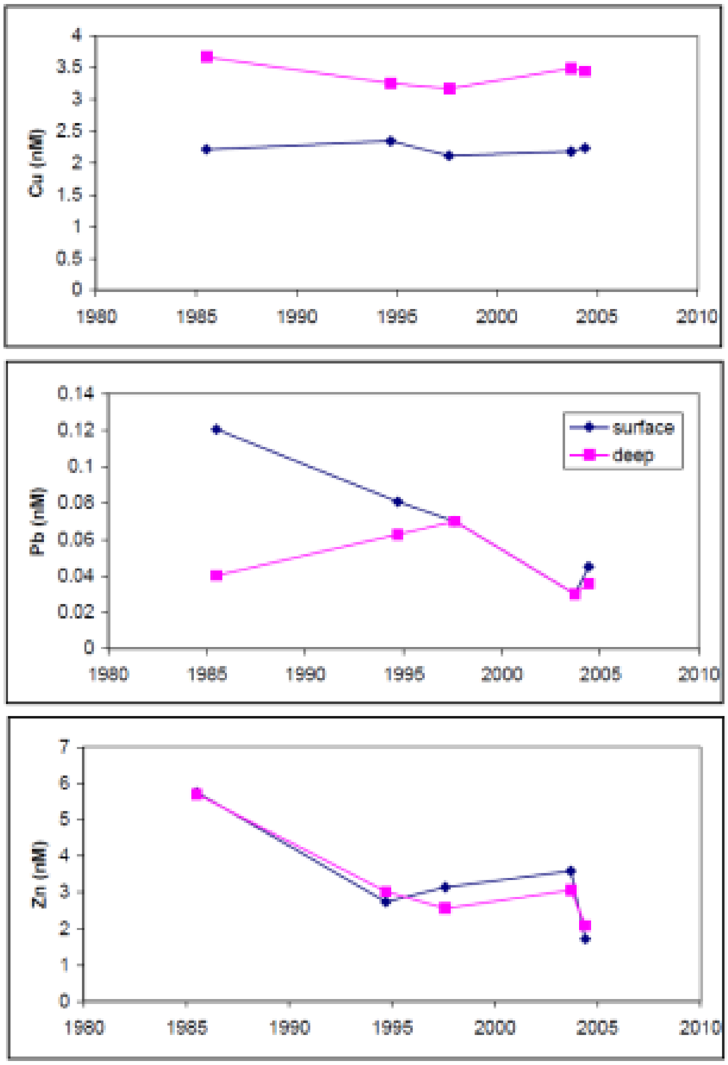
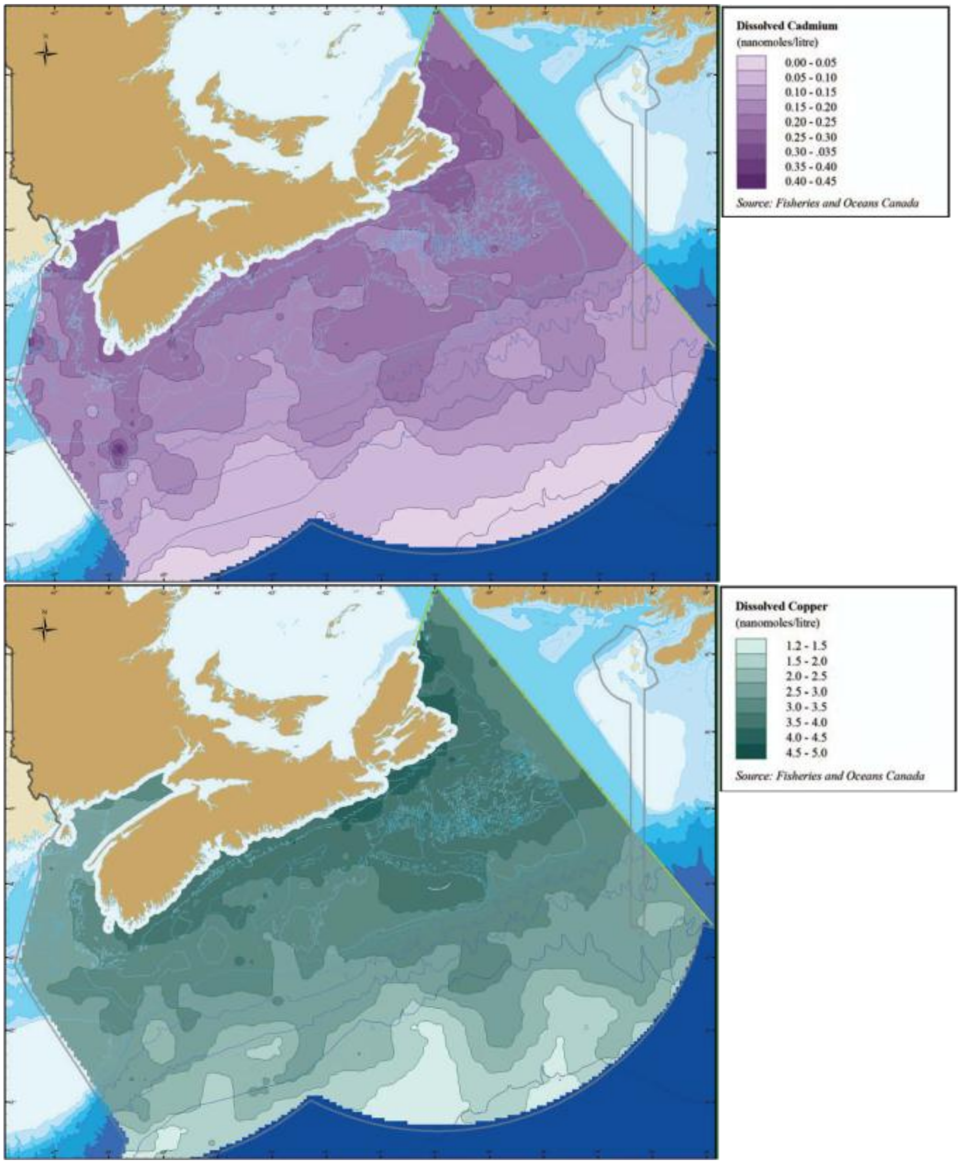


Figure 12-4: Levels of dissolved copper (Cu), lead (Pb) and zinc (Zn) in seawater on the Scotian Shelf, 1985–2005 (Source: Yeats et al. 2008).



Source: Fisheries and Oceans Canada

Source: Fisheries and Oceans Canada

Figure 12-5: Average concentrations of dissolved cadmium and copper in surface waters (0–25m) of the Scotian Shelf between September and December (1985–2005) (Source: Breeze and Horsman 2005).

12.3.3.2 Marine Sediments: Information about the concentrations of trace metals in offshore sediments is limited, but recent EEM programs associated with oil and gas developments and sediment sampling in the Gully MPA are helping to address this knowledge gap. Chromium, copper, iron, vanadium and zinc in sediments collected in and near the Gully MPA in 2006 and 2007 all show patterns that are indicative of natural concentrations (DFO 2009a). The concentrations of these metals along Sable Island Bank were lower than those for the deeper stations, but all are consistent with earlier observations for the Scotian Shelf. Elevated levels of barium and lead were observed in a small subset of samples on the eastern end of Sable Island Bank. Barium is a well-known tracer of drilling wastes and produced waters, and it is seen more frequently in sediments within a kilometre or so of drill sites. However, the source of the barium observed in these samples is uncertain as other metals associated with produced water and drilling wastes were not detected. The concentration of lead in nine samples from the finer-grained sediments collected deeper in the Gully also exceeded natural levels, but the potential source and transport pathway for lead into the Gully is not clear at present. Yeats et al. (2008) state that based on sediment sampling in the Gully MPA to date, the extent of metal contamination appears to be minor. They further state that sediments on the eastern end of Sable Island Bank have been much better sampled than the deeper areas, where contaminants may be accumulating.

Pre- and post-drilling sediment samples were collected from a well-site near Sable Island in 1982–83 and levels of trace metals were measured (Carter et al. 1985). Barium, copper, and mercury, possibly associated with the discharge of drilling wastes, showed post-drilling accumulations in sediments 0.5 nautical miles downcurrent from the well site. An accumulation of chromium, associated with the drilling discharges, was detected east of the well site. Metal accumulations in sediments were generally 2–3 times higher over predrilling levels at the sampling stations, with the exception of mercury levels which were 20 times higher in post-drilling sediments south of the well site. Overall, the levels of metals were low compared to levels in texturally equivalent Bay of Fundy sediments.

Sediment quality monitoring and toxicity testing conducted as part of the SOEP EEM between 1998 and 2007 consistently found all 24 metal chemical parameters unchanged from the 1998 baseline surveys with the exception of barium (CNSOPB 2011b). In 1999, barium levels were found to be above background levels at all platforms. Barium concentrations have been at baseline levels at the Venture platform from 2000 onward, and at the North Triumph platform from 2003 onward. Barium concentrations above background levels were still being detected out to 250 m at the Thebaud platform in 2007. Sampling sites on the western boundary of the Gully MPA have shown no elevated concentrations of barium since monitoring began in 1998.

Breeze and Horsman (2005) prepared maps showing the concentrations of chromium, copper, lead, and zinc in sediments of the Scotian Shelf (**Figure 12-6**). Since the background concentrations of most heavy metals in marine sediments increase with decreasing grain size of the sediments, the concentrations of these metals are highest in the shelf basins and along the continental slope where finer sediments are accumulating, and lowest along the coastline and on the offshore banks where coarser sediments are found (Breeze and Horsman 2005). The levels and distribution patterns of these four metals in sediments on the Scotian Shelf are described here.

Chromium: Levels of chromium in 283 of the 302 samples were at background concentrations (Breeze and Horsman 2005). Most of the samples that were above background concentrations were collected in the immediate vicinity of the Venture and South Venture offshore oil and gas platforms or in the vicinity of one of the exploratory drilling lease areas on the slope. Only two of the 302 samples, both collected in Emerald Basin (the largest depositional basin on the shelf), exceeded the CCME marine sediment quality guidelines threshold effects level (TEL). None of the samples are above the probable effects level (PEL).

Copper: Levels of copper in 97 of the 314 samples were at background concentrations, four were above background concentrations but below the CCME marine sediment quality guidelines TEL, 13 were above the TEL, and no samples were above the PEL (Breeze and Horsman 2005). The samples that are above background concentrations are located in Emerald Basin, three smaller basins on the eastern shelf and along the continental slope. None of the samples with elevated concentrations were associated with the Sable Island Bank offshore oil and gas locations or the pipeline corridor. The elevated levels of copper are likely the result of natural processes that generate larger gradients in copper concentrations between continental shelf and pelagic sediments.

Lead: Levels of lead in 265 of 303 samples were at background concentrations, 38 were above background concentrations, and none of the samples were above the CCME marine sediment quality guidelines TEL or PEL (Breeze and Horsman 2005). The observations of above-background concentrations are broadly distributed, including samples from Emerald Basin, the smaller basins on the eastern shelf, the pipeline corridor, the shelf break, and the immediate vicinity of the Sable Island Bank offshore gas production platforms.

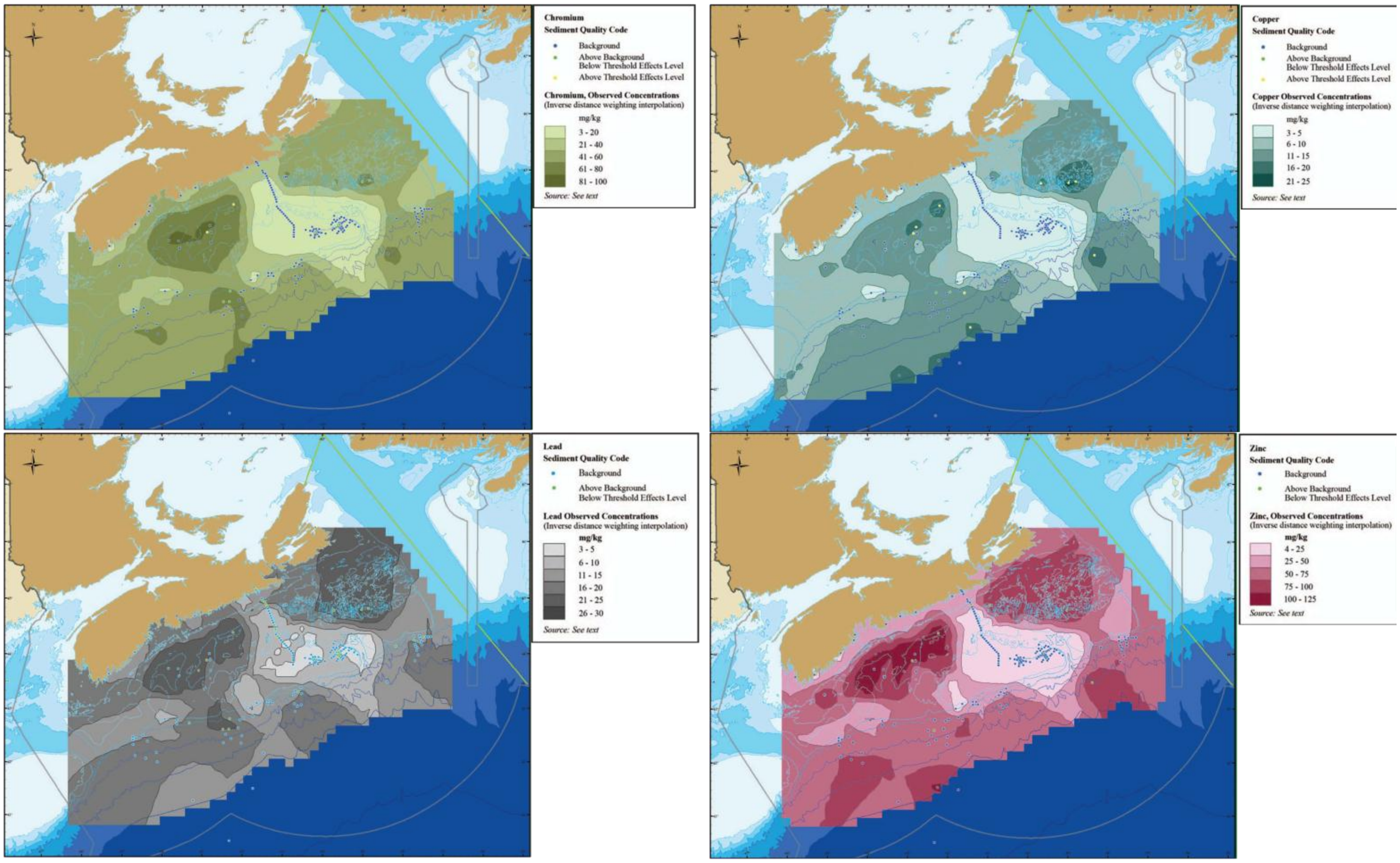


Figure 12-6: Concentrations of chromium, copper, lead and zinc in sediments of the Scotian Shelf (1970–2005) (Source: Breeze and Horsman 2005).

Zinc: Levels of zinc in 299 of 312 samples were at background concentrations, 13 were above background concentrations, and none were above the CCME marine sediment quality guidelines TEL or PEL (Breeze and Horsman 2005). The few above-background samples did not show a particular spatial pattern.

<u>12.3.3.3 Marine Biota</u>: Levels of trace metals in both pre- and post-drilling samples of scallop tissue were collected from a well-site near Sable Island in 1982–83 (Carter et al. 1985). Chromium and zinc had accumulated in scallop tissue at the well site and several nautical miles north and west of the well site, which suggests the influence of sacrificial zinc anodes at the well site and mud discharge at the more remote sites. There was no correlation of trace metal levels in

scallop tissue with those in the sediments. In the 1970s, total mercury levels in a range of fish species on the Scotian Shelf were relatively low, with the exception of offshore lobster and large fishes with long lifespans such as swordfish and some tunas, sharks, dogfish and large halibut (Beckett and Freeman 1974; Freeman et al. 1974; Zitko 1981). Levels of methylmercury (organic form of mercury) in a range of species from the Scotian Shelf were comparable to those in other uncontaminated marine areas (Freeman et al. 1974; Zitko et al. 1971; Stewart and White 2001).

Studies of shellfish from offshore areas of the Scotian Shelf found low levels of cadmium contamination, with the exception of sea scallops from Browns Bank and Georges Bank which had higher concentrations of cadmium than some contaminated coastal areas (Uthe et al. 1979; Uthe and Chou 1987; Stewart and White 2001). The total body burden of cadmium for similar sized scallops from Georges and Browns Banks ranged from 135 to 245 μg compared with only 71 μg for scallops from the Bay of Fundy; whereas levels of copper, lead, and zinc were not significantly different between the two regions (Ray et al. 1984). Since these offshore banks are far away from any known anthropogenic input of cadmium, Ray et al. (1984) suspected that the cadmium in these scallops came from natural sources.

In the 1970s, arsenic levels over 100 ug/g (wet weight) were detected in some fish products from the Scotian Shelf (Uthe et al. 1979). However, most of this arsenic was present in a less toxic, organic form. Levels of the more toxic, inorganic arsenic were below 0.5 μg/g and therefore did not pose a health risk to humans. Levels of both inorganic and the more toxic organic tetraethyl lead in these fish products were generally found to be low. Tetraethyl lead, an additive in gasoline, comprised a large proportion (9 to 91%) of the total lead content in the samples.

12.4 IMPACTS

Marine water and sediment quality on the Scotian Shelf has the potential to impact marine biodiversity and ecosystem function, human health, and economic activities such as commercial fisheries (see **Table 12-4**).

12.4.1 Biodiversity and Ecosystem Impacts

Elevated levels of contaminants in the marine environment could affect marine biodiversity and impair ecosystem function. Ross et al. (2007) state that the health of marine organisms can be affected as a result of (1) chronic exposure to contaminants; (2) toxic effects of contaminants on prey species; and (3) direct contaminant exposure (e.g., oil spills). Fish and invertebrates may be exposed to contaminants through both diet and gills, while marine mammals are exposed to environmental contaminants almost exclusively through dietary uptake

(with the exception of acute exposures such as oil spills) (Ross et al. 2007). Given the tendency of many contaminants to sorb to particulate matter and accumulate in sediments, sediments may act as long-term reservoirs of chemicals in the marine environment and represent a potentially significant hazard to the health of the organisms living in or having direct contact with contaminated sediments (CCME 1999). The effects of exposure to a chemical can be manifested at the cellular, organ, organism, population or community level (Pierce et al. 1998). Concentrations and health risks of environmental contaminants vary by trophic level in a food web, proximity to contaminant sources, and over time (Ross et al. 2007). Exposure to low concentrations of contaminants may rapidly harm or kill an organism, or cause chronic effects over time; while other contaminants may not cause adverse effects until they reach higher concentrations in an organism through bioaccumulation and biomagnification (Stewart and White 2001).

Overall, there is a lack of information about the biological effects of contaminants on marine biota in the Scotian Shelf region, but in most instances, levels of contaminants in the offshore do not appear to be high enough to cause any obvious or acute toxic effects (Zitko 1981; Addison 1984b; DFO 2009a). However, further research into the effects of observed contaminant levels on organisms, populations and communities is needed to assess the impact of contaminants on marine biodiversity and ecosystems (see *Marine Habitats and Communities*). The potential impacts of organochlorine compounds and other halocarbons, hydrocarbons and PAHs, and metals on marine biodiversity and the Scotian Shelf ecosystem are described here.

Table 12-4: Potential biophysical and socio-economic impacts of pressures on the marine water and sediment quality of the Scotian Shelf.

Element	Potential Impacts
Biophysical	
Biodiversity and Ecosystem Function	• Contaminants can cause a variety of lethal and sublethal effects in marine organisms including invertebrates, fish, seabirds, marine mammals, and species at risk. • Direct exposure to some contaminants can be lethal to some organisms (e.g., smothering and suffocation of seabirds during an oil spill). • Some contaminants have a tendency to bioaccumulate in marine organisms and biomagnify in marine food webs (e.g., PCBs, DDT, PBDEs, methylmercury), resulting in particularly high concentrations of these contaminants in higher trophic level organisms. • Some contaminants such as organochlorine compounds persist in the marine environment for long-periods and will cycle through marine food webs for decades and even centuries. • Environmental impacts may emerge as a result of the combined effects of multiple contaminants and other stressors on the Scotian Shelf ecosystem (cumulative impacts).
Socio-Economic	
Human Health	• Contaminated fish and fish products can pose a serious health risk to humans if consumed.
Economic Activities	• Economic losses to the fishing industry associated with market restrictions or consumption advisories for fish and fishery products. • Tainting (introducing an off-taste caused by the presence of contaminants) could reduce the marketability of fish and fishery products resulting in economic losses to the fishing industry. • Contaminants may impact the health and productivity of commercially valuable fish stocks (*Fish Stock Status and Commercial Fisheries*).

Organochlorine compounds and other halocarbons: These compounds pose a serious threat to marine water and sediment quality because they are highly toxic to marine biota, have a tendency to bioaccumulate in organisms and biomagnify in marine food chains (due to their high lipid solubility), and persist for long periods in the environment. For example, concentrations of PCBs can increase by factor of 10 to 100 times when proceeding upward on major trophic levels (e.g., plankton to fish to birds), and fish-eating birds may have levels of DDT about 30 to 100 times greater than those of their prey (Kennish 1997). Some organochlorine compounds, including PCBs and dioxins and furans, have a tendency to sorb to and accumulate in marine sediments and therefore pose a chronic health risk to benthic organisms. A number of organochlorine compounds have been detected in a variety of marine organisms on the Scotian

Shelf (e.g., Zitko et al. 1974; Addison and Stobo 2001; Stewart and White 2001; Hooker et al. 2008; DFO 2009a). However, the biological effects of these contaminants are largely unknown and additional research in this area is needed (DFO 2009a).

Hydrocarbons and PAHs: The effects of oil pollution on marine organisms depends on a range of factors including the nature of the discharge or spill, the volume of oil, the type and state of oil, the treatments and dispersants used in cleanup operations, environmental conditions, and characteristics of the biological communities involved (Baker 1978). Lethal and sublethal effects of oil contamination are manifested in both acute and chronic responses of marine organisms (Kennish 1997). Oil spills can have immediate lethal effects on organisms that become trapped in the oil through smothering and suffocation. Organisms that become coated in oil may lose normal physiological or behavioural function and be predisposed to greater long-term risk of death as a result. Sublethal effects of oil pollution can impact marine communities by adversely affecting reproduction, growth, distribution, and behaviour of organisms resulting in gradual shifts in species composition, abundance, and diversity (Kennish 1997; see *Marine Habitats and Communities*).

PAHs have a tendency to bioaccumulate in marine fish and invertebrates, but do not appear to biomagnify in aquatic food chains (Environment Canada and Health Canada 1994; Kennish 1997). These compounds also accumulate in sediments and pose a chronic threat to benthic organisms with limited mobility. PAHs are not acutely toxic to marine organisms, but may result in a variety of sublethal effects and have also been linked to the occurrence of cancers (Eaton et al. 1984; Kennish 1997).

Zwanenburg et al. (2006) note that hydrocarbons produced on the Scotian Shelf are either light condensate or natural gas, which pose less risk to the marine environment than crude oil. Surveys conducted under the Cohasset-Panuke Project (COPAN) and Sable Offshore Energy Project (SOEP) EEM programs suggest that offshore oil and gas activities have had little to no impact on benthic communities, fish health, or seabird populations (CNSOPB 2011b). However, it is estimated that ship-source oil pollution results in the oiling of thousands of seabirds in the Scotian Shelf region each year, and the number of oiled seabirds in the region increased 3.2% annually between the early 1970s and 2000 (Yeats 2000; Coffen-Smout et al. 2001; DFO 2009a).

Metals: The harmful effects of metals on marine organisms stem from their ability to impair enzyme function and ion exchange processes which, in extreme cases, can impact all physiological processes of an exposed organism (Ray and Bewer 1984; Stewart and White 2001). With the exception of methylmercury—the organic forum of mercury—there is little evidence for the biomagnification of metals in marine food webs (Kennish 1997). Marine organisms at higher trophic levels often have concentrations of methylmercury several orders of magnitude greater than organisms at lower trophic levels. While inorganic mercury is the dominant form in sediments, a significant amount of mercury accumulating in the tissues of benthic invertebrates (40–90%) and fish (>90%) is methylmercury (Kennish 1997). Marine mammals accumulate large quantities of mercury, but they rarely display harmful effects of the contaminant. In terms of other metals, organotin compounds have been shown to accumulate in higher trophic level organisms such as marine mammals, but do not biomagnify in marine food webs (Kennish 1997).

Only rarely have concentrations of any metal on the Scotian Shelf exceeded "safe" limits for the functioning of the marine ecosystem as regulated by law (Stewart and White 2001). Copper is very toxic to many planktonic organisms and concentrations on the eastern Scotian

Shelf may be high enough to limit the growth of certain copper-sensitive species (Breeze and Horsman 2005; see **Figure 12-4** above).

While most studies focus on the biological effects of a particular contaminant, there are numerous contaminants in the marine environment and it is not uncommon for multiple contaminants to be present in an individual organism, population, or community (e.g., Addison and Stobo 1993, 2001; Addison et al. 1998). However, the cumulative effects of multiple contaminants on marine biodiversity and ecosystems are poorly understood and may be significant. In addition, some environmental impacts may emerge as a result of the combined effects of all past and present natural and human stressors (Coffen-Smout et al. 2001; Crain et al. 2008). Therefore, the combined effects of contaminants and other stressors (see *Climate Change and its Effects on Ecosystems Habitats and Biota*; *Fish Stock Status and Commercial Fisheries*; *Incidental Mortality; Marine Waste and Debris; Invasive Species; Ocean Acidification*) may result in cumulative impacts on the Scotian Shelf ecosystem. The cumulative effect of multiple stressors on ecological communities remains largely unknown (Crain et al. 2008).

12.4.2 Human Health

The main impact of marine water and sediment quality on human health is the potential for acute or chronic health effects resulting from the consumption of contaminated seafood. The action and tolerance levels set by Health Canada and the CFIA for various contaminants in fish and fish products is shown in **Table 12-5**. Seafood contaminated with mercury is a major public health concern because exposure to elevated levels of mercury may result in serious health problems and even death in cases of extreme poisoning (Health Canada 2009a). Environment Canada (2006a) states that POPs can trigger a range of subtle effects on human health, even at the generally low concentrations found in the environment. A growing body of scientific evidence associates human exposure to individual POPs with cancer, diabetes, neurological disorders, reproductive disorders, immune system dysfunction, and other health effects. For most people, about 90% of overall exposure to POPs is through foods rich in animal fat, such as meats, fish, and dairy products. People are exposed to multiple POPs during their lifetime and most people today carry detectable background levels of a number of POPs in their bodies.

Table 12-5: Action and tolerance levels for contaminants in fish and fish products (Sources: CFIA 2005; CFIA 2011; Health Canada 2011).

Contaminant	Action or Tolerance Level
DDT and Metabolites (DDD and DDE)	> 5 ppm
Polychlorinated Biphenyls (PCBs)	> 2 ppm
Dioxin	> 0.0002 ppm
Mercury	> 1.0 ppm for the edible portion of escolar, orange roughy, marlin, fresh and frozen tuna, shark, and swordfish > 0.5 ppm for the edible portion of all other retail fish
Mirex	> 0.1 ppm
Polycyclic Aromatic Hydrocarbons (PAHs)	> 0.003 ppm benzo(a)pyrene toxic equivalents
Arsenic	> 3.5 ppm
Lead	> 0.5 ppm

Levels of contaminants in fish products from offshore areas of the Northwest Atlantic are usually well within ranges acceptable from public health reasons and only rarely have concentrations of any contaminant exceeded “safe” limits for human consumption as regulated by law (Addison 1984b; Stewart and White 2001). In the early 1970s, the sale of swordfish for human consumption was banned in Canada until 1979 after levels of mercury in the species exceeded the regulatory limits at the time of 0.5 parts per million (ppm) for total mercury (Freeman et al. 1974; Stewart and White 2001). The mercury found in the swordfish was thought to be mostly of natural origin. A 2002 survey measured levels of mercury, dioxins, furans, PCBs and PBDEs in fish and seafood products sold at the retail level in Vancouver, Toronto and Halifax (Health Canada 2004a). Based on the results of this study, Health Canada concluded that the levels of dioxins, furans, PCBs and PBDEs in fish and seafood products do not pose a health risk to Canadians. Average total mercury levels in the predatory fish samples were again above the Canadian standard, ranging from 0.930 ppm for fresh/frozen tuna to 1.820 ppm for swordfish. Average methylmercury levels in the predatory fish ranged from 0.489 ppm for marlin to 1.080 ppm for swordfish. Due to these elevated levels of mercury, Health Canada advises Canadians to limit their consumption of predatory fish such as shark, swordfish, and fresh and frozen tuna (Health Canada 2009a). Shark, swordfish, and fresh and frozen tuna sold commercially in Canada are now exempted from the 0.5 ppm guideline set for all other domestically produced and imported fish, and instead have an action level of 1.0 ppm (Health Canada 2004b; CFIA 2005).

12.4.3 Economic Impacts

The main economic impact of marine water and sediment quality is the potential for contaminated seafood to affect the commercial fishing industry. Market restrictions and consumption advisories associated with contaminated fish and fishery products (e.g., the ban on the sale of swordfish in the 1970s, and Health Canada’s current advisory regarding mercury levels in predatory fish) may lead to economic losses for the fishing industry. High levels of contaminants can cause a number of lethal and sublethal health effects in commercial fish stocks, such as the potential for PCBs to cause detrimental effects on the physiology of Atlantic cod (Zitko 1981; Freeman et al. 1982). Overall, the levels of contaminants in fish and fish products from offshore areas of the Scotian Shelf are usually well within ranges acceptable from public health reasons and do not appear to be high enough to cause any obvious or acute toxic effects (Zitko 1981; Addison 1984b; DFO 2009a).

Another potential economic impact of marine environmental quality on the fishing industry is the tainting (introducing an off-taste caused by the presence of contaminants) of fish and seafood products which reduces its marketability (Stewart and White 2001). Tainting studies conducted as part of the COPAN and SOEP EEM programs found only one instance of tainting since 1998 (CNSOPB 2011b). In that case, tainting effects were observed in Jonah crabs collected directly from the SOEP platform structure.

12.5 ACTIONS AND RESPONSES

Management actions and responses to marine water and sediment quality include legislation and policy, and scientific research and monitoring.

12.5.1 Legislation and Policy

There are numerous conventions, legislation, regulations and policies related to marine water and sediment quality on the Scotian Shelf (**Table 12-6**).

One of the main tools for managing POPs in the environment is the *Stockholm Convention on Persistent Organic Pollutants* (Stockholm Convention) that entered into force in

2004. Initially, the convention aimed to eliminate or restrict the production and use of twelve POPs, known as the "dirty dozen", that were recognized as causing adverse effects on humans and the ecosystem. These chemicals included many of the dominant organochlorine contaminants in the marine environment such as DDT, PCBs, and dioxins/furans. In 2009, nine new POPs were listed under the convention including alpha- and beta- HCH, lindane, and some PBDE compounds. As of January 2012, there were 177 parties to the convention. Canada was the first country to sign and ratify the convention in 2001. The Government of Canada released a national implementation plan in 2006 to inform the public about how the obligations of the Stockholm Convention will be implemented in Canada (Environment Canada 2006a). As a result of domestic actions taken from the 1970s through the 1990s, there are no stockpiles of POP pesticides in Canada and the majority of POPs entering Canada's environment now come from foreign sources. In 1990, dioxins and furans were declared toxic under the *Canadian Environmental Protection Act* and in 1992, regulations were developed for these substances in liquid effluent discharged from pulp and paper mills. As a result of these regulations and complementary regulations at the provincial level, releases of dioxins/furans to the aquatic environment were reduced by more than 99% by 1997 (Environment Canada 2006a).

Table 12-6: Key conventions, legislation, regulations and policies related to marine water and sediment quality on the Scotian Shelf.

Legislative or Policy Instrument	Purpose/Function	Comments
International Conventions		
Stockholm Convention on Persistent Organic Pollutants (2004)	• International treaty to protect human health and the environment from POPs	Signed and ratified by Canada in 2001.
Geneva Convention on Long-range Transboundary Air Pollution (1979) and associated protocols	• Limit and gradually reduce and prevent air pollution including long-range transboundary air pollution • Specific protocols to address POPs, heavy metals, and volatile organic compounds	Canada signed the convention in 1979 and ratified it in 1981.
International Convention for the Prevention of Pollution from Ships (MARPOL) (1973)	• Main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes	Managed through the International Maritime Organization. Canada has been a member since 1948.
International Convention on the Control of Harmful Anti-fouling Systems on Ships	• Prohibits the use of harmful organotins (e.g., TBT) in antifouling paints used on ships and will establish a mechanism to prevent the potential future use of other harmful substances in anti- fouling systems	Managed through the International Maritime Organization. Canada has been a member since 1948.
Federal and Provincial Legislation and Regulations		
Fisheries Act	• Section 36 of the Act includes provisions designed to prevent pollution of fish habitat and prohibits the deposit of "deleterious substances" into water frequented by fish or in a place where these substances may enter water frequented by fish	Section 36 of the Act is administered by Environment Canada.
Pulp and Paper Effluent Regulations (*Fisheries Act*)	• Regulates the discharge of effluent from pulp and paper operations	Administered by Environment Canada.
Metal Mining Effluent Regulations (*Fisheries Act*)	• Regulates the discharge of effluent from metal mining operations	Administered by Environment Canada.

Legislative or Policy Instrument	Purpose/Function	Comments
Petroleum Refinery Liquid Effluent Regulations (*Fisheries Act*)	• Regulates the discharge of liquid effluent from petroleum refineries	Administered by Environment Canada.
Canadian Environmental Protection Act (CEPA)	• Controls substances determined to be "toxic" and specifies time frames for developing and implementing preventive or control measures • Requires the "virtual elimination" of releases of the most dangerous toxic substances to the environment • Provides the authority to issue non-regulatory objectives, guidelines and codes of practice to prevent and reduce marine pollution from land-based sources	Administered by Environment Canada and Health Canada.
Disposal at Sea Regulations (CEPA)	• Restricts the disposal of wastes and other matter at sea within Canadian jurisdiction and by Canadian ships in international waters and waters under foreign jurisdiction	Administered by Environment Canada and Health Canada.
Persistence and Bioaccumulation Regulations (CEPA)	• Outlines criteria for determining whether a substance is "persistent" and "bioaccumulative" under CEPA	Administered by Environment Canada and Health Canada.
Prohibition of Certain Toxic Substances Regulations (CEPA)	• Prohibits and/or regulates the manufacture, use, sale, and import of certain toxic substances including DDT	Administered by Environment Canada and Health Canada.
Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations (CEPA)	• Prohibits the release of dioxins/furans in effluent from pulp and paper operations	Administered by Environment Canada and Health Canada.
PCB Regulations (CEPA)	• Regulates the use and release of PCBs into environment	Administered by Environment Canada and Health Canada.
Canadian Environmental Assessment Act (CEAA)	• Outlines requirements and process for environmental assessments in Canada	Administered by the Canadian Environmental Assessment Agency.
Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Acts (Accord Acts)	• Establishes the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) as the agency responsible for the regulation of petroleum activities in the Nova Scotia offshore area, including the protection of the environment during all phases of offshore petroleum activities	Administered by the CNSOPB.
Canada Shipping Act	• Regulates shipping and navigation	Administered by Transport Canada.
Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals (*Canada Shipping Act*)	• Establishes regulations to prevent the release of pollutants (e.g., oil, TBT) from ships into the marine environment	Administered by Transport Canada.
Nova Scotia *Environment Act*	• Regulates the release of substances into the environment; the use, sale, storage, and handling of dangerous goods, waste dangerous goods, and pesticides; and the management of contaminated sites in the Province of Nova Scotia	Administered by Nova Scotia Environment.

Legislative or Policy Instrument	Purpose/Function	Comments
Nova Scotia PCB Management Regulations (NS *Environment Act*)	- Regulates the use, storage and disposal of PCBs in the Province of Nova Scotia	Administered by Nova Scotia Environment.
Nova Scotia Pesticides Regulations (NS *Environment Act*)	- Regulates the sale, use, storage, and disposal of pesticides; and restricts the use of non-essential pesticides in the Province Nova Scotia	Administered by Nova Scotia Environment.
Nova Scotia Emergency Spill Regulations (NS *Environment Act*)	- Outlines reporting requirements and the powers of an emergency responder during an environmental emergency and/or unauthorized releases of a contaminants in the Province of Nova Scotia.	Administered by Nova Scotia Environment.
Federal and Provincial Policies, Plans, Strategies and Guidelines		
Canada's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants	- Plan to inform the public about how the obligations of the Stockholm Convention will be implemented in Canada	Administered by Environment Canada.
Chemicals Management Plan	- Immediate action on chemicals of high concern - New regulatory activities for chemicals - New investment in research and monitoring	Administered by Environment Canada and Health Canada
Toxic Substances Management Policy (TSMP)	- Requires the "virtual elimination" of releases of the most dangerous toxic substances to the environment	Administered by Environment Canada.
Canadian Council of Ministers of the Environment (CCME) Environmental Quality Guidelines	- Provide nationally endorsed science-based goals for the quality of atmospheric, aquatic, and terrestrial ecosystems	Administered by the CCME.
CNSOPB Offshore Waste Treatment Guidelines	- Guidelines for operators in the management of waste material associated with petroleum drilling and production operations in offshore areas	Administered by the CNSOPB.
National Policy on Oiled Birds and Oiled Species at Risk	- Specifies roles and approaches to be taken by the Canadian Wildlife Service (CWS) in the event of an oil spill, the presence of oiled migratory birds or oiled listed species at risk	Administered by the CWS.

In 1995, the Government of Canada introduced the *Toxic Substances Management Policy* (Environment Canada 1995). The Policy puts forward a preventive and precautionary approach to deal with substances that enter the environment and could harm the environment or human health. The key objectives of the Policy are (1) the virtual elimination of toxic substances that result predominantly from human activity and that are persistent and bioaccumulative from the environment; (2) management of other toxic substances and substances of concern, throughout their entire life cycles, to prevent or minimize their release into the environment.

In 2006, the Government of Canada introduced the *Chemicals Management Plan* (Government of Canada 2011). The Plan includes three key elements: (1) immediate measures to reduce risks to human health and the environment of approximately 200 chemicals identified as high priority for action; (2) new regulatory activities targeted at food, cosmetics, drugs, and pesticides as well as 160 chemicals used in the petroleum sector; and (3) new investment in research and monitoring including an ecological monitoring program that will also serve as an "early warning" system for harmful substances in the ecosystem.

The *Canadian Environmental Protection Act* (CEPA 1999) is one of the main legislative tools in Canada for preventing pollution and protecting the environment and human health. CEPA incorporated the policy directives of the Toxic Substances Management Policy into the relevant legislative requirements of the Act, and implementing CEPA has become the primary vehicle for the implementation of the Policy. CEPA requires the virtual elimination[24] of certain toxic substances, including those that are persistent and bioaccumulative (CEPA 1999; Environment Canada 2006a). For all substances on the Virtual Elimination List, CEPA requires the development of a regulation that sets the quantity or concentration of a substance that may be released into the environment. To date, only two substances (hexachlorobutadiene and perfluorooctane sulfonate and its salts) have been added to this list. Under CEPA, approximately 23 000 substances manufactured, imported, or used in Canadian commerce were categorized based on the risks they pose to the environment or human health. In addition, new substances are required to be evaluated for risks to the environment and human health before they are used in Canadian commerce. A number of regulations relevant to the management of toxic substances have been introduced under CEPA (see **Table 12-6** above).

The *Fisheries Act* provides the legal framework for regulating impacts on fish and fish habitat associated with works, undertakings, operations and activities occurring in or around fresh or marine waters throughout Canada. Section 36 of the *Fisheries Act* prohibits the deposit of "deleterious substances" into water frequented by fish, or in a place where it may enter fish-bearing waters, without an authorization from the Minister or by regulation. This applies to works or undertakings in the offshore areas of the Scotian Shelf (e.g., exploratory wells, pipelines). Although Fisheries and Oceans Canada (DFO) is the lead agency for ad-ministering the *Fisheries Act*, Environment Canada administers the pollution prevention provisions of the Act. During the course of emergency situations, such as spills and other abnormal deposits, Environment Canada's Environmental Emergencies Program provides environmental and technical advice to polluters, organizations and other levels of government; and employs several measures to ensure the protection of the aquatic environment (DFO 2003). Environment Canada's Enforcement Program aims to secure compliance with all acts that the department administers, including the pollution prevention provisions of the *Fisheries Act*. A number of regulations relevant to pollution prevention and the release of deleterious substances have been introduced under the *Fisheries Act* (see **Table 12-6** above).

Development proposals and offshore oil and gas activities are subject to the regulations outlined in the *Canadian Environmental Assessment Act* (CEAA). DFO's Habitat Management Program is responsible for assessing proposed activities in offshore areas which could result in the harmful alteration, disruption or destruction (HADD) of fish habitat. Environment Canada's Environmental Assessment Program is responsible for assessing proposed activities in offshore areas which could result in the release of a deleterious substance into fish-bearing waters. Environmental assessments are required before any proposed offshore petroleum related work or activity can be authorized by the CNSOPB. Under the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Acts (Accord Acts), the CNSOPB is responsible for ensuring the protection of the environment during all phases of offshore petroleum activities.

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[24] The term "virtual elimination" is defined as "the reduction of a toxic substance released into the environment to a quantity or concentration below that which can be accurately measured using sensitive but routine sampling and analytical methods" (Environment Canada 2006).

The International Convention for the Prevention of Pollution from Ships (MARPOL 1973/78) and the associated Protocol of 1978 is the main international convention covering prevention of pollution of the marine environment by ships. MARPOL includes regulations aimed at preventing and minimizing pollution from ships including both accidental pollution and that from routine operations (MARPOL 1973/78). Canada is a contracting party to MARPOL. In Canada, the *Canada Shipping Act* (CSA 2001) is the principal legislation governing protection of the marine environment from marine transportation. It applies to Canadian vessels operating in all waters and to all vessels operating in Canadian waters. The Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals under the CSA are designed to eliminate the deliberate, negligent, or accidental discharge of ship-source pollutants into the marine environment (Transport Canada 2010).

The CCME's *Environmental Quality Guidelines* provide nationally endorsed science-based goals for the quality of atmospheric, aquatic, and terrestrial ecosystems (CCME 1999). The Environmental Quality Guidelines include water and sediment quality guidelines for the protection of aquatic life. These guidelines are intended to provide protection for aquatic life and all aspects of the aquatic life cycles from anthropogenic stressors such as chemical inputs or changes to physical components (CCME 1999). The CCME Guidelines are numerical limits or narrative statements based on the most current, scientifically-defensible toxicological data available for a range of parameters and toxic substances. The CCME Guidelines for the protection of aquatic life are based on rigorous analysis of safe concentrations of a single contaminant in the environment which will allow organisms to complete their whole life cycle (DFO 2009a). According to DFO (2009a), a major limitation to this approach is that it does not allow for multiple exposures to the suite of contaminants an organism may encounter in the marine environment; therefore, species or community- level indicators may be more effective measures of environmental quality.

12.5.2 Scientific Research and Monitoring

DFO conducts research on toxic chemicals to identify the biological impact of toxic chemicals on aquatic ecosystems and to gain a better understanding of how these changes are reflected in the health of fishery resources (DFO 2011a). This research is used to provide scientific advice in regulatory and policy decision-making processes. Examples of current research by DFO on toxic chemicals include ecosystem assessment of marine environmental quality, and the use of health tracers to study the effects of toxic chemicals on marine mammals.

DFO operates two Laboratories of Expertise in Aquatic Chemical Analysis (LEACA): the Institute of Ocean Sciences in Sidney, British Columbia and the Maurice Lamontagne Institute in Mont-Joli, Quebec (DFO 2011b). The Pacific Region laboratory specializes in high resolution organic chemical analysis, testing for contaminants such as dioxins, furans, PCBs and PBDEs; while the Quebec Region laboratory specializes in inorganic chemical analysis, testing for metals such as lead, arsenic and mercury, and in low-resolution organic chemistry. At the LEACAs, contaminants in aquatic environments are measured, identified and monitored to allow DFO scientists to understand their evolution and dispersion and how they affect ecosystems and marine organisms. In 2002, DFO established the Centre for Offshore Oil, Gas and Energy Research (COOGER) in Dartmouth, Nova Scotia to coordinate the department's nation-wide research into the environmental and oceanographic impacts of offshore petroleum exploration, production and transportation (DFO 2011c).

Since 1998, DFO has conducted a number of studies and reviews of contaminants on the Scotian Shelf and Sable Island Bank (DFO 2009a). Existing information on contaminant monitoring that has been conducted in the vicinity of the Gully MPA was compiled in DFO (2009a) to provide guidance on future monitoring of contaminants and their biological effects in the Gully MPA (**Figure 12-7**). The report concludes that measurements in the Gully MPA of contaminants in biota and their associated biological effects are very limited and contradictory, and that very little can be concluded about the accumulation of contaminants or their potential for causing effects without additional research (DFO 2009a). The report also identifies a number of potential indicator species that could be used to measure contaminants and their biological effects in the Gully MPA.

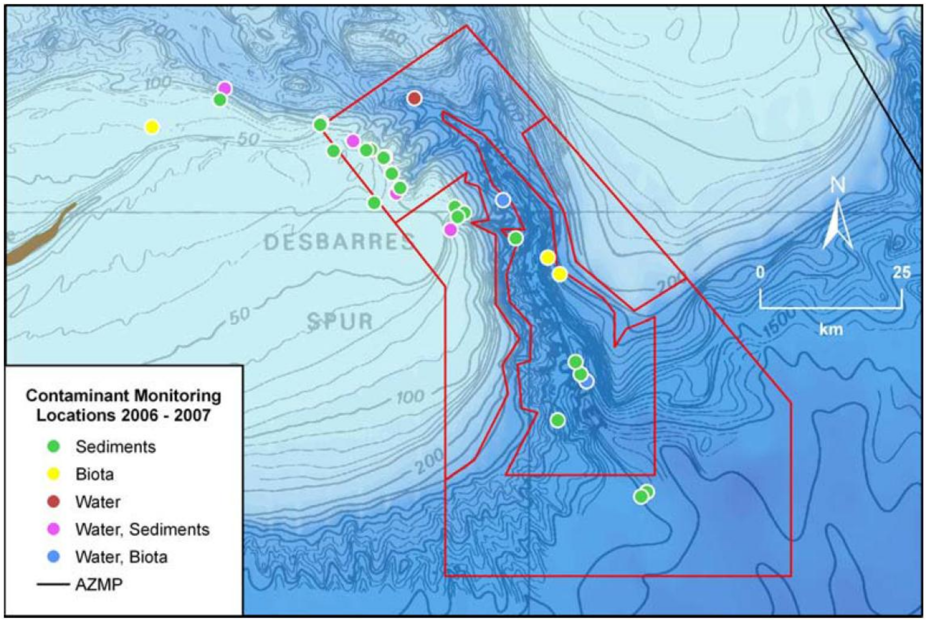

Figure 12-7. Map showing contaminant sampling locations in the Gully MPA (Source: DFO 2009a).

Environment Canada and DFO maintain several databases of information about pollutant releases, toxic contaminants in the marine environment, and marine biological and chemical samples:

National Pollutant Release Inventory (NPRI): The NPRI is Canada's legislated, publicly accessible inventory of pollutant releases to air, fresh and marine waters, and land. It is used to identify pollution prevention priorities, support the assessment and risk management of chemicals, develop targeted regulations for reducing releases of toxic substances and air pollutants, encouraging actions to reduce the release of pollutants into the environment; and improving public understanding. For more information visit: http://www.ec.gc.ca/inrp-npri/default.asp?lang=En&n=4A577BB9-1.

National Contaminants Information System (NCIS): The NCIS is a regionally distributed national database of information on toxic chemicals in fish, other aquatic life and their habitats. The purpose of the NCIS is to collect, store, and provide information on the toxic contaminants data holdings of DFO. For more information visit: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/ncis-snic/index-eng.htm.

Biological and Chemical Database (BioChem): BioChem is a national DFO repository for biological and chemical marine environmental sample measurements to help monitor climate change. BioChem’s archived data cover the North Atlantic between 1921 and the present. For more information visit: http://www.meds-sdmm.dfo-mpo.gc.ca/BioChem/biochem-eng.htm.

Environmental Effects Monitoring (EEM) programs for offshore oil and gas activities are a requirement for offshore oil and gas projects approved by the CNSOPB. EEM programs involve scientific monitoring of the effects of production and exploration activities on specific components of the surrounding environment (CNSOPB 2011b). The results of the EEM program provide knowledge for the implementation of management strategies that identify and mitigate the effects of oil and gas activities on the ecosystem.

Through the Total Diet Study (TDS), Health Canada regularly monitors foods to ensure that chemicals are not present in foods at levels that would pose an unacceptable health risk to Canadians (Health Canada 2009b). The TDS provides estimate levels of exposure to chemicals that Canadians in different age-sex groups accumulate through the food supply.

12.6 INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT	TREND
Quantities of organochlorine compounds and other halocarbons, hydrocarbons and PAHs, and metals released into the marine environment from various sources	Water and sediment quality	Pressure	Unknown	?
Concentrations of organochlorine compounds and other halocarbons in marine biota, and fish and fish products relative to national standards, guidelines, and/or known background concentrations	Water and sediment quality, biodiversity and ecosystem impacts, human health, economic impacts	State	Fair	/
Concentrations of metals in marine biota, and fish and fish products relative to national standards, guidelines, and/or known background concentrations	Water and sediment quality, biodiversity and ecosystem impacts, public health, economic impacts	State	Good	/
Concentrations of hydrocarbons and PAHs in the water column relative to national guidelines and/or known background concentrations	Water quality	State	Good	/
Concentrations of metals in the water column relative to national guidelines and/or known background concentrations	Water quality	State	Good	/
Concentrations of hydrocarbons and PAHs in marine sediments relative to national guidelines and/or known background concentrations	Sediment quality	State	Good	/
Concentrations of metals in marine sediments relative to national guidelines and/or known background concentrations	Sediment quality	State	Good	/
Number of consumption advisories due to contaminated fish and fish products	Public health, environmental protection and regulation	Actions and Responses	Good	/
Number of banned and regulated chemicals and substances	Public health, environmental protection and regulation	Actions and Responses	Good	+

[1] Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.

[2] Trend: is is positive or negative in terms of implications for the state of the environment? It is not the direction of the indicator, although it could coincide with the direction of the indicator.

Key:

Negative trend: - Positive trend: + Unclear or neutral trend: / No assessment due to lack of data: ?

Data Confidence

- Reliable data on the concentrations of some organochlorine compounds (i.e., ∑DDT, PCBs) in marine biota on the Scotian Shelf from studies conducted during the 1970s and early 1980s.
- Recent studies have provided data on contaminants (i.e., metals, hydrocarbons) in sediments and biota in The Gully Marine Protected Area.
- Environmental Effects Monitoring (EEM) programs on the Scotian Shelf provide data on the effects of contaminants (i.e., metals, hydrocarbons) from offshore oil and gas activities on nearby marine waters, sediments, and biota.
- Some regulations require monitoring and reporting of spills and pollutant releases from offshore oil and gas activities, marine shipping, and land-based industrial activities.
- Health Canada regularly monitors contaminant levels in Canadian fish and fish products for public safety.
- Health Canada and Environment Canada assess the risks posed by conventional and emerging contaminants to human health and the environment.

Data Gaps

- Data on conventional marine contaminants (e.g., DDT and PCBs) are largely outdated and may not reflect current conditions on the Scotian Shelf.
- Emerging contaminants (e.g., brominated flame retardants, chlorinated paraffins, perfluorinated compounds) have not been monitored or assessed on the Scotian Shelf.
- The ecological impacts of contaminants on marine organisms, communities, and the Scotian Shelf ecosystem are largely unknown.

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13. OCEAN NOISE[25]

Danny Walmsley, Environmental Science Program, St. Mary's University, Halifax, NS
Jim Theriault, Defence R&D Canada Atlantic, Dartmouth, NS

13.1 ISSUE IN BRIEF

There is increasing international concern about the extent to which anthropogenic noise is impairing the quality of the marine environment for animals that make use of sound as a key sensory tool for survival issues such as prey detection, predator evasion, reproduction, communication, echolocation, and orientation (McCarthy 2004. IMO 2004; IUCN 2004, International Fund for Animal Welfare 2008; OSPAR Commission 2009; see **Figure 13-1**). The Scotian Shelf is an active economic area and there are many sectors (e.g., shipping, commercial fishing, oil and gas, defence force, construction, marine scientific research, and tourism) that contribute to ocean ambient noise on a constant or intermittent basis. Shipping, and its associated machinery, appears to be the major consistent contributor to low-frequency ambient noise on the Scotian Shelf as sound profiles in the offshore zone are indicative of high-density shipping (Zakarauskas et al. 1990; Pecknold et al. 2010). Studies indicate that, at frequencies dominated by shipping noise, background noise levels are up to 40 dB higher than noise levels generated by strong winds. Whilst there have been no definitive noise-impact research studies on the Scotian Shelf, comparable global literature indicates that there are numerous potential impacts that might adversely influence its resident and migratory marine animals. Depending on the species, and their proximity and length of exposure to various sound sources, the potential impacts on marine animals include, amongst others: mortality, physiological damage, behavioural changes, loss of hearing capabilities, masking, and area avoidance (DFO 2004; Worcester 2006; Payne et al. 2008). There are international governmental initiatives underway aimed at developing workable regulations and protocols to reduce noise in the marine environment. The main aspects which are being given attention include reductions in undesirable noise from shipping, seismic exploration, sonar, and tourist activities. Canadian regulations and policies are in place for seismic exploration, sonar, and whale watching on the Scotian Shelf (Theriault et al. 2005).

Linkages

This theme paper also links to the following theme paper:
- At Risk Species

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[25] Completed June 2011.

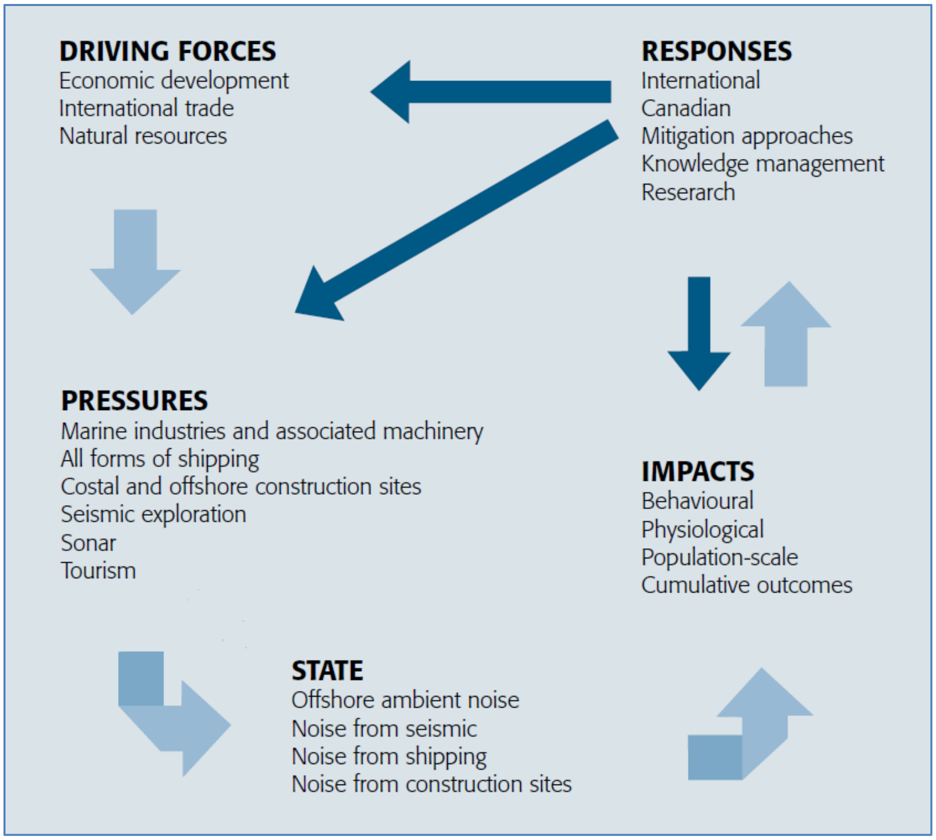

Figure 13-1: Driving forces, pressures, state, impacts and responses (DPSI R) for ocean noise on the Scotian Shelf. The DPSI R framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems and natural resources, which may elicit a societal or government response that feeds back on all the other elements.

13.2 DRIVING FORCES AND PRESSURES

13.2.1 Economic Development

On the basis of data for the period 1950 to 1998, Frisk (2007) has demonstrated that there is a significant relationship between the increase in global gross domestic product (GDP) and the increase in ocean noise, thereby accentuating the importance of economic activity as the main driver of anthropogenic noise in ocean areas throughout the world. The Scotian Shelf represents a highly-developed and active marine area with numerous economic sectors making use of its geographic position and natural resources (DFO 2005). The area is an important contributor to the economy of Canada and Nova Scotia with the main marine industries comprising commercial fisheries, aquaculture, fish processing, oil and gas (exploration, development, and production), water transportation and support activities, tourism, marine construction, shipbuilding and boat building, and government services including research and defence (Gardner Pinfold 2009). All of these sectors use various forms of technology that emit noise into the ocean environment, and there are a wide variety of activities, each with its own characteristic mobility, timing, frequency, duration and intensity (**Table 13-1**). The Atlantic-facing seaboard of Nova Scotia is more than

500 km long and has numerous nodes of economic development (ports, bays, and small-craft harbours), which each have specific, and differing, sound sources linked to them. The development and economic sustainability of all of these sectors is a prime strategic objective of the region (Nova Scotia Department of Economic and Rural Development 2009), hence ensuring the perpetual presence of numerous sources and fluctuating levels of anthropogenic noise in most areas of the Scotian Shelf.

Table 13-1: Characteristics of some noise sources that are associated with various marine industry sector activities on the Scotian Shelf (selected from Simmonds et al. 2004; Wyatt 2008).

Activity/ Source	Economic Sector	Dominant Frequency (kHz)	Source Level (dB re 1µPa-m)	Characteristics
650cc jet ski	Recreation/tourism	0.8-50.0	75-125	Intermittent movement in estuaries/bays/surf zone/inshore
7m outboard	Recreation/tourism/ aquaculture	0.63	152	Intermittent movement in estuaries/bays/surf zone/inshore
Fishing boat	Fisheries/aquaculture	0.25-1.0	151	Intermittent movement offshore and inshore
Fishing trawler	Fisheries	0.1	158	Intermittent movement in offshore/inshore/bays/estuaries/ harbours
Tug	Support for transportation	1.0	170	Occasionally in all zones
Tanker	Transportation	0.06	180	Constant movement in offshore shipping lanes and ports
Container ship	Transportation	0.008	181	Constant movement in offshore shipping lanes and ports
Freighter	Transportation	0.041	172	Constant movement in offshore shipping lanes and ports
Airgun array	Oil and gas	0.01-0.10	255	Occasionally only by permit and localized in specified exploration areas
Naval Sonar	Defence	2-8	225	Intermittent in offshore
Depth sounder	Fisheries, defence, oil and gas, transportation	3	200	In association with shipping
Bottom profilers	Fisheries, defence, oil and gas, transportation	1-10	215	In association with shipping
Side scan	Fisheries, defence, oil and gas, transportation	60-300	225	In association with shipping
Acoustic deterrent devices	Aquaculture	10-25	205	localized inshore, embayments, estuaries
Dredging	Oil and gas, construction	broadband	131	Construction sites
Impact pile driving	Oil and gas, construction	0.010-0.12	190	Periodic and localized in areas of marine construction
Assorted motors, pumps, generators,	All sectors	-	-	Associated with construction sites, oil rigs and shipping
Aircraft – fixed wing and helicopters	All sectors			Associated with construction sites, oil rigs and shipping

Sound in the Marine Environment

Sound is produced by travelling waves or vibrations that occur at different frequencies and sound pressure or intensity is measured on a logarithmic scale (decibels, dB) (Chapman and Ellis 1998).

Sound in the marine environment is made up of a mixture of a variety of natural and anthropogenic sources (see figure below, National Research Council 2003). These contribute on a prevailing (constant), intermittent, or local basis. Prevailing sounds includes geological noise, noise from seismic surveys, distant ocean traffic, and sea surface bubbles and spray. Additionally, bioacoustic sound from crustaceans, fish, and mammals contributes over a wide frequency band. Episodal events and activities, such as earthquakes, nearby shipping, construction, wind, rain, seismic surveys (for Oil and Gas Exploration), and the use of active sonars by commercial and government sectors contribute at intermittent times in localized areas.

Noise is sometimes interpreted as being “unwanted sound” from anthropogenic sources, which being a form of energy, may be treated as a pollutant of the marine environment (Scott 2004).

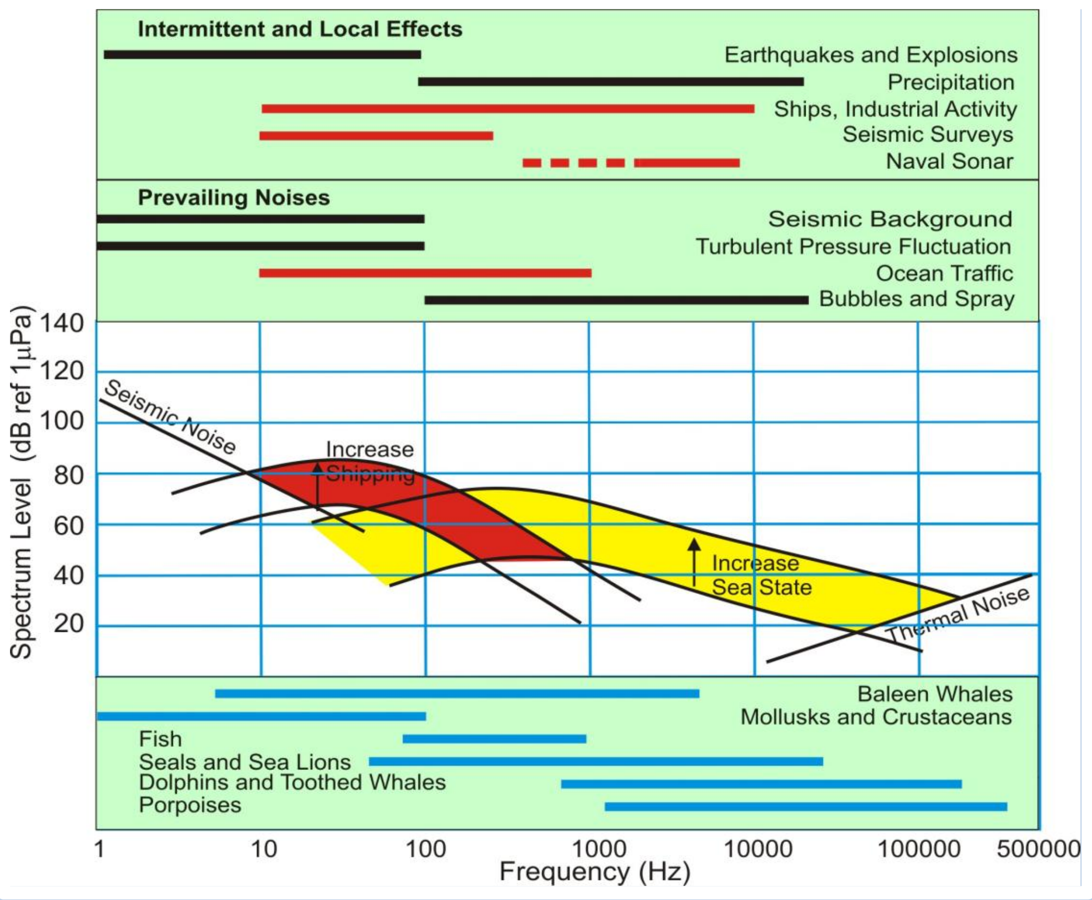

Figure: Typical ambient noise-frequency profiles for the marine environment (adapted from Wenz 1962 and the National Research Council 2003). Frequency bands associated with intermittent, prevailing and biological sources are indicated (red bars = anthropogenic; black bars = natural, and blue bars = biological).

The following sections describe in more detail two of the main contributors of noise on the Scotian Shelf: shipping and oil and gas. Although there are other sources of noise, for example from military operations, these are minor and infrequent.

13.2.2 Shipping

Shipping traffic is considered to be one of the main anthropogenic drivers of marine ecosystem change and the northwest Atlantic Ocean, part of which incorporates the Scotian Shelf, contains some of the busiest sea routes in the world (Halpern et al. 2008). There are main shipping lanes traversing the Scotian Shelf in a north-south direction (DFO 2005) and several ports in Nova Scotia receive international shipping, including Sydney, Port Hawkesbury, Halifax, Shelburne and Hantsport. Nova Scotia has about 247 small craft harbours that cater to vessels that are involved in commercial fishing in ocean waters surrounding the province. There are no published reviews on the trends or exact numbers of shipping traffic traversing the Scotian Shelf, but figures for international ships making use of Nova Scotian ports show a regular pattern of between 1,600 and 2,000 large vessels per annum, of which the majority enter Halifax or Port Hawkesbury (**Figure 13-2**).

Pelot and Wootton (2004) report that merchant traffic (bulk, tanker, cargo) in the Halifax Sea Search and Rescue area (HSSR) remains relatively constant over the course of the year, but that commercial fishing and cruise ships are heavily seasonal. During 2001 there were 346,348 fishing vessel trips recorded inside the HSSR, indicating a heavy usage of the area by commercial fishing interests. Each vessel constitutes a moving source of sound that contributes to both background and local noise as it moves through an area. In general large ships create noise that covers a distance greater than approximately 50-80 km, and the noise fades into background levels as the ship passes. Oil tankers have been estimated to have an average area of ensonification at the 120 dB level of about 2,000 km^2 (Hatch et al. 2009).

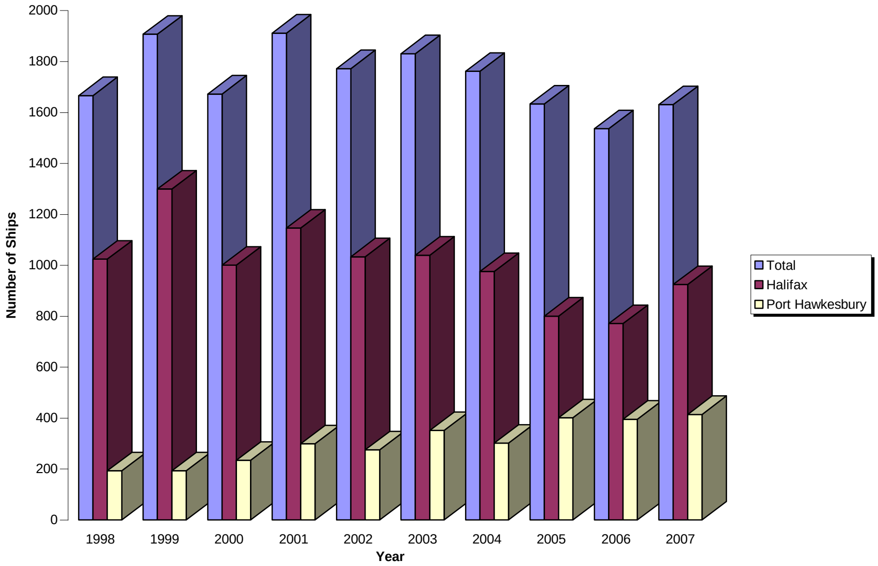

Figure 13-2: International shipping movements into ports of Nova Scotia for the period 1998 to 2007 (data obtained from Statistics Canada) showing annual total to all Nova Scotian ports, and trends for Halifax and Port Hawkesbury.

12.2.3 Oil and Gas Exploration

A large portion of the Scotian Shelf has been designated for oil and gas exploration and development, and there are currently several areas that are under license with active extraction taking place centred on the Sable Island area (see Nova Scotia Department of Energy 2010). The oil and gas offshore industry creates numerous potential sources of noise that are generated on an impulsive, transient, or permanent basis (Wyatt 2008). Exploration-related seismic surveys represent one of the highest source levels (**Figure 13-3**, Walmsley 2007). Since 1960, there have been about 400,955 km of 2-D seismic and 29,512 km2 of 3-D seismic shot on the Scotian Shelf and slope. This has occurred intermittently, with the majority of the activity taking place between the periods 1968- 1975, 1980-1985 and 1996-2003. No commercial seismic surveys have occurred on the Scotian Shelf since 2005, although there have been geological research surveys on the Shelf and commercial surveys in areas adjacent to the Shelf (e.g., 3 D seismic survey during summer of 2010 in the Laurentian Channel north of the shelf).

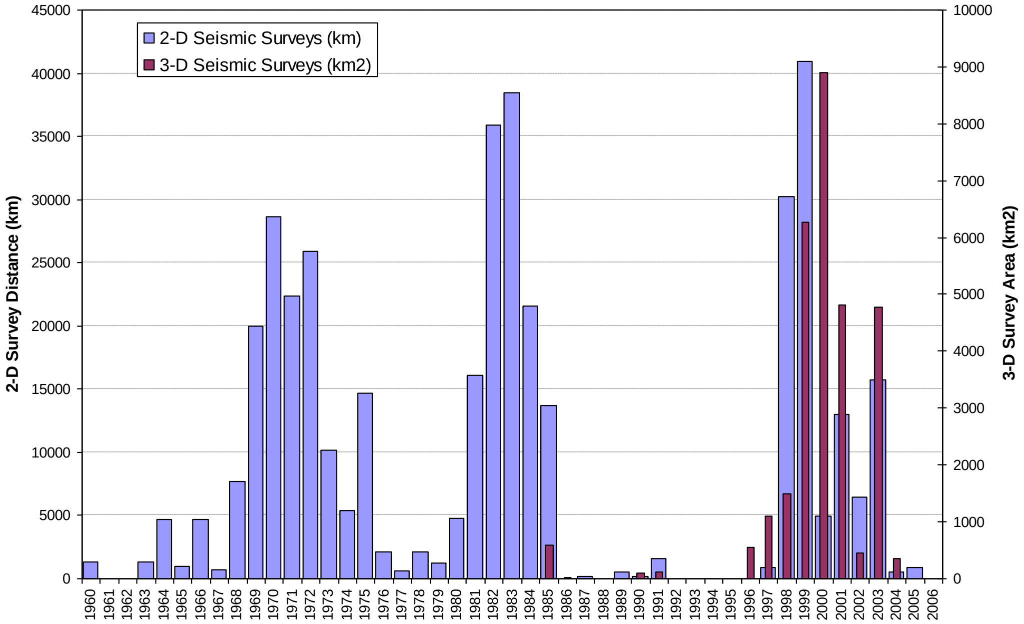

Figure 13-3: Seismic surveys undertaken on the Scotian Shelf from 1960 to 2006 (Source: Canada Nova Scotia Offshore Petroleum Board, CNS OPB, http://www.cnsopb.ns.ca/reflection_seismic.php).

13.3 STATUS AND TRENDS

13.3.1 Ambient Noise

Ambient noise is defined by the National Research Council (2003) as “the overall background noise caused by all sources such that the contribution from a single specific source is not identifiable”. It represents the background noise typical of the location and depth where the measurements are taken after identifiable, occasional noise sources are accounted for. Although there is a lot of data that has been collected on the Scotian Shelf over the years, there has not been any formal program on long-term monitoring of ambient noise on the Scotian Shelf, nor any analysis which reports on long-term changes at fixed sites or depths. There are however several reported studies over the last 50 years that allow for the general ambient noise characteristics of the Scotian Shelf to be defined.

Dataset for 1959/1960: Piggott (1964) investigated the relationship between noise levels and wind speed over an annual period and reported that there was a strong relationship between sea-noise spectrum levels (8.4 – 3100 Hz) and the logarithm of wind speed at an unspecified shallow water site (2 nm offshore at 40 - 50 m) on the Scotian Shelf. He also demonstrated that there were seasonal differences with higher ambient noise being encountered in winter months. The intermittent influence of shipping noise at the station was noted and possibly represented up to 30% of data in summer and 60% in winter.

Dataset for 1972/1985: Zakarauskas et al. (1990), collected data (30 – 900 Hz) at several sites during cruises between 1972 and 1985, and used an analysis approach that averaged transect data at mid-depth levels in the water column to give representative ambient noise profiles of the Scotian Shelf. They reported that ambient noise levels for frequencies of 150 Hz and above were the same as those given by Piggott (1964), but that at lower frequencies the noise levels were up to 15 dB higher. This difference was attributed to three possible reasons: 1) propagation characteristics in inshore shallow waters, 2) position of hydrophones, and 3) higher shipping density. Zakarauskas et al. (1990) report that there was high variability of ambient noise on the Scotian Shelf and attributed this to shipping noise and propagation of ship noise from longer distances. They also reported that higher ambient noise during winter was related to improved propagation of shipping noise. They concluded that ambient noise profiles on the Scotian Shelf are representative of high shipping density.

Dataset for 1998: Desharnais and Collison (2001) investigated four sites on the Scotian Shelf with monthly sampling using four sonar buoys for each site over a period of one year. The values are high over all frequencies, and the variation and higher levels are likely associated with specific temporal and geographic factors.

Dataset for 2002: Hutt and Vachon (2004) obtained ambient noise profiles (10-1000Hz) on the Sable Bank in June 2002, and reported that measurements indicated that a ship noise parameter of 88 dB was appropriate for modelling purposes because there were 41 ships in the vicinity, corresponding to a moderate to high shipping density.

Dataset for 2009: A more recent study by Pecknold et al. (2010) using a small temporal data set, and focusing on wind generated noise, also confirmed the nature of ambient noise on the Scotian Shelf and its influence by high shipping activity. A comparison of the spectrum-frequency profiles of these datasets is shown in **Figure 13-4**. This demonstrates their positions in accordance with curves of Wenz (1962) and the relative influence of shipping in all of datasets. The studies undertaken have been limited, so that it is not possible to assess or predict any trends. The studies show that there is obviously considerable temporal and spatial variation, and that ambient noise is higher than that predicted for deep water by Wenz (1962). Wind and wave generated noise (> 100 Hz) is generally higher than that predicted for average sea state. At the frequencies dominated by shipping noise (10 - 100 Hz), the studies have shown ambient noise levels that are up to 10 000 times (40 dB) higher than noise levels generated by high winds.

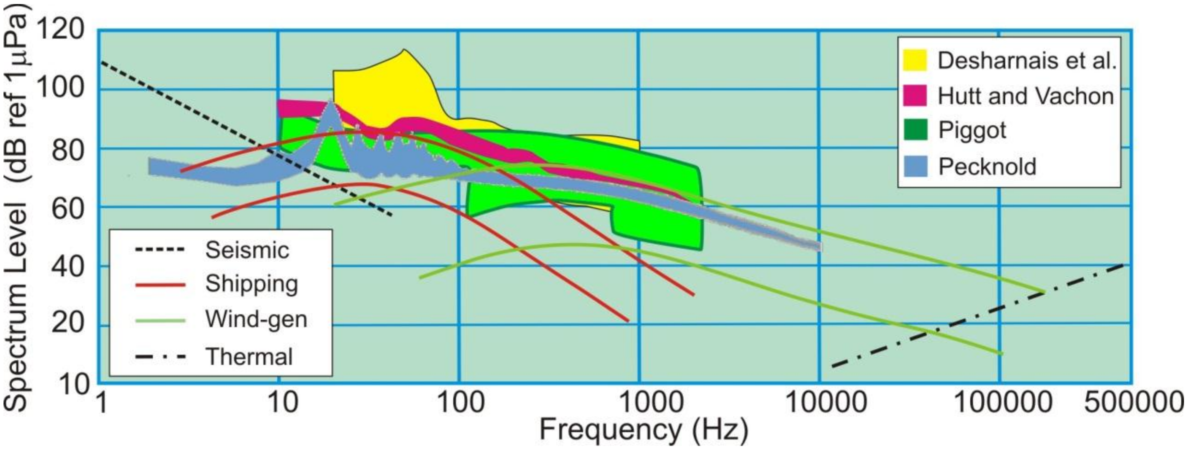

Figure 13-4: Spectrum-frequency profiles for datasets showing ambient noise at sites on the Scotian Shelf (Desharnais and Collison 2001; Hutt and Vachon 2003; Piggott 1964; and Pecknold 2010).

13.3.2 Intermittent and Local Noise

There is limited published work available on measured noise from intermittent or local sources on the Scotian Shelf, although generic source level information is available for numerous intermittent and local sources (see Simmonds et al. 2004, Wyatt 2008, **Table 13-1**).

The acoustics of air-gun arrays for seismic surveys, with one of the highest source levels, have received attention in areas of the Scotian Shelf. Far field sound measurements were included as part of a research investigation associated with a 3-D seismic survey near the Gully Marine Protected Area in 2003 (Lee et al. 2005). During this survey Austin and Carr (2005) showed that:

- A maximum measured average peak sound level of 175 dB re μPa was received at 30 m water depth, and at a range of 2.6 km from the seismic array; and
- The measurements recorded in the Gully Marine Protected Area, at a range of approximately 55 km from the airgun array, had average received peaks of 143 and 136 dB re μPa at depths of 77 m and 180 m, respectively (see also McQuinn and Carrier 2005).

Seismic airgun noise has the capacity to propagate over large distances. Nieukirk et al. (2004) report that noise from seismic exploration on the Scotian Shelf was recorded at a station on the mid-Atlantic Ridge 3,000 km away. As with prevailing noise, the ranges at which seismic surveys can be heard is highly variable and their influence is restricted to the period of operation.

Ocean floor morphology, ocean depth, temperature, salinity, and proximity to land are important modifying factors in determining the characteristics of noise distribution in the marine environment (Wenz, 1962, Piggott 1964; OSPAR Commission 2009). Because of this, sounds from industrial activities on the inshore part of the Scotian Shelf can be expected to be more varied, and different, to those of the offshore. Noise can be expected to be higher close to fixed developments and sites where there are numerous forms of mechanization (pumps, generators, motors, mobile rigs, aircraft etc.).

13.4 IMPACTS

There are diverse animal groups (plankton, benthic and pelagic invertebrates, reptiles, fish and mammals) that make use of benthic and pelagic habitats on the Scotian Shelf (Breeze et al. 2002; Zwanenburg et al. 2005). Many of these groups have been shown to be sensitive to various forms of sound (DFO 2004a; Hawkins et al. 2008; OSPAR 2009). While there is an absence of verifiable experimental information on the impacts of sound on specific biota, which makes it extremely difficult to specify the exact impact of a particular sound type on any particular species in Canadian waters (DFO 2004a), there is a developing body of research synthesis which suggest there may be wider impacts of anthropogenic sound on marine organisms (DFO 2004a; Simmonds et al. 2004; Hawkins et al. 2008; IFAW 2008; OSPAR Commission 2009; see **Table 13-2**).

Table 13-2: Potential impacts of noise on major groups of marine animals that occur on the Scotian Shelf.

Animal Group	Potential Impacts
Invertebrates	Wide range of possible impacts: extremely high levels of noise such as seismic may result in bruised organs and abnormal ovaries, smaller larvae, delayed development, soiled gills, altered feeding patterns, signs of stress in response to seismic noise (DFO 2004 a, b; Payne *et al.* 2009).
Fish	Wide range of possible effects: high levels of noise cause startle response, orientation problems, structural damage to swim bladders, ablated ear cells, internal bleeding, or blindness. Most damage occurs upon exposure within 5 m of the source. Temporary and/or permanent hearing loss, physiological changes as a result of stress, masking (DFO 2004a; Worcester 2006).
Reptiles	Wide range of effects: increased swimming speed, increased activity, change in swimming direction, and avoidance (DFO 2004a).
Mammals (whales, dolphins, seals)	Wide range of effects including: cessation of feeding, changes in behaviour, orientation, changes in socializing and vocalizing, avoidance, attraction, masking (see **Figure 13-5**), damage to ears (hearing threshold shift), stress, displacement from area, cumulative impacts, social disruption (Abgrall *et al*. 2008; DFO 2004a; Simmonds *et al.* 2004; Weilgart 2007). Sonar exposure has been associated with strandings and mortality in some beaked whale species.

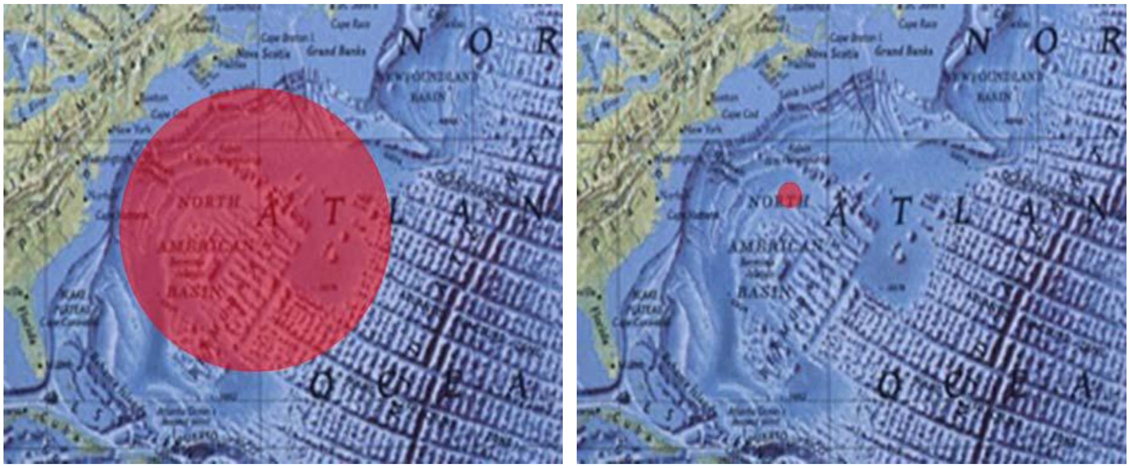

Figure 13-5: Expected reductions in blue whale communication ranges from the many hundreds of square kilometres possible prior to the advent of commercial shipping and other industrialized sounds (left) compared to the greatly reduced possible ranges for those same calls today (right). Figure courtesy of Christopher Clark, Cornell University based on historical and recent low frequency ambient noise and whale call measurements (from Wright 2008).

In the marine environment where senses such as vision, touch, smell and taste are limited in range, sound is an important sensory tool for many marine organisms (marine mammals, fish and some invertebrates) that have developed special mechanisms both for emitting and detecting underwater sound (Hawkins et al. 2008). Sound is important for detection of prey and predators, for echolocation and avoidance of obstacles, and for communication between individuals. It is, therefore, vital for survival of many individual animals through its role in directing movement, behaviour, feeding, reproduction, and avoidance of threats.

The Population Consequences of Acoustic Disturbance (PCAD) model (National Research Council 2005), provides a general perspective of the wide range of potential impacts on marine organisms (**Figure 13-6**). Noise creates a risk of impacts involving the behaviour and biological functions at both individual and population levels, and ultimately, at wider socio-economic and ecosystem scale levels. Richardson et al. (1995) cite a range of possible impacts (e.g., mortality, injury, behavioral changes, avoidance, attraction, and masking) with the level of impact related to many factors including amongst others: proximity of animals to the sound source, the nature of the sound source, environmental factors, the sound sensitivity and behavioral state of the organism, and the duration of exposure. The situation is complex as the groups and species all have different wavelength spectra to which they are sensitive, and therefore a source might have an impact on one species but not on others.

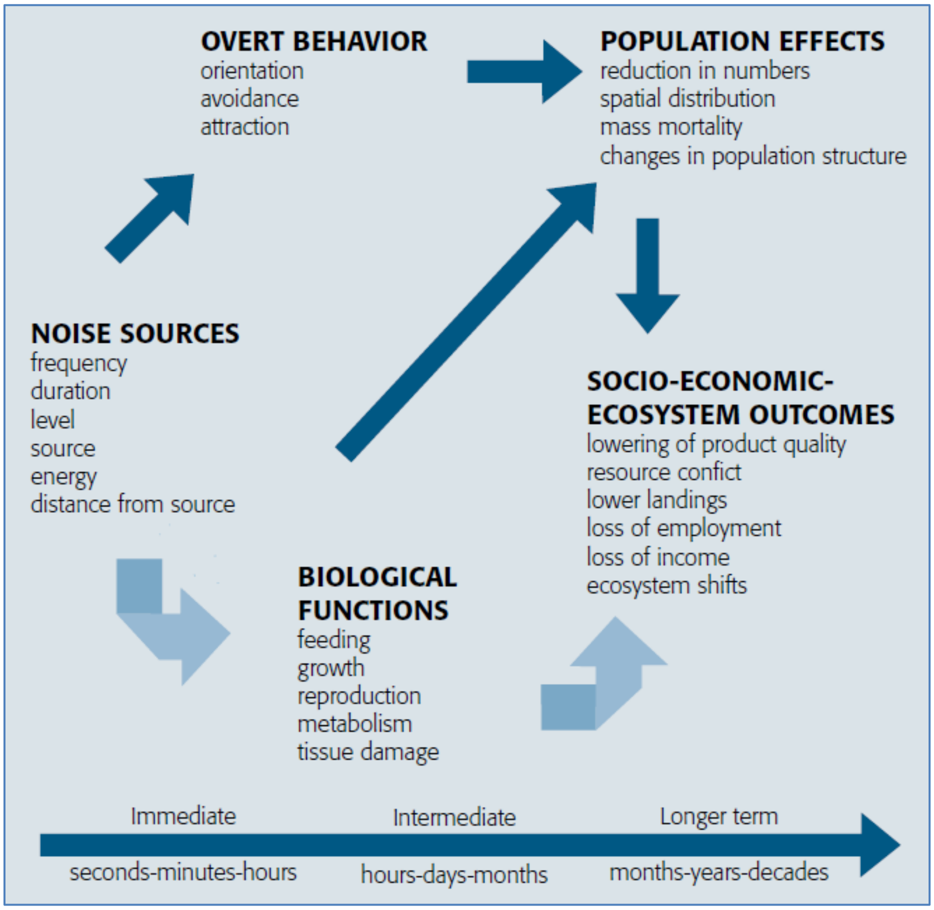

Figure 13-6: PCA D model to illustrate the impacts of noise at individual, population and ecosystem levels (Walmsley 2007; adapted from National Research Council 2005).

The potential impacts of seismic airgun noise, one of the loudest sources of noise on the Scotian Shelf, has received attention in Canada (DFO 2004a, b, Lee et al. 2005, Worcester 2006; Moriyasu et al. 2004; Payne et al. 2008). Studies indicate that there is a wide range of potential impacts, but they still require confirmatory research.

Animals on the Scotian Shelf are exposed to a wide range of intermittent and prevailing noises, and there is concern that long-term exposure within such an environment might lead to cumulative impacts, ultimately causing stress-related effects on the general condition of animals, making them prone to secondary indirect impacts (e.g., disease, loss of reproductive capability; Simmonds et al. 2004).

13.5 ACTIONS AND RESPONSES

Concern about noise as a detrimental environmental factor for marine mammals was raised as long ago as the 1970's (see Payne and Webb 1971). There is a growing opinion that noise in the marine environment is a priority issue which needs to be addressed at the global level (IUCN 2004; Scott 2004; International Maritime Organization (IMO) 2009, International Whaling Commission 2006, OSPAR Commission 2009). Because propagation of noise occurs over long distances in the marine environment, it is recognized that the management of noise will require an international collaborative effort (IMO 2009). A lack of research on the exact quantifiable impacts of noise has limited the development of regulations based on concrete scientific fact, and most of the current approaches are based on a "precautionary approach" aimed at reducing risks of certain types of potential impact (Theriault et al. 2005).

13.5.1 International Response

Although there is no specific international legislation for the regulation of noise in the sea, there is recognition that responsibility for addressing the situation lies within the mandate of the UN and its structures (IUCN 2004; IMO 2009). The *United Nations Law of the Sea* (UNLOS - http://www.un.org/Depts/los/index.htm) obliges parties to: "take all measures that are necessary to prevent, reduce and control pollution of the marine environment from any source." Pollution is broadly defined by UNLOS in Article 1(4) as: "the introduction by man, directly or indirectly, of substances or energy into the marine environment". Based on this definition, anthropogenic noise, which is a form of energy, should be regarded as a pollutant (Scott 2004). However, noise does not yet feature on any of the international pollution regulations which are coordinated through The *International Convention for the Prevention of Pollution from Ships* (MARPOL- http://www.imo.org/conventions/contents.asp?doc_id=678&topic_id=258) under the IMO. This omission is in the process of being addressed, as evidenced by several actions and activities which have taken place in recent years. These have included:

- A resolution by the World Conservation Union (IUCN 2004) that recognizes that "anthropogenic underwater noise, depending on source and intensity, is a form of pollution, comprised of energy, that can degrade habitat and have adverse effects on marine life ranging from disturbance to injury and mortality". The resolution urged member governments that are parties to the UN to work through UNLOS, MARPOL and the IMO to develop mechanisms for the control of undersea noise (http://www.awionline.org/ht/a/GetDocumentAction/i/10132). The IUCN also called for assistance of IUCN members, Commissions and Council, to identify and implement measures to promote among governments the reduction of anthropogenic ocean noise, and to support and conduct further research into the effects and mitigation of anthropogenic ocean noise.

- Statements from the UN General Assembly (20 December 2006, and December 2009) that encourage further research, studies and consideration of the impacts of ocean noise on marine living resources, and request the UN structures to continue to compile peer-reviewed scientific studies (http://www.un.org/depts/los/general_assembly/noise/noise.htm).
- The establishment of a correspondence group by the Marine Environment Protection Committee (MEPC) of the IMO to investigate the adverse impact of ship noise on marine life. The correspondence group prepared a review and report that was submitted to the MEPC in 2009 (IMO 2009). Work is continuing on the development of voluntary technical guidelines for ship quieting technologies.
- Concerns by the International Whaling Commission (IWC) about the cumulative impacts of noise on whales and the regular inclusion of anthropogenic sound as an agenda item on annual meetings of the IWC Scientific Committee (IWC 2006, IWC 2010). There has also been agreement for increased coordination and cooperation between the IWC and the IMO on the issue of anthropogenic noise. The main focus points for international management appear to be shipping noise, seismic exploration, use of sonar, and whale watching activities (IMO 2009, IWC 2010).

13.5.2 Canadian Regulations and Policy

Canada is a member of the UN, and a signatory to both UNLOS and MARPOL, and has been a participant in the above-mentioned international activities. Some of the Canadian regulations and policies that are, or could be, applicable to the regulation of noise on the Scotian Shelf include (Theriault et al.2005):

- The *Species at Risk Act* is aimed at the legal protection of listed "at risk" species, and includes provision for management of critical habitats in which these species are found. There are currently 28 Scotian Shelf species that are listed by COSEWIC as being either extirpated, endangered, or of concern (http://www.sararegistry.gc.ca/). For many of these species noise is cited as being an issue of concern (see *At Risk Species*).
- The *Canada Shipping Act* makes provision for the regulation of shipping in Canadian waters. Section 658 of Part XV of the Act relates to provisions for implementation of any MARPOL-related regulations.
- The *Canadian Environmental Protection Act* is designed to protect the ecological health of Canada, and prescribes activities to ensure environmental protection. The Act defines marine pollution as "the introduction by humans, directly or indirectly, of substances or energy into the sea."
- The *Oceans Act* defines the efforts that can be employed to protect resources and endangered species in offshore areas. The Act (sections 52.1) allows for development related to marine environmental quality requirements and standards. An example is The Statement of Canadian Practice with respect to the *Mitigation of Seismic Sound in the Marine Environment*, which specifies the mitigation requirements that must be met during the planning and conduct of marine seismic surveys, in order to minimize impacts on life in the oceans (see http://www.dfo-mpo.gc.ca/oceans/management-gestion/integratedmanagement-gestionintegree/ seismic-sismique/statement-enonce-eng.asp).
- The *Fisheries Act* contains several provisions that are relevant to noise. Section 35 states that "no person shall carry on any work or undertaking that results in the harmful

alteration, disruption or destruction of fish habitat."; Section 7 states "no person shall disturb a marine mammal except when fishing."; and Section 32 of the Fisheries Act prohibits the destruction of fish by means other than fishing.

- The *Canadian Environmental Assessment Act* requires federal departments and agencies to assess the environmental impact of proposed projects and activities.
- *Canada–Nova Scotia Offshore Petroleum Resources Accord Implementation Act* contains Nova Scotia Offshore Area Petroleum Geophysical Operations Regulations (SOR/95-144) and applies to oil and gas activities. The Canada Nova Scotia Offshore Petroleum Board (CNSOPB; http://www.cnsopb.ns.ca/) is the agency responsible for regulations concerning seismic exploration activities in Nova Scotian waters. No petroleum development activity takes place offshore Nova Scotia without an environmental assessment. The convening of a public commission involving stakeholders in the assessment of potential impact of seismic exploration (http://www.cnsopb.ns.ca/pdfs/Report1upPublicComm.pdf) off Cape Breton is an example of this.
- Maritime Forces Atlantic issues Maritime Command Orders (MARCORDS) dealing with the use of sonar in association with marine mammals.

13.5.3 Knowledge Development and Research

There are numerous international and Canadian research organizations and agencies that are involved in the support of research and dissemination of information on the impacts of noise in marine waters. Some of these include:

- The Canadian Environmental Studies Research Funds (ESRF) sponsors projects designed to assist in the decision-making process related to oil and gas exploration and development (see http://www.esrfunds.org/pubpub_e.php).
- The Offshore Energy Environmental Research Association (OEER) has a program on the impacts of seismic on invertebrates (http://www.offshoreenergyresearch.ca/Default.aspx?tabid=54).
- Petroleum Research Atlantic Canada (PRAC) is an organization that has provided funding support for seismic- related research in Atlantic Canada (http://pr-ac.ca/programs/).
- The DFO regularly carries out research projects and reviews on noise (DFO 2004, 2005, Worcester, 2006, Payne et al. 2008, Lawson 2009)
- Defence R&D Canada is an agency of the Canadian Department of National Defence that has been involved in numerous assessments of noise on the Scotian Shelf (http://www.drdc-rddc.gc.ca/index1-eng.asp).
- The United States, which has several agencies and actions underway (e.g., The Marine Mammal Commission - http://mmc.gov/reports/workshop/; National Oceanic and Atmospheric Administration - http://www.nmfs.noaa.gov/pr/pdfs/acoustics/shipping_noise.pdf). An Interagency Task Force on Anthropogenic Sound and the Marine Environment has motivated a research plan for US federal agencies (Southall et al. 2009).
- The International Association of Oil and Gas Producers (http://www.soundandmarinelife.org/Site/index.html) has a E&P Sound and Marine Life Joint Industry Programme (JIP).

- Ongoing conferences and symposia that present and synthesize information on the effects of noise on aquatic life (see- http://www.aquaticnoise.org/).
- Numerous websites that present useful information on noise and its environmental impacts (e.g. http://www.acousticecology.org/aboutus.html , http://www.dosits.org/, http://www.noaa.gov/).

13.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR*	Assessment	Trend
Marine ship traffic	Noise impact from shipping	Pressure	Poor	/
Extent and frequency of seismic surveys	Noise impact from seismic surveys	Pressure	Fair	+
Ambient noise	Environmental quality	State	Poor	?
Airgun noise propagation	Environmental quality	State	Fair	?
List of potential impacts	Impact assessment	Impact	Poor	?
Applicable regulations	Policy and regulations	Response	Fair	/
List of knowledge development activities	Knowledge management and research	Response	Poor	/

Key:
Negative trend: - Positive trend: + Unclear or neutral trend: / No assessment due to lack of data: ?

Data Confidence

- Cited source levels are generic and not necessarily those that might be measured on the Scotian Shelf.
- Shipping traffic values are proxy indicators and do not reflect the overall dynamic shipping situation on the total area of the Scotian Shelf.
- Cited ambient noise levels only reflect the situation at a single point over a limited time period.

Data Gaps

- No continuous record of ambient noise levels in critical habitats of the Scotian Shelf. Ocean bottom seismometers and Cornell pop-up acoustic recorders have been deployed in canyons and along the slope of the Scotian shelf and the data could be analyzed to gain a better understanding of ambient noise.
- No long-term monitoring or assessment of noise from fixed sites.
- No analysis of shipping patterns and ship types is readily available.
- No analysis of noise sources or noise budgets is available.
- Few conclusive studies of impacts on organisms have been undertaken.

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14. MARINE WASTE AND DEBRIS[26]

Kayleigh Grieve, Fisheries and Oceans Canada, Oceans and Coastal Management Division,
Dartmouth NS

14.1 ISSUE IN BRIEF

Marine waste or marine debris is any manufactured or processed solid material that enters the ocean environment either directly or indirectly (United Nations Environmental Programme 2011b; United States Environmental Protection Agency 2011; National Ocean and Atmospheric Administration 2011). Debris can range from plastic resin pellets to couches (Vancouver Aquarium Marine Science Centre no date); Marine debris includes abandoned fishing gear (ghost gear), but excludes unexploded ordinances.

Marine debris is becoming increasingly problematic on the Scotian Shelf. There is overwhelming evidence that plastic pollution is a threat to marine biodiversity, and particularly to marine biota, which is already at risk from various forms of anthropogenic disturbance (Derraik 2002). Sea life can become entangled in marine debris causing injury or death. Waste also causes socio-economic issues as it detracts from the beauty of beaches and other coastal areas.

> Marine debris – trash in our oceans – is a symptom of our throw-away society and our approach to how we use our natural resources. It affects every country and every ocean…
>
> - Achim Steiner (UNEP 2011a)

Studies show that marine debris originates from sea-based sources like shipping and fishing industry dumping practices, and abandoned construction (Dufault and Whitehead 1994). Land waste is also a major contributor to marine debris (UNEP 2011b). Waste from landfills and beaches makes its way to coastal and ocean environments primarily through untreated waste and storm water overflows.

A lack of awareness among main stakeholders and the general public are major reasons that the marine litter problem appears to be increasing on the Scotian Shelf, and worldwide (UNEP 2011b). The North Atlantic contains high concentrations of plastic debris, comparable to those observed in the region of the Pacific known as the “Great Pacific Garbage Patch”. This has been made evident, in part, by studies of marine debris on the Scotian Shelf from 1984- 1986 (Lucas 1991). More recent evidence from the Sable Island area suggests that litter accumulation has not diminished (Lucas, personal communication, April 6, 2011).

This paper will explore the driving forces and pressures behind the persistent problem of marine waste, as well as the state and impacts of waste on the Scotian Shelf environment. It will also outline key international and regional responses to the problem. (**Figure 14-1**).

Linkages

This theme paper also links to the following theme papers:

- Water and Sediment Quality
- Species at Risk

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[26] Completed December 2012.

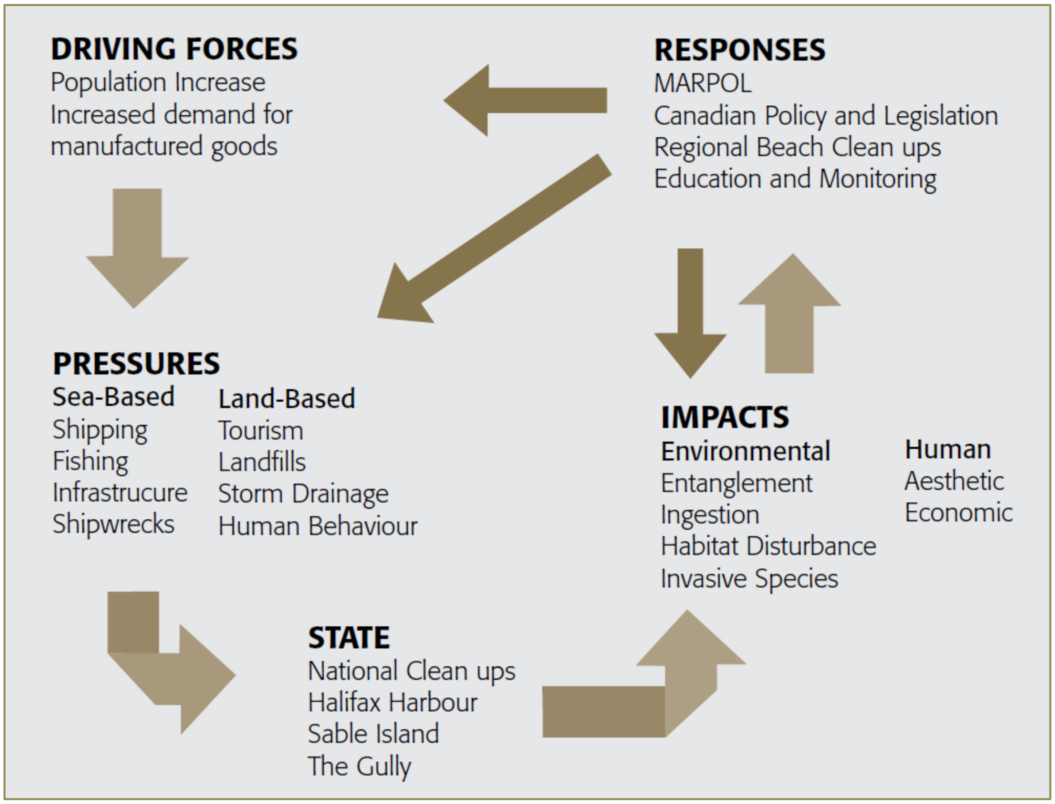

Figure 14-1: Driving forces, pressures, state, impacts and responses to marine waste on the Scotian Shelf.

14.2 DRIVING FORCES AND PRESSURES

14.2.1 Population Growth and Increased Demand for Manufactured Goods

As coastal communities continue to grow, there will be increasing stress on natural resources, leading to environmental degradation. Ribic et al. (2010) identified several mechanisms through which human population can drive the proliferation of marine debris; population size is of particular significance. Increased marine and coastal debris is linked to population increases and proximity to ports. The population of Nova Scotia remained relatively constant from 1996-2006 at roughly 900,000 (Statistics Canada 2010). The population of Halifax, however, has been steadily increasing over the same time period: from 340,000 to 369,000. It is likely that Halifax, as both a major port and as a city centre, contributes to higher levels of marine waste than smaller coastal communities on the Scotian Shelf. Ross et al. (1994) offer insight on the level of marine waste around Halifax in a 1989 study.

> It has been estimated that over 13,000 pieces of plastic litter are floating on every square kilometre of ocean surface.
> - UNEP 2011b

Human behaviour is increasingly consumptive and generates waste. Worldwide demand for manufactured plastic products is expected to continue growing faster than the economy as a whole (Industry Canada 2011). In Canada, the packaging and plastics industry is considered a high growth industry. Twenty nine percent of plastic products produced in Canada are considered “packaging,” which contribute to solid waste totals soon after use (Industry Canada 2011). Two percent of these are manufactured in Nova Scotia.

Plastics are the main source of marine debris worldwide; between 60% and 80% of litter collected (Derraik 2002). Most commonly, items constructed of plastic occur on the Scotian Shelf and Atlantic coastal waters, and can account for up to ninety two percent of marine debris (Lucas 1992; Dufault & Whitehead 1994; Clean Nova Scotia Foundation 2010). Most of the plastic is millimetres in size and consists of polyethylene or polypropylene, materials that float in seawater (UNEP 2011b). The identifiable plastics include: grocery bags, nylon rope, potato chip bags, Styrofoam, bottles, cans, and cigarette filters (US EPA 2011).

Canada produces the most municipal waste per capita with some estimates at 791 kg per person (The Conference Board of Canada 2011). This figure has been steadily rising since the 1980s. In Nova Scotia, per capita waste estimates were 429 kg in 2008. Although much of Nova Scotia's waste is diverted through recycling and composting programs, three of the top five marine debris items collected during national marine debris monitoring were items that potentially could have been recycled: plastic bottles, plastic bags, and cans (US EPA 2011).

14.2.2 Land Based Sources of Marine Debris

Debris enters the aquatic environment via sewage outflows and storm water drains during periods of intense rainfall and flooding. Litter is improperly disposed of down drains and toilets or stormwater carries litter and other debris through municipal water systems and over land to be discharged into marine environments (Ribic et al. 2010; US EPA 2011). Other extreme natural events are capable of carrying objects or directing objects into the ocean as well (NOAA 2011).

As population increases, there will be more pressure on the environment from human consumption. Increasing consumptive populations contribute to land-based debris (**Table 14-1**), which becomes marine debris through improper waste management regimes and extreme weather. Irresponsible beachgoers leave behind waste and debris which gets swept into the ocean or remains to litter the shoreline (US EPA 2011).

Table 14-1: Canada's Dirty Dozen List (2009) generated by the Great Canadian Shoreline Cleanup. This suggests that the top twelve sources of coastal debris as recorded by volunteers are land-based items. This is a finding which points to human behaviour as a significant factor driving the marine debris problem.

2009 Rank	Item	Number of Items Collected
1	Cigarettes/Cigarette Filters	367,010
2	Food Wrappers/Containers	116,138
3	Bags (Plastic)	74,276
4	Caps, Lids	63,471
5	Cups, Plates, Forks, Knives, Spoons	40,799
6	Beverage Cans	38,702
7	Beverage Bottles (plastic) 2 litres or less	37,618
8	Bags (paper)	30,019
9	Straws, Stirrers	29,925
10	Beverage Bottles (glass)	29,361
11	Tobacco Packaging/Wrappers	19,906
12	Cigar Tips	17,328

14.2.3 Sea Based Sources of Marine Debris

Sea-based sources of marine debris include: recreational and commercial fishing, routine disposal of garbage at sea by shipping vessels, and construction projects.

Debris from the fishing industry includes: fishing nets, lines, lures, rope, bait boxes, and light sticks. It is estimated that 52 metric tonnes of abandoned fishing gear accumulates annually (UNEP 2011b).

Recreational boats, military vessels, cargo ships, cruise ships, ferries, and charter boats can be sources of galley waste, garbage, plastic bags, and other materials. All of these materials can accidentally fall, blow, or wash off the vessels into the water and become marine debris. In some cases, waste and debris is deliberately thrown overboard; routine disposal of garbage at sea has been reported for fishing and merchant fleets, and Canadian military and government research vessels (Lucas 1992). In one study, only 1% of selected vessels reported all garbage taken to shore (Lucas 1992).

14.3 STATUS AND TRENDS

Little quantitative information is available about marine debris either regionally or internationally (Ribic et al. 2010; UNEP 2011b). Although there are no recent or certain statistics on how much litter is released into ocean and coastal environments worldwide, in 1997, the US Academy of Sciences estimated the total input of marine litter into the oceans at approximately 6.4 million tonnes per year (UNEP 2011b). Environment Canada (2010) reports that each year in Canada, between two and four million tonnes of material are disposed of at sea. About 90 percent of that quantity is not considered waste, but dredged sediment from estuarine or marine sources or excavated native till from land based sources.

On the Scotian Shelf, marine debris has been sporadically tracked since the 1980s. Generally, data on marine waste and debris are collected by survey monitoring. Surveys are undertaken visually, by passengers on vessels, or physically by collecting waste and debris either in the ocean or on coastal beaches. Waste collected during surveys gives us a general impression of the condition of the surrounding waters.

Many areas including the Gully, Sable Island, Halifax Harbour and numerous coastal beaches have been surveyed over time to record marine debris and waste. The following sections describe results and trends identified through the research, moving from the coast to the offshore, which contribute to our understanding of the marine waste issue on the Scotian Shelf.

> Some estimates reveal that roughly 8 million debris items enter the oceans every day, about 5 million of which are thrown overboard or lost from ships
> - UNEP, 2011b

14.3.1 Shorelines Cleanups

On the Atlantic coast, a substantial amount of debris is directly deposited by visiting beach areas (not simply washed ashore). In 2009, participants of the Canadian Shoreline Cleanup removed litter from 2,457 km of shoreline nation-wide (**Table 14-2**). Clean up results indicate that the amount of waste collected during national shoreline cleanups (kg/km2) has increased over time.

Items recovered during the Canadian Shoreline Cleanup were classified by activity: recreational, ocean-related, smoking, dumping and medical/hygiene (**Table 14-3**).

Provincial marine debris data is highly variable. **Table 14-2** gives some perspective on the state of the coastal debris issue in the Atlantic Provinces. According to this table, in Nova

Scotia 64% of debris collected was attributed to smoking-related activities. However, preliminary data via beach sweeps conducted by Clean Nova Scotia's Ship to Shore program suggest that smoking-related activities make between two and five percent of waste collected on shorelines, whereas, ocean/waterway activities can contribute up to 95%. Variations could be attributed to the location of the cleanup, access to the site, the time of year, or other factors, such as data collection methods.

A survey of the Atlantic coast also identified large quantities of fishing-related marine debris, which poses significant danger to the marine environment (Thom 2009). Ribic identified the correlation between ocean-based indicator debris and the regional fishing sector in his 1999 study; overall, the results support the expectation that oceanic fishing activity is related to the amount of oceanic debris deposited on coastal beaches.

Table 14-2: Canadian Shoreline Cleanup Results for 2009 (National).

Year	Registered Sites	Distance Cleaned (km)	Garbage bags	Weight (kg)*	Weight (kg) per kilometre
2009	1,568	2,457	15,930	160,914	65
2008	1,531	2,152	13,202	135,467	63
2007	1,240	1,772	13,473	87,489	49
2006	965	1,640	8,867	84,735	52
2005	812	1,477	10,383	78,356	53
2004	658	1,147	9,319	64,988	57
2003	477	771	5,438	49,859	57
Totals	5,683	8,958	60,682	500,894	

Table 14-3: Canadian Shoreline Cleanup Results: Recovered Waste Items by Province and Activity (Maritimes Provinces).

Province	Shoreline and recreational activities		Ocean waterway activities		Smoking related activities		Dumping activities		Medical personal hygiene activities	
	n	%	n	%	n	%	n	%	n	%
New Brunswick	5148	27.1	1273	6.7	293	1.5	11570	60.9	721	3.8
Newfoundland and Labrador	1093	9	179	1.5	8482	69.9	367	3	2012	16.6
Nova Scotia	2051	6.8	1273	4.3	19290	64.4	457	1.5	6708	22.4
Prince Edward Island	881	32.8	9	0.3	862	32.1	31	1.2	75	2.8

14.3.2 Halifax Harbour

Ross et al. (1991) assessed the type and source of persistent marine debris in Halifax Harbour in 1989. The majority (62%) of waste on the shores of the Halifax Harbour originated from recreation and land-based sources. They recorded the highest amounts of waste in recreational areas. Their data reveal that over one half (54%) of total marine debris in the Harbour was plastic. Styrofoam accounted for 12%, glass 8.4%, paper and wood 5.2%, and rubber 3%.

Halifax, as a the population centre of Nova Scotia and as a major port in the Atlantic Region shows high percentages of land-based marine debris, which can likely be attributed to its location, accessibility, status as a tourist hub, and human behaviour. The study concluded that waste in the Halifax Harbour is created mainly by citizens in the area rather than by industry, the military, or other sources. Other studies on the Atlantic coast echo this finding; a study undertaken by Thom (2009) traced markings on plastics recovered to primarily local sources such as household or small ship waste. The results of Ribic et al.'s (2010) study on marine debris in the North Atlantic reveal that land-based indicator-waste decreases as distance to the nearest population centre decreases. Similarly, the number of ocean-based indicator items declines with increasing distance from a port.

14.3.3 Sable Island

The amount of debris washing up on the shores of Sable Island is substantial. Lucas undertook surveys of marine debris on the shores of Sable Island between May 1984-September 1986. Unlike other Atlantic coastal shorelines, persistent waste on Sable Island comes from the ocean and does not originate on the island itself. A total of 11 183 persistent litter items were collected and sorted, representing 219 items/km/month. 92% of this total was plastic material such as tampon applicators, polystyrene cups, packing materials, bags, liquor and soft drink bottles, light bulbs, rope and fishing gear. Lucas identified 30% of the items to be of domestic origin, with 20% clearly originating from the fishing industry (i.e. gear, nets, etc.). Lucas documented deposition rates as being fairly consistent from year to year and site to site, and extrapolated from this study that waste is accumulating at a monthly rate of 219 items per km, or over 18,000 items per month on the entire island.

It is also important to note that accumulation and deposition rates on Sable Island may be influenced by natural conditions such as ocean circulation. Ribic et al. (2010) found that large scale circulation systems affected ocean-based indicator debris loads in his study of marine debris in the North Atlantic. The Northeast and Mid-Atlantic regions are influenced by the southward flowing Labrador Current as part of the western North Atlantic Gyre (Ribic et al. 2010). The surface circulation of the area is proposed as a southward movement along the length of the Nova Scotian coast which then circles back offshore toward Sable Island and beyond creating a large cyclonic eddy centre at Sable Island (Dufault & Whitehead 1994).

14.3.4 The Gully

In the 1990s, floating marine debris was surveyed, visually and by net tow, in the Gully in three separate studies (1990, 1996/7, 1999). The results of the surveys suggest that, during this period, the quantity of marine debris decreased. Data revealed a continuous drop in quantity and density.

Dufault and Whitehead (1994) observed that all items with identifiable labels were traced to domestic sources. They found greater concentrations of large debris (visible floating items) and lower concentrations of smaller debris (captured in a fine-meshed, 0.308 mm net) than reported in the literature for other areas of the world (Scarfe 1999). They attributed a great deal of marine debris to the local fishing industry or other small pleasure craft in the area.

In 1999, Scarfe also found that the quantity of large debris in the Gully had decreased since the original 1990 survey. Floating marine debris was only noted in half of the visual surveys, as opposed to almost all in the original 1990 study. Small plastic debris was found in 90% of the garbage tow surveys.

It has been suggested that the 1998 designation of the Gully as a pilot Marine Protected Area was successful in contributing to overall public awareness and the decreasing amount of debris in the area, particularly debris originating from fishing and shipping vessels.

14.4 IMPACTS

14.4.1 Environmental Impacts

The marine environment experiences the effects of marine waste both directly and indirectly. Biota can be physically harmed by debris through entanglement, ingestion, smothering or through the transportation of invasive species to new environments. Indirectly, marine habitats can be harmed when beach clean ups result in changes within coastal ecosystems (US EPA 2011).

Entanglement: Sea life can become entangled in marine debris causing injury or death. Entanglement can lead to suffocation, starvation, drowning, increased vulnerability to predators by restricting the animal's movement, or other injury such as wounds from tightening material (UNEP 2011b). Lost or abandoned fishing nets pose a particular risk to both fish and marine mammals. Ghost nets continue to catch animals even if they sink or are lost on the seabed. Around the world, people have reported entanglement for several marine species – notably, species of endangered sea turtles (UNEP 2011b), sea birds (Mallory 2008) and seals (Lucas 1992). Volunteers participating in the 2008 International Coastal Cleanup event discovered 443 animals and birds entangled or trapped by marine debris (US EPA 2011).

On the Scotian Shelf plastic debris is a particular threat to marine diversity (Derraik 2002). Sampling of marine birds has shown that pollution by plastic debris has increased in Canada's oceans in the past few decades (Derraik 2002; Mallory 2008). The Atlantic Fisheries International Observers Program has documented numerous cod and dogfish entangled in gillnets and other forms of plastic. Other surveys have also found plastics in the contents of the stomachs of cod. Young seals are attracted to floating debris and can easily become entangled (Derraik 2002). Of 241 grey seal pups handled during a research program in May 1987, 2.5% were entangled in trawl net (Lucas 1992). In 1978, 99 dead seabirds and over 200 dead salmon were recorded during the retrieval of a 1500 m ghost net on the Scotian Shelf (Derraik 2002).

Ingestion: Many species mistake marine debris for food. A plastic bag floating on the surface of the water resembles a jelly-fish, which are eaten by many species of fish and turtles (UNEP 2011b). In 1992, a Sable Island study reported ingestion of plastics by leatherback turtles on the Scotian Shelf (Lucas 1992). A 2009 report revealed that plastic ingestion by leatherback turtles was as high from 1885-1968 (Mrosovsky et al. 2009). From the 1960's to the 1980's the percentage of turtles with ingested plastics peaked; up to 37% of reports identified plastics in the remains of turtle stomachs Mrosovsky et al. 2009). Also, at least 26 species of cetaceans on the Scotian Shelf, have been documented to ingest plastic debris (Derraik 2002).

The effects of ingestion are broad. Plastics and other debris can accumulate in an animal's stomach causing it to feel full. Eventually, this can be fatal since debris material reduces meal size and prevents nutrients from being absorbed (Derraik 2002; US EPA 2011). Internal injuries, infections, hormone imbalances, and reproductive failure may also result from ingestion. Threat can also be chemical; toxic chemical leaching from ingested debris have been documented in birds and turtles (Fisheries and Oceans Canada 2010).

> At least 267 marine species worldwide are affected by entanglement in or ingestion of marine debris, including 86 percent of all sea turtle species, 44 percent of all seabird species and 43 percent of all marine mammal species…
> - UNEP 2011b

Invasive species: Marine debris contributes to the movement of aquatic organisms since floating debris in the marine ocean can acquire encrusting organisms and other fauna. Alien species use debris to increase their range and migrate to new territory, where they can colonize and overwhelm local marine ecosystems (US EPA 2011; Derraik 2002). Lucas (1992) identified marine organisms encrusted to 5-10% of plastic containers and fragments collected during beach surveys. There is also evidence that drifting plastic could be contributing to the introduction of exotic species in coastal ecosystems with resulting detrimental impacts (Fisheries and Oceans Canada 2010).

Disturbance: Smothering of the seabed occurs when debris collects in benthic environments. Debris can suffocate seabed animals and plants, while other debris items can be dragged along the seabed, tearing up the fragile habitat for bottom dwellers (US EPA 2011). Plastics and fishing nets are particularly detrimental, while abandoned fishing gear and other large marine debris can break sensitive corals (US EPA 2011). Ultimately, this can alter the composition of life on the sea-floor (Goldberg 1994). Sometimes, efforts to clean marine debris contribute to habitat disturbance. Mechanical techniques like raking disturb nests or result in ecosystem changes that alter the function of the area (UNEP 2011b). Beach raking can also contribute to beach erosion if the natural vegetation is disturbed (US EPA 2011).

14.4.2 Socio-economic Impacts

Social and economic impacts caused by marine debris are difficult to assess (Fisheries and Oceans Canada 2010). Generally, socioeconomic impacts fall under two categories: damage to fisheries and potential lost tourism.

Fishing Industry: Debris can damage boats used for recreation and fishing. It can become entangled in propellers, clogs valves or break hulls. Repairing boats damaged by marine debris is costly and contributes to lost fishing opportunities (Ross et al. 1994; US EPA 2011). For commercial fisheries, there is damaged market potential for fish and fish products which are entangled in marine debris or have ingested marine debris (US EPA 2011).

Tourism: The tourism industry needs clean, healthy beaches to attract visitors (Fisheries and Oceans 2010).The major impact of marine debris is its negative aesthetic effect, which is unwelcoming to beachgoers (Ross et al. 1991; UNEP 2011b. Marine debris makes public spaces less attractive and less safe, which can lead to beach closures or lost revenue from tourism (US EPA 2011; UNEP 2011b). Accordingly, marine debris can also have a serious economic impact on communities who are dependent on tourism for their livelihood (UNEP 2011b).

14.5 ACTIONS AND RESPONSES

Despite growing awareness of marine debris, the problem is still largely unexplored and unreported (Derraik 2002; Thom 2009), and little solid scientific information exists about the nature and scope of the issue (National Science Foundation 2010). The United Nations Environmental Programme stated that contemporary and historical measures to prevent and reduce marine waste were inadequate, and the problem will likely worsen in the 21st Century. However, the following actions are being taken to address this growing problem in the marine environment.

14.5.1 International Commitments

The *International Convention for the Prevention of Pollution from Ships* (MARPOL) is an international agreement that recognizes that vessels present a significant and controllable source of pollution into the marine environment (Centre for Marine Conservation 1994; Derraik

2002). In 1973, Canada joined other nations in drafting the Convention (and is signatory to it), which prohibits disposal at sea of persistent pollutants; it restricts any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms, or other man-made structures at sea (Pearce 1992). Annex V of the MARPOL Convention, called the London Convention, specifically prohibits the disposal of plastics and garbage from ships (Centre for Marine Conservation 1994). Transport Canada reports that if MARPOL restrictions were not in place, up to 35 percent of pollution in the world's marine environment would be the direct result of marine transport (Transport Canada 2010).

Derraik 2002 reported that the legislation is widely ignored and ships are still estimated to discard 6.5 million tons per year of plastics The compliance of individuals is partly a question of economics and logistics; in order to discourage waste disposal in the marine environment, ships need to have access to adequate and affordable waste reception facilities at ports (National Academy of Sciences 2008).

14.5.2 Canadian Policy and Legislation

In 1987, Canada's Oceans Policy noted increasing concern with the issue of marine debris (Pearce 1992). Taking political action, Canada ratified the MARPOL Convention, and meets its international obligations and supports its own pollution prevention objectives for disposal at sea through the *Canadian Environmental Protection Act* (CEPA). Consistent with the MARPOL Convention, the CEPA controls disposal of substances into waters from activities taking place at sea through legislated general prohibition; disposal of any substance into the sea is not allowed unless it is done in accordance with a permit issued by Environment Canada (Environment Canada 2011). Only a small list of wastes or other matter can be considered for permits and these are individually assessed to ensure that disposal at sea is the best environmental alternative, that pollution is prevented, and that any conflicts with other marine users are avoided (Environment Canada 2011).

The disposal at sea permit also triggers the *Canadian Environmental Assessment Act* and therefore requires at least a screening assessment of all Disposal at Sea activities in addition to the assessment conducted under CEPA (Environment Canada 2011). It is still unclear how existing waste and debris is being dealt with. Environment Canada has a mandated responsibility to deal with waste in the marine environment. However, there are no known federally-led programs which aim to reduce existing waste or prevent new waste accumulation.

14.5.3 Provincial and Community-led Initiatives

In Nova Scotia, the Clean Nova Scotia Foundation has been partnering with the public, governments, and businesses to advocate for a clean marine and coastal environment in the province for over 20 years (The Clean Nova Scotia Foundation 2009). In cooperation with various agencies including the Small Craft Harbours Branch of Fisheries and Oceans Canada, the Foundation has launched an outreach and monitoring program aimed at eliminating the disposal of wastes at sea by the commercial fishing sector and encouraging proper waste receptacles on shore at fishing harbours. This program, called Ship-to-Shore, is a pilot program administered through 21 fishing harbours throughout Nova Scotia.

The Clean Nova Scotia Foundation also administers a provincial shoreline cleanup project titled "The Great Nova Scotia Pick-Me-Up," which aims to beautify Nova Scotia's beaches as well as to identify and characterize the source of marine waste in the province. Similar initiatives are undertaken on a nation-wide scale, including the World Wildlife

Foundation-sponsored Great Canadian Shoreline Cleanup and Pitch-In Canada sponsored beach clean ups.

Efforts are also being made by the Nova Scotia government to reduce the amount of land-based waste generated per capita throughout the province. With a target of 300 kg per person, Nova Scotia will have to cut waste generated by 50% (Nova Scotia Environment 2010). To achieve this, the Nova Scotia Department of Environment is developing new programs to promote environmental stewardship and implementing waste regulations.

14.5.4 Education and Monitoring

Education and public outreach are the most significant drivers for change related to the problem of marine debris in Canada (Derraik 2002). Many national and regional education programs have been undertaken to reduce the problem of marine debris in Canadian waters. These programs have been targeted at both the general public as well as specific sectors. Fisheries and Oceans Canada recently undertook an initiative regarding marine debris aimed at public education. A four-part DVD was produced which provided a comprehensive overview of the problem, both worldwide and in Canada. As part of the Federal Health of the Oceans initiative, Transport Canada is also developing and implementing a Ship Waste Reduction Strategy to further prevent marine pollution from ships.

Pitch-In Canada is a national non-profit organization started by several volunteers concerned about plastics and other packaging and their effects on the land and marine environments (Pitch-In Canada 2006). They recognized that personal action, with assistance from governments and other stakeholders, is needed to conserve, enhance and protect the environment and to reduce waste. Pitch-in Canada has been informing and educating the public about marine debris, through youth programs and other forums, for 40 years and also supports and promotes beautification of shorelines nationwide.

Locally, Clean Nova Scotia’s Ship-to-Shore program currently works with commercial fishermen and has, in the past, worked with recreational boaters on waste disposal habits at sea and on land. The Ship to Shore program involves outreach at community and public events, presentations and materials distribution on responsible boating through proper waste management.

Therefore, debris management strategies targeted at changing people’s behaviour have some potential for reducing debris load on beaches (Ribic et al. 2010).The Ross et al. (1991) study suggests that public education and municipal law enforcement could reduce the marine debris problem in the Halifax Harbour by 82%.

Nova Scotia does have a waste management strategy, but properly managing waste requires extra time and effort. Garbage or recycling centers may not be efficient, which can lead to inappropriate or illegal disposal (US EPA 2011).

14.6 INDICATOR SUMMARY

Indicator	Policy Issue	DPSIR	Assessment	Trend
Waste per capita (Halifax)	Human Behaviour, Waste Management	Pressure	Fair	-
Shoreline Cleanup Results	Human Behaviour, Waste Management	State	Poor	+
Marine mammals entangled in debris	Waste Effect on Animals	Impact	Poor	+
Plastics ingested by marine mammals	Waste Effect on Animals	Impact	Poor	+

Key:
Negative trend: - Unclear or neutral trend: / Positive trend: + No assessment due to lack of data: ?

Data Confidence

- Much of the evidence that exists on the Scotian Shelf is circumstantially collected
- Worldwide, current statistics and future trends for marine debris are uncertain
- Unsure of accuracy of marine waste studies

Data Gaps

- More recent (2000-2010) comparative studies are needed to examine trends in marine debris on the Scotian Shelf
- Landfill data for Nova Scotia unavailable

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Emerging Issues

15. EMERGING ISSUES[27]

Atlantic Coastal Zone Information Steering Committee Secretariat, Halifax, NS

15.1 ISSUE IN BRIEF

This paper discusses a number of emerging issues that are beginning to impact or are expected to impact the economic, social and environmental health of the Scotian Shelf. This document follows the definition of "emerging issue" used in the recent State of the *Gulf of Maine Report* on Emerging Issues: "an issue, positive or negative, which is not yet generally recognized but which may have significant impact on human and/or ecosystem health in the 21st Century" (Wells 2010 from Munn et al. 1999). The issues selected for this paper are emerging in one of three ways. Issues are either already present on the Scotian Shelf, but are currently in a state of flux; are of concern on a global scale and may or may not already be impacting the Scotian Shelf; or are already recognized on the Scotian Shelf, but have not yet been addressed by management. The selection of topics was made in recognition of broader studies that have identified research directions with the greatest potential to address future opportunities and challenges in Canada's oceans (e.g. Council of Canadian Academies' *40 Priority Research Questions for Ocean Science in Canada*) and with the aim of avoiding duplication with issues already discussed in previous theme papers (see *State of the Scotian Shelf* website). Additionally, offshore issues were given priority, as detailed discussions of coastal issues in Nova Scotia can be found elsewhere (e.g. *Nova Scotia's State of the Coast Report*). Similar to other theme papers, this report is informed by the driving forces-pressures-state- impacts-response (DPSIR) framework. However, due to the large number of topics discussed, it was not feasible in this brief report to apply the DPSIR framework in its entirety.

15.2 PRESSURES

Other theme papers in the State of the Scotian Shelf report provide in-depth examinations of important pressures and drivers that presently affect the Scotian Shelf. Established pressures such as climate change, ocean acidification, and pollution have been well documented in past theme papers and are not discussed here (see *Climate Change and Its Effects on Ecosystems, Habitats and Biota; Ocean Acidification and Marine Waste and Debris*). The pressures discussed below are exerting influence on human activities and thus affecting the Scotian Shelf ecosystem.

15.2.1 Changing Consumer Demands for Seafood

Demand for Scotian Shelf seafood products is not new, but consumers are increasingly seeking sustainable and traceable fishery and aquaculture options. Furthermore, commercial interest is expanding for both low-trophic level fish species and alternative products derived from ocean resources. These market pressures have already begun to affect activities on the Scotian Shelf, and will continue to do so in the future.

15.2.1.1 Sustainable and Traceable Fisheries: As mentioned in past State of the Scotian Shelf theme papers (see *Fish Stock Status and Commercial Fisheries* and *Trophic Structure*), there is growing interest in sustainable seafood options. Recent research from the World Wildlife Fund (WWF) found that 91% of Canadians feel that it is important that the seafood they purchase comes from sustainable and non-overfished stocks (WWF 2011). In Atlantic Canada,

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[27] Completed June 2013.

consumer demand for sustainable seafood products is evidenced by the success of initiatives such as community supported fisheries (e.g. Off the Hook) and eco-certification. The Marine Stewardship Council (MSC) is the primary eco-certification body at work in Atlantic Canada. A number of Scotian Shelf fisheries have received MSC certification, including Scotian Shelf shrimp, Scotian Shelf snow crab (trap), and swordfish. More fisheries are currently undergoing screening for future certification, such as Atlantic halibut (MSC 2013).

While the rise of eco-certified fisheries is encouraging, consumers still encounter challenges when making seafood purchasing decisions. For example, only 8% of Canadians surveyed by WWF felt they had access to adequate information about the source of their seafood (WWF 2011). Unregulated labelling can make it difficult for a consumer to accurately weigh the sustainability claims of a given seafood product (Nikoloyuk and Adler 2013). Some groups have criticized the criteria and standards used by certification bodies such as the MSC. For example, some non-government organizations criticized the certification of the swordfish longline fishery off Nova Scotia due to its bycatch (EAC 2011).

As well as certification, other consumer initiatives exist. For example, SeaChoice has developed a widely used consumer guide that provides recommendations on the sustainability of specific seafood products (SeaChoice 2012). Another initiative, Ecotrust Canada's ThisFish (2011), allows for even more specific traceability by providing information on individual fish. In the future, the growing influence of these initiatives may place pressure on Scotian Shelf fisheries to adapt their fishing practices to meet certification requirements, and to communicate these changes to consumers.

Although growing demand for sustainably caught seafood is present in the Nova Scotian market, it's not clear if there is the same demand in foreign export markets. Over 50% of Nova Scotia seafood is exported to the United States, Europe and Asia (for details see the theme paper on *Fish Stock Status and Commercial Fisheries*). There are mixed indications of demand in those markets for sustainable seafood (see Jacquet and Pauly 2007; MSC 2011; 2012a; 2012b). Since consumer pressures may not influence fisheries that are destined for other countries, non-market mechanisms may be required in order to increase the sustainability of export fisheries.

15.2.1.2 Sustainable Aquaculture Alternatives: Due to the depletion of wild fish stocks, much of the recent increase in global demand for seafood has been met by aquaculture. Overall aquaculture production in Nova Scotia increased from 1.5 million kilograms in 1994 to 8 million kilograms in 2011 (NSFA 2012b). The expansion of nearshore finfish (largely salmon) aquaculture in Nova Scotia, supported by the Nova Scotia Aquaculture Strategy, has been accompanied with some opposition due to competing coastal uses and concerns about environmental impacts (NSFA 2009a; 2009b). Some concerns associated with nearshore aquaculture expansion may be eased by moving facilities to offshore areas, to land-based systems, or by applying integrated multi-trophic aquaculture (IMTA).

One alternative to coastal open-pen aquaculture is offshore aquaculture: the cultivation of either finfish or shellfish in exposed areas of the open ocean that are still within a country's Exclusive Economic Zone (Troell et al. 2009). Initial research projects in the Gulf of Maine have successfully cultivated cod in open pens 13 kilometres offshore (Rillahan et al. 2011). Though offshore aquaculture addresses the coastal use conflict, environmental impacts could still arise (Brenner et al. 2012; Kaiser et al. 2011; Rillahan et al. 2011). Ongoing offshore aquaculture research in the Bay of Fundy and in Newfoundland could help to locate sites on the Scotian Shelf with the potential to cultivate species such as sturgeon, char, halibut and cod (ACOA 2012a;

ACOA 2012b). Another alternative is integrated multi-trophic aquaculture (IMTA), or the integration of finfish aquaculture within vertebrates such as mussels and/or algae to aid in the decomposition of wastes linked to environmental impacts (Ridler et al. 2007). IMTA research completed in the Bay of Fundy may assist the development of this type of aquaculture on the Scotian Shelf (Barrington et al. 2010; Chopin and Robinson 2004).

DFO has noted that sustainable aquaculture development will require the development of ecologically appropriate technology and environmentally sustainable practices (DFO 2013). Management and policy regimes, at both federal and provincial levels, need to address issues associated with sustainable aquaculture expansion. The 2012 report Aquaculture in Canada mentions that a movement exists towards integrating "legislation and regulations to facilitate sustainable development, improve financial viability, and encourage investment so that the full potential of the sector can be achieved" (DFO 2012a). In addition, the Nova Scotia Aquaculture Strategy outlines the province's intentions to improve current legislation (i.e. licensing and leasing processes, environmental monitoring methods) to make aquaculture expansion in Nova Scotia sustainable (NSFA 2012a).

15.2.1.3 Fishing at Lower Trophic Levels: Over the past three decades, a significant trend in Scotian Shelf fisheries has emerged involving the type of species being harvested; species are from lower trophic levels than in the past. An ecosystem's trophic structure, also called "food chain" or "food web", represents the feeding relationships in an ecosystem (see *Trophic Structure*). Traditionally, Scotian Shelf capture fisheries were predominantly comprised of groundfish (Anderson et al. 2008). Over-fishing of these top predator fish species altered the trophic structure of the Scotian Shelf: the species they preyed on were released from predation pressure and became more abundant (Frank et al. 2005). This change has been reflected in Scotian Shelf fishery landings: in the mid-2000s, low-trophic level shellfish accounted for 80% of the value of landings (GPCE 2009). Traditional fisheries of Atlantic cod and haddock have now been replaced with lobster, crab, sea cucumber and sea urchin. Overall, the average trophic level of Scotian Shelf fish landings has declined sharply since the collapse of the cod fishery (Anderson et al. 2008). The ecological effects of "fishing down marine food webs" are not entirely understood (Anderson et al. 2008). Future cod stock recovery may have effects on some low trophic fisheries. Cod has been shown to exert top-down predatory control on lobster (Boudreau and Worm 2010), meaning that a cod recovery could potentially negatively impact the lucrative lobster fishery.

15.2.1.4 Alternative Products from Ocean Resources: Bioprospecting is the search for bioactive substances in natural environments. To date, the majority of bioproducts used in chemistry, pharmacology, cosmetics, food, and agriculture have originated from terrestrial ecosystems. Increasing activity to search for bioactive substances in the marine environment may increase environmental disturbances. International negotiations have repeatedly noted the lack of detailed information to support policy responses on the conservation and sustainable use of marine genetic resources (Leary 2008). Leary identified a number of knowledge gaps including legal frameworks and intellectual property rights in relation to the Convention on Biological Diversity. Patents on genetic resources are a significant part of the commercialization of new discoveries; for example, 135 patents using marine genetic resources were filed in the United States and Europe between 1973 and 2007 (Leary 2008).

In addition to bioprospecting for bioactive substances, there is already ongoing use of local marine resources for the functional food and nutraceutical industry. Nutraceuticals are isolated or purified products that offer a physiological benefit or provide protection against chronic disease; they are generally sold in medicinal forms (AAFC 2012). Nutraceutical products produced in Nova Scotia include fish oils, dietary supplements, and seaweed-based food additives (NSDA nd). Nova Scotia's Life Sciences and Biotechnology Industry Association, BioNova, emphasizes that most of the research and development efforts in the province's life science sector are focused on marine biotechnology, indicating a strong orientation towards exploiting ocean resources (BioNova 2007). The expansion of the marine bio resources industry is evidenced by the 2013 BioMarine International Business Convention, held in Halifax and co-organized by the National Research Council (BioMarine 2012).

15.2.2 Energy Demand

The International Energy Agency forecast that by 2035, global energy demand will increase by one third (IEA 2012). With this significant growth, exploration and development of fossil fuels in offshore areas such as the Scotian Shelf is expected to intensify. In addition, development of ocean-based renewable energy sources is also expected to expand; these include tidal, wave and offshore wind energy.

15.2.2.1 Deep Water Oil and Gas Exploration: Deposits of crude oil and natural gas exist within sediments below the ocean floor of the Scotian Shelf (CCEI 2007). Current production includes natural gas from the Sable Offshore Energy Project; the Deep Panuke project is expected to begin production in 2013 (Encana 2013). In 2012, permits were issued to Shell Canada Limited and BP Exploration Company Limited to explore deep-water locations adjacent to the Scotian Shelf, illustrating a trend of oil and gas exploration in increasingly deep offshore waters (**Figure 15-1**).

Concerns surrounding the exploration and development of petroleum resources in the deep waters of the Scotian Shelf include impacts on seabirds, deep-water coral communities, deep diving whales, and commercial fisheries (Lee et al. 2011) (see theme papers on *Incidental Mortality* and *Ocean Noise*). These concerns were heightened by the Deepwater Horizon incident in April 2010 in the Gulf of Mexico, when five million barrels of oil were released. Fisheries were closed for a year or longer, but the long-term impacts of this unprecedented oil spill are still unknown (McNutt et al. 2012; Ylitalo et al. 2012). In Nova Scotia, the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) is the entity responsible for "compliance, environmental protection; management and conservation of petroleum goods; and safety" (CNSOPB 2012). The 2012 Fall Report of the Commissioner of the Environment and Sustainable Development reported that the CNSOPB generally achieved its responsibilities in terms of environmental protection (CESD 2012). The same report identified several areas where imporvements in the Board's operations were recommended. Those recommendations were accepted and efforts are underway to respond to them (CESD 2012; CNSOPB 2013a).

If these recommendations can be addressed, Nova Scotia will be well-situated to respond to the persistent global demand for petroleum by supplying new export markets, for example in the United States (NSDoE 2012a). This could provide significant economic benefit to the province. In 2006, the offshore petroleum industry contributed $800 million to Nova Scotia's GDP and employed over 600 people (GPCE 2009).

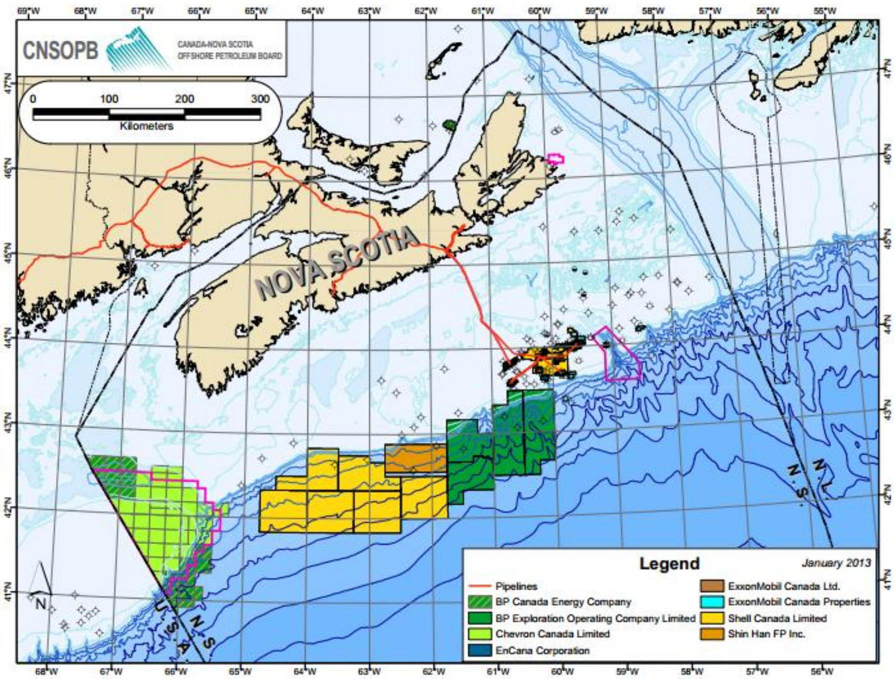

Figure 15-1: Map showing boundaries of exploration licenses on the slope and deep water adjacent to the Scotian Shelf (CNSOPB 2013b).

14.2.2.2 Marine Renewable Energy: The government of Nova Scotia has set ambitious renewable energy targets of 25% by 2015 and 40% by 2020 (NSDoE 2010). Tidal, wind, and wave energy are all forms of renewable marine energies suitable for development on the Scotian Shelf (Cornett 2006; DFO 2012b). Marine energy systems can also promote economic development, decrease reliance on fossil fuels, and potentially improve the stability of electricity prices in the province (NSDoE 2012b).

The Inventory of Canada's Marine Renewable Energy Resources has led to an increased recognition of the Canadian potential of tidal energy (Cornett 2006). Unlike wave and wind energy, tidal power is predictable and more reliable (Cornett 2006). Tidal energy is currently in the developmental stage and research is focussed in the Bay of Fundy; however tidal power potential of sites on the Scotian Shelf has been shown to be significant (see **Table 15-1**) (NSDoE 2012b).

Table 15-1: Mean power for tidal energy sites on the Scotian Shelf (after Cornett 2006).

Site Name	Latitude	Longitude	Mean Power Density (kW/m^2)	Mean Potential Power (MW)
The Hospital	43.44	-66.00	0.63	50
Ellewoods Channel	43.66	-66.05	0.63	1
Cape Sable	43.35	-65.66	0.63	15
Baccaro Point	43.44	-65.47	0.26	2
Great Bras d'Or	46.29	-60.41	1.22	3
Barra Strait	45.96	-60.80	0.26	3
Flint Island	46.17	-59.79	0.20	2
St. Ann's Harbour	46.29	-60.41	1.22	2

As with tidal power, wave energy has received increased recognition due to the Ocean Energy Atlas project (Cornett 2006). Wave energy has great potential, but available energy varies seasonally and is unpredictable. As illustrated in **Figure 15-2**, several areas within the Scotian Shelf could support wave energy (Cornett 2006). However, despite promising research completed off the coast of Newfoundland (NRCan 2008), the Nova Scotia Marine Renewable Energy Strategy (2012b) indicated that wave energy is not a priority. Wind energy in offshore areas is often more constant and powerful than in coastal locations (Cornett 2006). However, like wave energy, it is unpredictable. Despite this challenge, offshore wind energy has had considerable success in countries such as Denmark and Sweden (Breton et al. 2009). An established understanding of wind energy technology, as well as proposed developments on the west coast of Canada and in the Great Lakes (DFO 2012b) could eventually spur the placement of turbines on the Scotian Shelf.

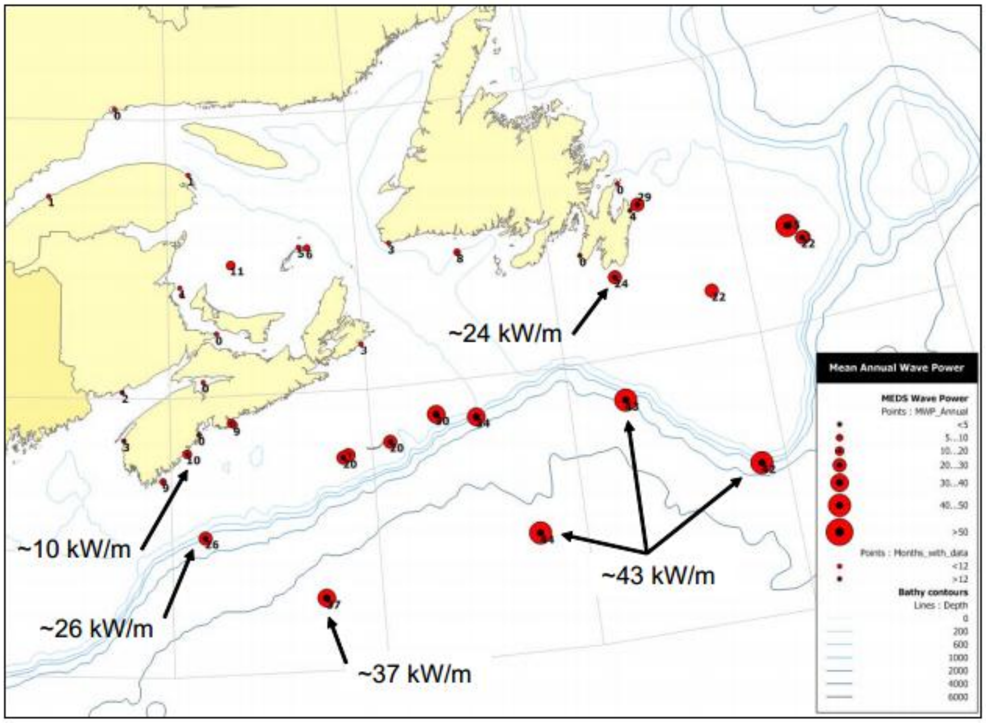

Figure 15-2. Annual mean wave power for sites in the Northwest Atlantic (after Cornett 2006).

15.3 IMPACTS

Other theme papers have examined current drivers and pressures and their impacts on the Scotian Shelf. Below, we discuss a number of emerging impacts that warrant greater monitoring to fill information gaps. They have been selected to inform resource managers and the interested public of impacts that conceivably may affect the Scotian Shelf in the near future, based on global observations and scientific theories.

15.3.1 Impacts from Increased Greenhouse Gas Emissions and Climate Change

Global emissions of carbon dioxide increased by 3% in 2011, reaching an all-time high of 34 billion tonnes in 2011 (Olivier et al. 2012). Global energy demand is driving fossil fuel use, which increases atmospheric concentration of carbon dioxide. The resulting changes in ocean temperature and ocean chemistry are occurring rapidly and will have significant impacts on the marine ecosystem. For a detailed analysis of climate change impacts that have already been observed on the Scotian Shelf, refer to the theme paper on *Climate Change and Its Effects on Ecosystems, Habitats and Biota*.

15.3.1.1 Impact of Ocean Acidification on Sound Transmission: Rising concentrations of atmospheric carbon dioxide is lowering the pH of oceans, a process known as ocean acidification (see **Figure 15-3**; for further detail see *Ocean Acidification*). This issue is particularly relevant to the Scotian Shelf because the North Atlantic is responsible for a disproportionally high amount of carbon dioxide uptake, and is also particularly vulnerable to pH changes (Sabine and Feely 2007). Impacts of ocean acidification on marine ecosystems are not fully understood and require further study.

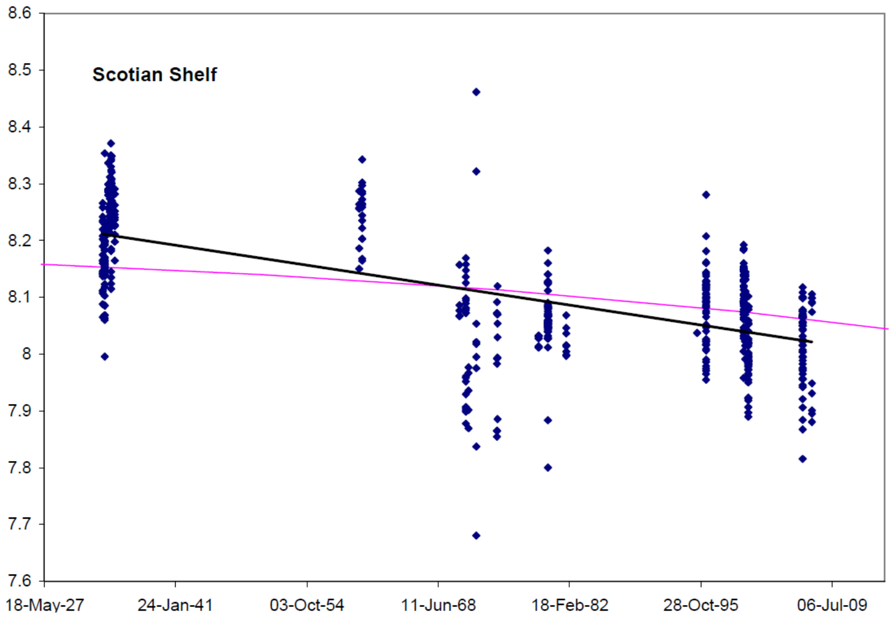

Figure 15-3: Decrease in pH on the Scotian Shelf over the past century (adapted from DFO 2009). Time is displayed as day-month-year. Blue points represent pH measurements from various locations on the Scotian Shelf, the black trend line indicates a decrease in pH with time, and the pink trend line represents the mean global ocean decrease in pH over the same time period.

For example, the potential effect of ocean acidification on ocean noise has yet to be fully researched. As the ocean becomes more acidic, the sound absorption capacity of sea water at low frequencies is decreased (University of Rhode Island 2011). As sound travels through the ocean, some of the energy in the sound wave is absorbed, causing the sound wave to become weaker. As borate ions are largely responsible for sound absorption and their concentration in seawater depends on pH, acidification would result in a decrease in sound absorption (see **Figure 15-4**) (University of Rhode Island 2011). Many marine mammals, such as the 23 species that inhabit and migrate through the Scotian Shelf, depend on sound for communication, navigation and hunting, so this impact could potentially affect their behaviour (DFO 2003).

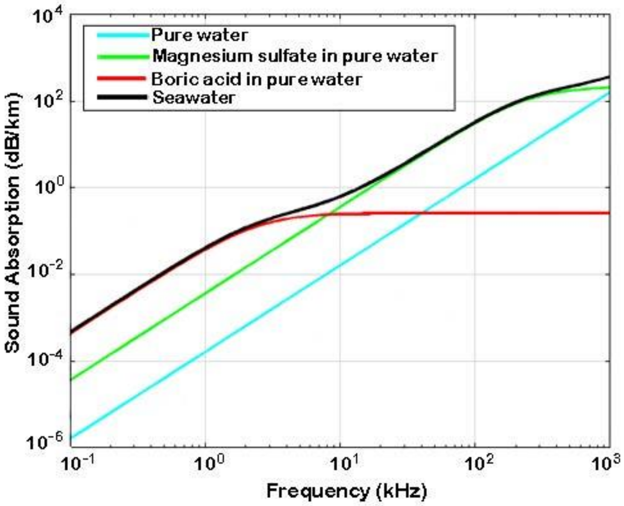

Figure 15-4: Sound absorption capacity vs. frequency response of pure water, seawater and solutions of magnesium sulphate and boric acid (Brewer and Hester 2009 calculated from Ainslie and McColm 1998).

15.3.1.2 Timing of Seasonal Ecosystem Events: As discussed in other theme papers, climate change has a strong potential to alter seasonal ecosystem events on the Scotian Shelf. This, for example, could disrupt predator-prey relationships or reproduction success of some species. The timing of these events can differ in response to both seasonal environmental variability and anthropogenic climate change (FAO 2013). A key component of the Scotian Shelf ecosystem is phytoplankton, as the rest of marine ecosystems rely on this primary producer (see *Primary and Secondary Producers*). A complex picture is emerging of how climate change may affect phytoplankton abundance and distribution generally and on the Scotian Shelf in particular. For example, Sameoto (2004) showed that annual phytoplankton blooms on the Scotian Shelf have been occurring earlier in the year, and that abundance increased over the period from 1991-2000. While climate change's effects on ocean temperature, salinity and circulation may explain these changes, Frank et al. (2005) suggest that the collapse of Scotian Shelf cod stocks resulted in cascading effects through lower trophic levels of the food web, including an increase in phytoplankton. However, a global study showed that overall phytoplankton abundance in seven of nine ocean regions, including the North Atlantic, is declining (Boyce et al. 2010). These inconsistent findings emphasize why this is an emerging issue on the Scotian Shelf that requires further investigation into the various mechanisms, including climate change, that affect the timing of important ecosystem events like seasonal phytoplankton blooms.

15.3.2 Impacts from Debris and Pollutants

Marine pollution in all its forms has long been recognized as a threat to marine ecosystems around the world. The theme papers on *Marine Waste and Debris, Water and Sediment Quality,* and *Incidental Mortality* review the current range of these impacts on the Scotian Shelf. Here, we focus on two issues that have not yet been studied on the Scotian Shelf, but nonetheless pose a potentially significant threat.

15.3.2.1 Microplastic Particles: Microplastics are micro-sized (≤5mm) particles of plastic in the marine environment that originate from solid waste entering the ocean via land or sea based sources (e.g. waste water discharge, illegal dumping and shipping) (GESAMP 2010). A particular challenge is the high resistance of microplastic to aging, and its minimal biological degradation in the marine environment (Moore 2008). Microplastics are a concern for the Scotian Shelf ecosystem for a number of reasons: not only are they ingested by marine animals, but they may act as vectors for transporting harmful substances (GESAMP 2010). As microplastics are not currently monitored on the Scotian Shelf the extent of current impacts is unknown, but there is evidence of microplastics throughout the western North Atlantic (Cole et al. 2011; Morét-Ferguson et al. 2010), and no reason to suggest that the Scotian Shelf would be an exception to this pattern.

As plastic debris persists in the marine environment, it fragments into increasingly smaller pieces which are more likely to be ingested by smaller marine organisms (Browne et al. 2008). Also, the buoyancy of smaller pieces of plastic increases the likelihood of mixing with surface food sources (Boerger et al. 2010). The ingestion of plastic by larger organisms like seabirds, marine mammals, turtles and some fish species has been well documented; however, the ingestion of these microplastics by lower trophic organisms has not been as thoroughly investigated. A laboratory study on ingestion of microplastics found several marine invertebrates and filter-feeders were able to ingest microplastics, including lugworms, amphipods, barnacles and even mussels (Browne et al. 2008). Little is known about the effects of ingestion of microplastics by species at the base of the food web and it is unknown if microplastics can be transferred across different trophic levels (Moore 2008). For example, it is still uncertain whether or not microplastics are being deposited in deep sea sediments (Betts 2008, GESAMP 2010). The movements of these plastics also need special attention. For example, plastic fragments with biofilms may sink, but may then become buoyant once the biofilm has been removed (GESAMP 2010). Marine managers should be aware of these knowledge gaps, and moving forward, the quantity and nature of microplastics on the Scotian Shelf should be monitored.

As microplastics decrease in size, the possibility for chemical transport through absorption of chemicals or leaching out increases (Teuten et al. 2009). Evidence suggests that microplastics act as a medium for transporting bioaccumulating toxic substances (GESAMP 2010), invasive species (Barnes 2002), and persistent organic pollutants (POPs) (Ritter et al. 2007). Microplastics provide a new habitat within pelagic ecosystems, and some marine insects use microplastic particles as a surface on which to lay eggs (Goldstein et al. 2010). This new habitat could lead to changes in marine insect populations, with repercussions for the broader ecosystem. Also of concern are chemicals added to plastics during the manufacturing process, which may then leach out upon ingestion (Teuten 2009). There is also evidence that some bacteria may contribute to the decomposition of marine plastic, which could potentially reduce the quantity of microplastic debris (Zaikab 2011). It is possible but not well understood how this plastic decomposition may constitute a new entry point in the food chain. The potential for microplastics to carry disease-causing organisms is discussed in section 15.3.4, Emerging Diseases. More information is clearly required about the sources, distribution, fate, and potential impact of microplastics in the marine environment, as we lack adequate knowledge of their potential physical and chemical effects on marine organisms (GESAMP 2010).

<u>15.3.2.2 Emerging Chemical Containments</u>: The theme paper on *Water and Sediment Quality* summarizes the state of contamination of Scotian Shelf waters by known pollutants (i.e., halocarbons, hydrocarbons and metals). The same theme paper also lists a number of emerging

contaminants that are not routinely monitored on the Scotian Shelf, including flame retardants, pharmaceuticals, organophosphate esters, chlorinated paraffins, perfluorinated compounds (PFCs), and antifouling biocides. Some of these chemical constituents had not historically been considered contaminants and are now present in the environment on a global scale. Still others are new chemicals manufactured for the presumed benefit of society, and are entering the environment through pathways such as agricultural applications and disposal of industrial and municipal waste water. There are a number of programs in Canada that monitor chemical contaminants in marine environments. There is also legislation that requires contaminant emitters to report pollutant releases of 346 different anthropogenic substances (see National Pollutant Release Inventory). However, there is a gap in monitoring of emerging chemical contaminants in Canada. In contrast, the United States Geological Survey currently analyzes for 168 emerging contaminants including pharmaceuticals, fire retardants, polyaromatic hydrocarbons (PAH), plasticizers and household chemicals.

Of particular concern are compounds with the potential to disrupt the endocrine systems of marine organisms, meaning possible interference with normal hormone production. This disruption could result in, for example, problems with the reproductive cycle. Mearns et al. (2012) summarizes a number of studies where pollutants disrupted endocrine function in a number of marine species. Endocrine-disrupting alkylphenols can kill larvae at relatively low concentrations, and they are thought to have adverse effects on segmented worms and molluscs as well (Laufer et al. 2012). Further experiments are needed to understand endocrine-disrupting compounds, and to help predict the effects of mixtures of these substances (Rodríguez et al. 2007).

15.3.3 Emerging Diseases

As the result of climate variability and human activity, disease-causing pathogens (e.g., viruses, bacteria and fungus) have emerged in many regions of the world's oceans (Harvell 1999). Research and monitoring on this topic is lacking on the Scotian Shelf; however, species that are important to the aquaculture and fishing industries (e.g., oysters and quahogs) have been shown to be vulnerable in nearby regions, such as coastal Massachusetts (Cook et al. 1998; Perrigault et al. 2011). While these pathogens occur naturally in marine environments, their prevalence, and therefore potential to cause negative effects, is often increased due to sources such as sewage effluent, runoff, ship waste, industrial processes and recreational activities (Zielinski et al. 2009). For example, globally, stressors associated with fish and shrimp aquaculture (e.g. displaced animals, high density culture, artificial feeds) coupled with increasing human stressors on wild populations (e.g. over-exploitation), have led to a number of new diseases affecting many marine species (Walker and Winton 2010). Climate change, specifically rising sea surface temperatures, is another pressure that has been linked with increasing occurrence and distribution of disease-causing pathogens in marine animals (Bally and Garrabou 2007; Harvell et al. 1999; Munn 2006; Ward and Lafferty 2004; Ward et al. 2007). A warmer climate is generally expected to increase the prevalence of hosts infected with disease-causing pathogens (Harvell et al. 2009). However, Lafferty (2009) noted that little evidence exists that current climate warming has already expanded the range of infectious diseases, and that other factors may be to blame for recent increases in diseases. Six of nine marine species studied by Lafferty (2009) have seen an increase in disease prevalence, but climate change was the suspected cause in only corals and sea turtles. The same study predicted that climate change will mostly cause a shift in the range of infectious diseases, as opposed to a net increase in their distribution.

As discussed above, microplastics are an emerging pollutant worldwide (Harrison et al. 2011). It is known that oceanic plastic debris can lead to invasions of foreign species (Barnes 2002), but the potential for interactions between microplastics and disease-causing organisms is less understood (Harrison et al. 2011). In one study, the most common genus of bacteria found on plastic debris (Vibrio) was one known to cause disease in both humans and animals (Amaral-Zettler et al. 2011).

15.4 ACTIONS AND RESPONSES

15.4.1 Information Accessibility

The Commissioner of the Environment and Sustainable Development has stated that "solid, objective, and accessible information is essential to identify and respond to the quickening pace and complexity of environmental change, in Canada and globally" (CESD 2010). Availability of and access to information is a prerequisite for successful management initiatives (Mossbauer et al. 2012) to address the multiple complex existing and emerging issues on the Scotian Shelf. The European Commission (2012a) suggested, for example, that existing data should be standardized, integrated with socioeconomic data, and organized in information systems that can work together to help identify gaps, steer coastal and marine monitoring and spatial data acquisition and improve assessment and policy advice (Meiner 2011). Although there are some promising information management initiatives in Canada (e.g. RDSWG 2011; Canadian Space Agency 2013), a concerted and coordinated investment in marine data and information infrastructure could help to improve the accessibility of information necessary for the sustainable development of oceans and coasts.

15.4.1.3 The Open Data Movement: The principle of data accessibility is taken a step further with the open data movement. Open data means data and information that is freely available to use without restrictions. Some benefits of open government data include improved public services, oversight of public sector activities, reduced costs of collecting and managing data, creating business opportunities, building trust with citizens, and creating platforms for public engagement (Deloitte Analytics 2012). However, unintended harmful consequences (e.g., unintentionally revealing the location of commercially valuable endangered species habitat) should be anticipated and avoided. In Canada, the open data movement is represented by two related federal government initiatives: the Open Data Portal (data.gc.ca) and the Federal Geospatial Platform (Canadian Space Agency 2013). Several open data initiatives have been established at the provincial (e.g. British Columbia data.gov.bc.ca) and municipal levels (e.g. Halifax Regional Municipality Open Data Pilot). The Government of Nova Scotia is exploring Open Data options for geographic data (GeoNova 2013).

Coastal mapping plays an important role for decision makers (O'Dea et al. 2011), and Internet-based coastal management portals are becoming a more common way to provide access to geospatial data. They are often in response to supporting policy initiatives (e.g. U.S. *Coastal Zone Management Act* and the European Union Water Framework Directive) (ICAN 2013, European Commission 2012b). Such a portal has not been realized for the Scotian Shelf.

15.4.2 Integrated Coastal and Oceans Management on the Scotian Shelf

Integrated Coastal and Ocean Management (ICOM) is an emerging issue on the Scotian Shelf as identified by a number of authors (Hedley 2006; Dutka et al. 2010; Rutherford et al. 2010). In order to move forward with integrated oceans management, Rutherford et al. (2010) suggest that there must be: more consistent higher level commitment and advocacy; dedication of long-term funding; development of measurable goals and targets with timelines; more effective strategies; and implementation of comprehensive monitoring and adaptive management. The Eastern Scotian Shelf Integrated Management (ESSIM) initiative is the most significant effort for ICOM on the Scotian Shelf to date. Drafting the ESSIM plan involved over ten years of stakeholder involvement to develop from concept to final draft plan (1998-2007). The absence of endorsement of the final draft plan by the Minister of Fisheries and Oceans has been interpreted by partners and stakeholders as a shortage of commitment and consistency at a higher level. Implementation of the plan has thus been voluntary and unofficial. The final meeting of the Stakeholder Advisory Council (SAC), one of the components of the collaborative planning model in the ESSIM plan was held on May 23, 2012 ending the ESSIM Initiative (McCuaig and Herbert 2013) and the SAC's shared "responsibility for leadership and guidance in meeting the vision for the ESSIM Initiative" (DFO 2007: 23). However, the Regional Committee on Coastal and Ocean Management (RCCOM) has continued to meet. The RCCOM is comprised of federal and provincial governments and its continued work is seen by some as an ESSIM success story (Dutka et al. 2010). Several other tangible outcomes and benefits from ESSIM have been identified (Hedley 2006; Dutka et al. 2010; McCuaig and Herbert 2013). In general, voluntary and unofficial implementation of management strategies for the ESSIM plan has led to moderate to significant progress on some strategies and limited progress on others (McCuaig and Herbert 2013).

Future progress for ICOM on the Scotian Shelf requires improvements some of which are described by Rutherford et al. (2010) above. Two specific improvements that have been identified are: drafting a detailed implementation plan soon after the management plan is finalized to maintain momentum and senior level support (McCuaig and Herbert 2013); and providing greater leadership for implementation (Dutka et al. 2010).

15.4.2.1 Indicators for Ecosystem Based Management : Ecosystem based management (EBM) is an approach that seeks to broaden the scope of traditional resource management by treating ecosystems as whole entities affected by a broad range of factors (Curtin and Prellezo 2010). Instead of managing for a single species or single issue, EBM tends to evaluate multiple simultaneous "drivers" or "pressures" affecting a geographic region (Curtin and Prellezo 2010).

In order to implement EBM, indicators are needed that can provide timely insight into the behaviour, state and trajectory of a system as complex as a marine ecosystem. Active and adaptive management can only occur when robust indicators are routinely collected, as is the case, for example, with national economies (Gibbs 2012). Gibbs argues for dynamic indicators and supporting monitoring systems that focus on flows and rates. New technologies should eventually provide the needed information to support new indicators (Gibbs 2012). Other theme papers of the State of the Scotian Shelf Report have identified dozens of indicators, both biological and socioeconomic. However, not all of the indicators identified are being consistently measured; data gaps are common and data confidence is varied. It may be helpful for Scotian Shelf managers to know what indicators are actively being monitored on the Scotian Shelf, and have routine access to assess these datasets. In addition, the suite of indicators as identified in the theme papers should be reviewed to meet the needs of operational management.

15.4.2.2 Ecosystem services valuation has been increasingly used as a tool to assist in the implementation of EBM. Ecosystem services are the benefits humans obtain from ecosystems, including food, fuel, clean air, genetic information, and climate regulation processes, as well as cultural, spiritual, educational and recreational benefits that contribute to human health and well-being (UNEP-WCMC 2011). The Economics of Ecosystems and Biodiversity (TEEB) project (2012) suggested that according to some estimates coastal and ocean biomes may provide as much as two-thirds of global ecosystem services. A better understanding of the economic value of marine ecosystems could substantially improve the management of critical marine resources; improve governance, regulation, and emerging ocean policy; and, provide better understanding of the potential economic challenges that arise from a rapidly changing ocean environment (TEEB 2010, 2012). New economic opportunities might also be revealed through demonstrating the economic value provided by ocean and coastal biomes (TEEB 2012). For example, Fujita et al. (2013) suggest an approach called "ecomarkets," whereby new kinds of markets for coastal ecosystem goods and services not recognized by conventional markets are created based on area and resource use privileges. DFO is currently pursuing another application of ecosystem services, as discussed in the 2012 Fall Report of the Commissioner of the Environment and Sustainable Development, which is to identify and assess the specific ecosystem services provided by existing or planned marine protected areas (CESD 2012).

15.4.2.3 Emerging Aspects of Marine Spatial Planning: Marine spatial planning (MSP) has been identified as an important tool to support ecosystem-based management (Ehler 2008). Doherty (2005) suggests that zoning, an aspect of MSP, could play a role in ecosystem-based management on the Scotian Shelf. MSP is heavily influenced by increasing demand for ocean space and ecologically responsible decision-making about new uses of the sea (Douvere and Ehler 2009).

Ehler (2008) defines factors that are needed for successful MSP implementation (see **Table 15-2**). MSP has been implemented in marine areas where conflicts for use of ocean space made other management techniques difficult to implement. For example, in Belgium and the Netherlands, where conflicts for the use of marine space were clear, MSP was a response to new national objectives for offshore wind farms and European requirements for marine protected areas (Douvere and Ehler 2009). In contrast, levels of competition for offshore ocean space have not yet materialized on the Scotian Shelf to the same degree as the North Sea. If new uses of marine space on the Scotian Shelf are realized (e.g. offshore wind farms, wave energy, marine bioprospecting) the need for marine spatial planning for the Scotian Shelf may increase. In addition, the need to implement climate change adaptation measures may require proactive planning of human activities in certain parts of the ocean, a process that can be supported by MSP. The Gully Marine Protected Area, the first MPA on the Scotian Shelf, is a local example of MSP as regulations define three zones of acceptable use. A range of other spatial planning measures are already at play on the Scotian Shelf, like the MPA network planning process (see *National Framework for Canada's Network of Marine Protected Areas*), but there is an opportunity for these efforts to exhibit greater coordination.

An important emerging aspect of MSP is its ability to allow for greater public participation. One example is the ESSIM plan, which saw the establishment of an open and inclusive process for involving stakeholders in the development of an integrated ocean management plan (Hall et al. 2011). However, there is no policy direction or legislative mandate that requires MSP to be included in Canadian ocean management (Douvere and Ehler 2009). New technology can also play a role in facilitating public input in marine spatial planning. SeaSketch is an innovative GIS platform and web-based tool that enables collaboration over the internet; allowing ocean resource managers to work with partner agencies and stakeholders to make decisions about ocean resources (McClintock and Paul 2012). Systems like SeaSketch could fundamentally transform the landscape of marine planning (Rumore 2012), although the tool is intended to help, not supplant, a well-designed collaborative planning processes. Another emerging application of MSP is the use of marine cadastres: information systems that chart rights and interests present in a marine area (Sutherland 2003). While this technique is evolving rapidly in other jurisdictions (e.g., USA and Australia), only a modest case study has been performed for Nova Scotia, in St. Margaret's Bay (Boateng 2009).

Table 15-2: Factors required for successful MSP implementation (from Ehler 2008).

1.	Legal authority and political support for MSP; ideally statutory and enforceable.
2.	Sound information base of both natural and social science.
3.	Clear and measurable objectives.
4.	Early and frequent stakeholder involvement.
5.	Consideration of plans and objectives in other sectors of the economy.
6.	Integration with plans for adjoining coastal areas, terrestrial land-use plans, and coastal watershed plans.

MSP yields the best results when it is underpinned by accurate spatial information. Acoustic imaging technology, like multibeam echo sounding, is now able to provide a picture of the ocean floor, revolutionizing the ability to collect invaluable contextual information for marine benthic habitat management (Pickrill and Kostylev 2007). In the context of a national marine mapping program, this bathymetry information has the potential to significantly advance our understanding of seafloor ecosystems (Brown et al. 2011). For example, Ireland's national marine mapping program has successfully supported the integrated management of multiple marine activities, collectively projected to be valued at over €400,000 million by 2016 (PricewaterhouseCoopers 2008). While many individual marine mapping projects occur in Canada, Canada has failed to develop a national marine mapping program, despite the success of early investments.

15.4.2.3 Marine Protected Areas Network Planning: Like integrated oceans and coastal management, the federal government has faced challenges in implementing Marine Protected Areas (MPAs). A recent report of the Commissioner of Environment and Sustainable Development concluded that DFO had not met its commitment to create a network of MPAs, although some progress towards that goal is being made (CESD 2012). MPAs were originally conceived in the context of larger ocean management plans such as ESSIM. Although these larger plans have taken longer, and in the case of ESSIM, the initiative has come to an end, the network model of MPA planning has benefitted from this work. MPAs can provide a range of benefits for fisheries, local economies and the marine environment (Toropova et al 2010). The network model for MPA planning is in progress and will help in responding to pressures on the Scotian Shelf ecosystem.

15.4.3 Climate Change Adaptation

Consequences of climate change in the marine environment of Atlantic Canadian include impacts on species, pest and pathogen distributions, aquaculture operations, and offshore operations (Vasseur and Catto 2008). DFO (2013) has recently identified six risks to aquatic ecosystems and society stemming from climate change: 1) ecosystem and fisheries degradation and damage; 2) changes in biological resources; 3) species reorganization and displacement; 4) increased demand for emergency response services; 5) infrastructure damage; 6) changes in access and navigability of waterways. While many management actions aim to mitigate these impacts, the focus is increasingly shifting toward management aimed at adaptation. In their *Planning Guide for State Coastal Managers* (2010), the National Oceanic and Atmospheric Administration (NOAA) advised that climate change adaptation will require new plans, laws and regulations, as well as changes to existing ones. It recommended that "all planning and rulemaking activities should consider climate change and future conditions so outcomes support, and do not deter, adaptation efforts" (NOAA 2010).

Climate change has been found to adversely impact the life cycle and workability of marine-related infrastructure (CBCL 2012). Infrastructure that is built with a multi-year design life deteriorates in the context of higher tides, stronger surges and/or accelerated erosion through increased wave action. Impacts on fisheries and infrastructure would be limited over the next 20 years, but significant in 50 to 100 years (CBCL 2012). For infrastructure adaptation, CBCL (2012) recommends keeping up maintenance in the short term, planning for increases in maintenance and protection in the medium term, and a range of adaptation options for the longer term, including abandonment. It is also possible that an increase in the severity and frequency of storms may trigger an increased need for search and rescue operations (Vasseur and Catto 2008). Debate remains as to whether or not storm severity and frequency on the Scotian Shelf has or will increase because of climate change (Masson and Catto 2013).

In relation to fisheries, it is possible that changes to species due to climate change may not be discernible from natural variability over the next 20 years (CBCL 2012). The challenge will be deciding when and how to change laws, regulations, quotas or harvest seasons in order to adapt to the impact of climate change that might only be significant in 50 to 100 years. These changes, both climate-related and regulatory, will have significant social and economic impacts on marine industries and dependent communities. Aquaculture operations would also need to be flexible as to the species cultivated and the timing of cultivation. A Washington State report (Adelsman and Whitely Binder 2012) also recommends measures that would significantly change the operation of fisheries and aquaculture sensitive to ocean acidification (see also the theme paper on *Ocean Acidification*).

Natural Resources Canada (NRCan) published climate change impact and adaptation reports in 2004 and 2008 which outline climate change adaptation in the natural resource, food, infrastructure, industry, natural environment, and health sectors. Since 2010, DFO's Aquatic Climate Change Adaptation Services Program (ACCASP) has supported large ocean basin climate change risk assessments; the development of new knowledge through science and technology to improve DFO's understanding of the impacts of climate change; and the development of science-based and applied climate change adaptation tools for use by DFO decision makers and the Canadian public. Two adaptation tool projects relevant to the Scotian Shelf were funded in 2012-2013: Incorporating Climate Change into Marine Protected Area Network Planning and Pilot Tools for Estimating Waves and Sea-level Extremes under Uncertain Climate Change Conditions (ACCASP 2013a, 2013b).

Handbooks have been published to guide municipalities in the creation of climate change adaptation plans (CIP 2011; Service Nova Scotia 2011). However, these handbooks do not directly address the particular vulnerabilities of communities dependent on fishing or other marine industries linked to the offshore. The range of existing planning resources for marine industry dependent communities may be inadequate for capturing the impacts of climate change on the offshore environment.

In examining the scope of adaptation measures suggested by NOAA (see **Table 15-3**), the present adaptation responses for offshore areas of the Scotian Shelf do not fully address the range of recommended measures. The Atlantic Climate Adaptation Solutions projects that have recently been active in coastal areas of Nova Scotia have focussed on adapting to socioeconomic impacts of climate change, such as flood mapping and infrastructure damage. Consequently, a broad ecosystem-based approach to climate change adaptation planning may be needed to better prepare for climate change impacts.

Table 15-3: Climate change adaptation measures recommended by NOAA (2010)

1. Impact Identification and Assessment
2. Awareness and Assistance
3. Growth and Development Management
4. Loss Reduction
5. Shoreline Management
6. Coastal and Marine Ecosystem Management
7. Water Resource Management and Protection

15.4.4 Science and Technology

Given the scientific complexity of the issues discussed in this report, it is clear that scientific and technological responses will be crucial in addressing emerging issues on the Scotian Shelf. The direction of scientific research in Canadian oceans is critically important, and has been recently commented on by two significant studies. The Royal Society of Canada Expert Panel (2012) recommended improved monitoring programs, a national program for mapping ocean habitat, the strengthening of basic and discovery-oriented research, and a comprehensive research program to forecast changes to marine biodiversity caused by climate change. Meanwhile, the Council of Canadian Academies (CCA) has identified priority areas for science investment. Among those relevant to the Scotian Shelf are the need for increased understanding of deep water areas and the role of microbial biodiversity (CCA 2012). In order for these scientific advancements to have tangible benefits on the Scotian Shelf, they must be integrated into policy. Although the integration of science in policy is a perennially popular topic, the strengthening of the science-policy interface can be seen as a missed opportunity in many cases (Kinder 2010). There is increasing demand that the science advice process not only be transparent to the public but actually involves the public and includes local and traditional knowledge (Kinder 2010).

15.4.4.1 *In Situ* Monitoring Sensors and Platforms: New types of technology are being utilized in ocean observation. For example, the Ocean Tracking Network (OTN) has employed acoustic tracking technology using receivers and tagged animals on the Scotian Shelf. There are two locations of multiple acoustic receiver deployments: offshore of Halifax and in the Cabot Strait (OTN 2012). Autonomous Vehicles are starting to be deployed to collect oceanographic information and are very cost effective over ships and buoys for some data collection tasks. Alternatively, cabled network observatory platforms have the advantages of high power, high band width, high temporal resolution, longevity, and interactivity, and are already well established on the west coast of Canada (OTN 2012).

There were 65 ocean observing system (OOS) projects in Canada as identified by the Ocean Science and Technology Partnership in 2010. The observations collected and disseminated by the responding systems were diverse in the types of data collected, addressed issues at the regional and local level, and were used for research (76.2 %), regulatory (42 %) and operational (53.6 %) monitoring purposes (OSTP 2011). Concerns identified were OOS sustainability and lack of coordination, in contrast for example to the Integrated Ocean Observing System in the United States which works closely with eleven regional associations to establish core capabilities that meet both national requirements and regional user needs.

15.4.4.2 Ocean Fertilization: As the effects of climate change are increasingly apparent, interest in large scale mitigation is growing as well. Ocean fertilization is a type of geoengineering, the "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming" (Royal Society 2009). One controversial technique introduces iron into the marine environment with the goal of stimulating a phytoplankton bloom, with the aim of increasing the amount of absorbed atmospheric carbon dioxide. In July 2012, a private company deposited approximately 100 tonnes of iron sulphate into the ocean off the Pacific Coast of Canada, resulting in a claimed phytoplankton bloom 10 thousand square kilometres in size (Lukacs 2012). The practice is considered a breach of the United Nations' Convention on Biological Diversity and the London Convention and Protocol on dumping wastes at sea and in 2013, amendments were proposed to the London Convention to clarify this.

The Intergovernmental Panel on Climate Change concluded that the effectiveness of ocean fertilization is unproven (IPCC 2007). Much more extensive research would be needed to determine if ocean fertilization is a viable climate change mitigation method and in fact, the July 2012 event was widely criticized (Tollefson 2012). Specifically, better mathematical models of the ocean's biogeochemical processes would be needed to predict the side-effects of large-scale ocean fertilization (Lampitt et al. 2008). While unlikely to occur on the Scotian Shelf, this event shows the interest in human interventions to combat the effects of climate change.

15.4.4.3 Using DNA to Assess Biodiversity: Another influential scientific advancement does not pertain to a specific technological application, but rather to a shift in a whole field of scientific inquiry. Developments in genetic understanding of biodiversity are rapidly transforming traditional concepts of biodiversity, and this paradigm shift may have significant impacts on approaches for studying and measuring marine life. Marine scientists have started to exploit advances in the use of DNA sequencing techniques. The advance of these techniques and the integration with traditional methods of taxonomy for species identification will influence the field of ecology and potentially change approaches to monitoring and conserving biodiversity (Vandenkoornhuyse et al. 2010). For example, the Marine Barcode of Life and its partner the Census of Marine Life are international initiatives aiming to identify and categorize marine life by utilizing DNA barcoding. DNA barcoding is expected to substantially increase the number of documented marine species. Genetic techniques have been explored for utility in biodiversity conservation (Krishnamurthy and Francis 2012), invasive species and biological invasions (Miura 2007) and environmental chemical contamination (Veldhoen et al. 2012). These developments may suggest changes to the indicators used to monitor biodiversity on the Scotian Shelf.

15.5 SUMMARY TABLE

Issue	DPSIR	Level of Priority[1]	Scotian Shelf (SS) Emerging Issue Characterization[2]	Proposed Indicators
Consumer demand for sustainable and traceable seafood	Pressure	1	Presently evolving on SS	Export revenue from certified fisheries Landed value from certified fisheries Percent stocks eco-certified[3]
Fishing at lower trophic levels	Pressure	1	Presently evolving on SS	Average trophic level of landings[3]
Deep water oil and gas exploration	Pressure	1	Presently evolving on SS	Average water depth of oil and gas developments on the SS
Microplastic particles	Impact	1	Global concern with potential to impact SS	Abundance of microplastic particles on the SS Range/distribution of microplastic particles on the SS Microplastic particles ingested by marine animals
Emerging chemical contaminants	Impact	1	Global concern with potential to impact SS	Number of regulated emerging chemicals
Information accessibility	Response	1	Recognized but requires additional attention on the SS	Number of data-providing organizations with approved open data policies and procedures
Climate change adaptation	Response	1	Recognized but requires additional attention on the SS	Integration of climate change into existing DFO planning processes[3]
In situ monitoring sensors and platforms	Response	1	Presently evolving on SS	Number of ocean observing systems with SS data Number of SS ocean observing systems that are collaborating with a national coordinating body
Sustainable aquaculture alternatives	Pressure	2	Presently evolving on SS	Number of offshore aquaculture operations Number of IMTA operations
Marine renewable energy	Pressure	2	Presently evolving on SS	Percent of Nova Scotia's energy use from renewable marine sources
Timing of seasonal ecosystem events	Impact	2	Global concern with potential to impact SS	Timing of phytoplankton blooms[3] Match-mismatch of ecosystem events[3]
Emerging diseases	Impact	2	Global concern with potential to impact SS	Number of diseases (of marine organisms) new to the SS Distribution and spread of marine invasive species[3]
Ecosystem based management and ecosystem service valuation	Response	2	Recognized but requires additional attention on the SS	Total area of habitat protected by conservation and management measures[3] Marine management plans take an ecosystem rather than a single-species approach

[1] Levels of priority are meant to categorize the relative importance of the various issues in terms of their imminent significance to the Scotian Shelf. Level 1 issues require immediate action; level 2 issues need to be addressed in the short to medium term; level 3 issues should be treated as a “watching brief,” meaning that managers should remain alert to future developments.

[2] As per the definition of emerging issue presented in the ”Issue in Brief” section of the report, the issues reported in this paper are characterized in one of the following three ways: an issue that is already present on the Scotian Shelf, but the situation is rapidly evolving; a globally recognized issue that may or may not already be impacting the Scotian Shelf, and which requires additional monitoring to fill information gaps; and issues that have been already recognized on the Scotian Shelf, but which have not been adequately addressed and require additional attention or management action.

[3] This indicator has been used in another theme paper.

Issue	DPSIR	Level of Priority[1]	Scotian Shelf (SS) Emerging Issue Characterization[2]	Proposed Indicators
Emerging aspects of marine spatial planning	Response	2	Recognized but requires additional attention on the SS	Management tools use a spatially-explicit approach
Alternative products from ocean resources	Pressure	3	Presently evolving on SS	Number of businesses using marine resources for alternative products in Nova Scotia
Impact of ocean acidification on sound transmission	Impact	3	Global concern with potential to impact SS	Ocean pH level[3] Research studies into ocean acidification[3]
Ocean fertilization	Response	3	Global concern with potential to impact SS	Number of national and international laws and regulations addressing ocean fertilization
Using DNA to assess biodiversity	Response	3	Global concern with potential to impact SS	Species diversity[3] Number of species identified using DNA techniques on the SS

[1] Levels of priority are meant to categorize the relative importance of the various issues in terms of their imminent significance to the Scotian Shelf. Level 1 issues require immediate action; level 2 issues need to be addressed in the short to medium term; level 3 issues should be treated as a "watching brief," meaning that managers should remain alert to future developments.

[2] As per the definition of emerging issue presented in the "Issue in Brief" section of the report, the issues reported in this paper are characterized in one of the following three ways: an issue that is already present on the Scotian Shelf, but the situation is rapidly evolving; a globally recognized issue that may or may not already be impacting the Scotian Shelf, and which requires additional monitoring to fill information gaps; and issues that have been already recognized on the Scotian Shelf, but which have not been adequately addressed and require additional attention or management action.

[3] This indicator has been used in another theme paper.

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