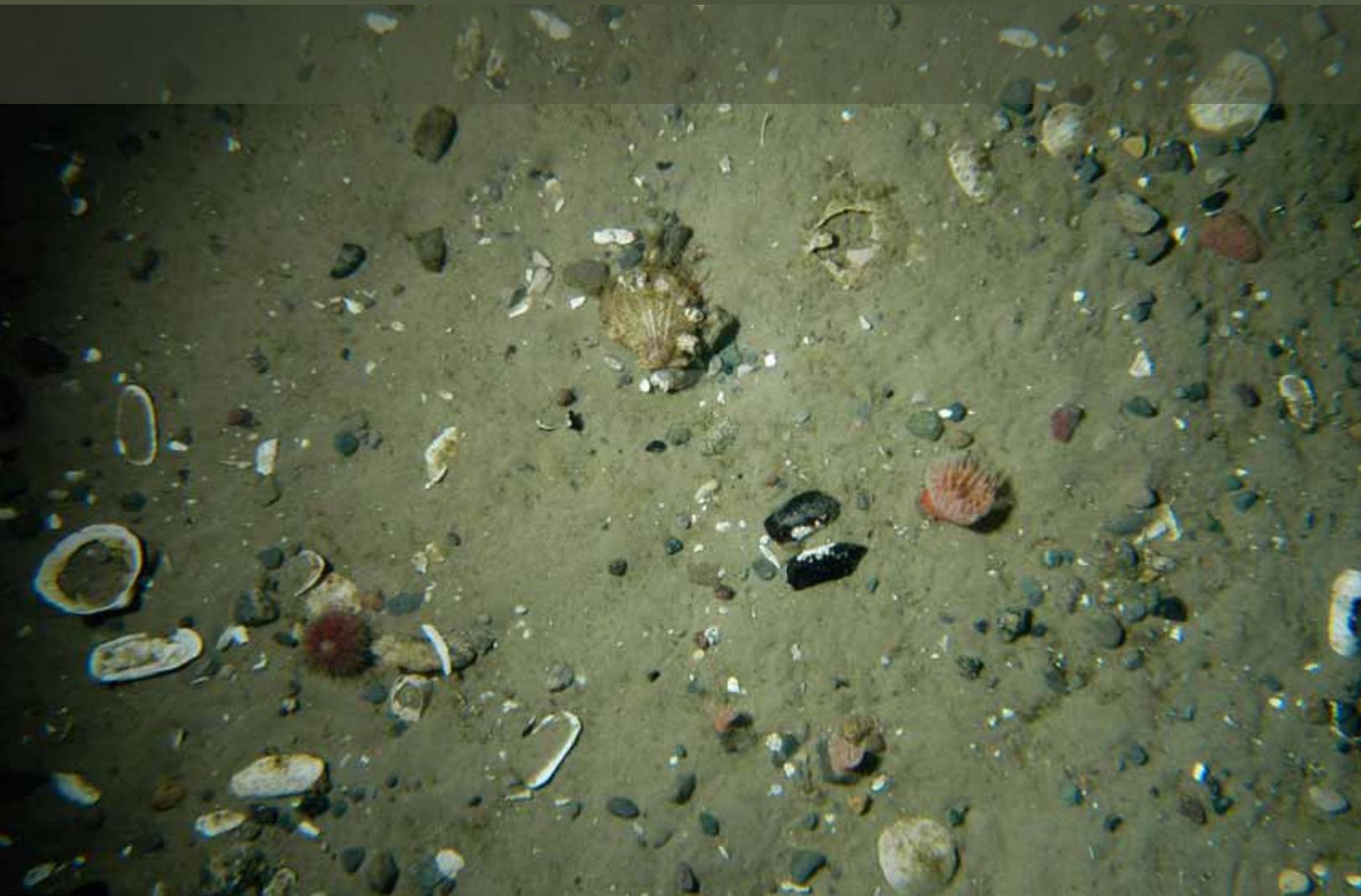


# WATER AND SEDIMENT QUALITY



State of the Scotian Shelf Report

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The material in this document is co-published as:  
MacLean M, Breeze H, Walmsley J and Corkum J (eds). 2013.  
State of the Scotian Shelf Report. Can. Tech. Rep. Fish. Aquat. Sci. 3074.

First published April 2012

ISBN: 978-0-9869437-8-2



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# 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  $\Sigma$ DDT.

**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.

# 1

## ISSUE IN BRIEF

### 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

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<sup>1</sup> 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 *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 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

<sup>1</sup> 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).



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.

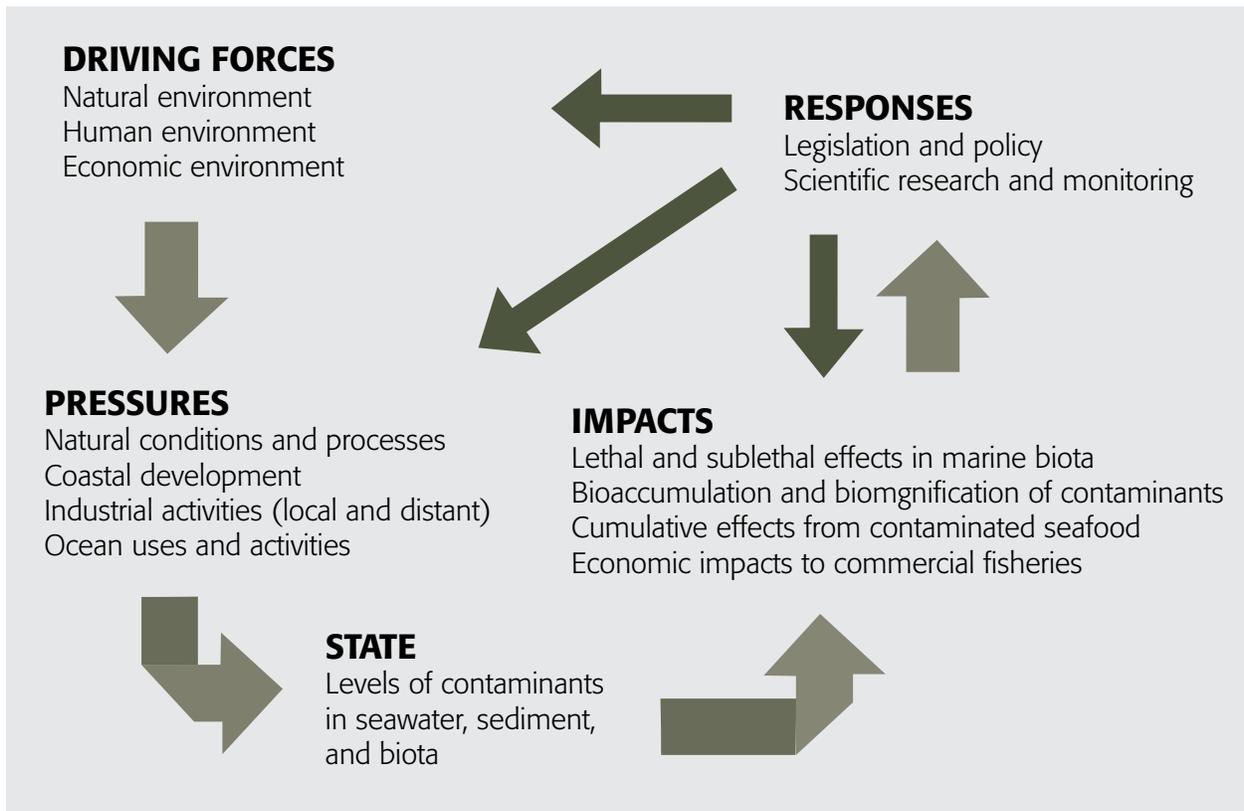


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) for water and sediment quality on the Scotian Shelf. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural 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.

# 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 2).

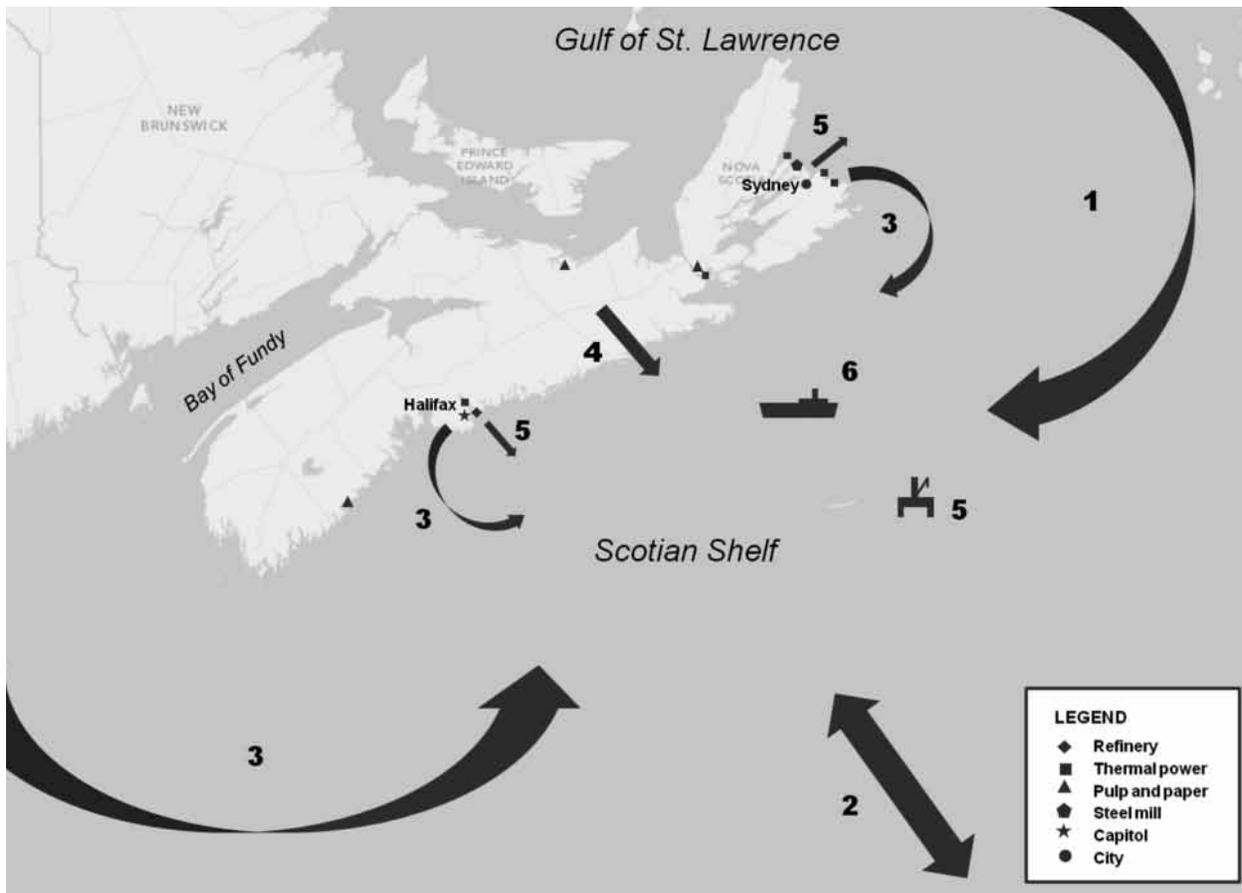


Figure 2. The main sources of natural and anthropogenic contaminants on the Scotian Shelf: (1) the Gulf of St. Lawrence outflow; (2) offshore exchange; (3) atmospheric deposition (long-distance and local); (4) Nova Scotia rivers; (5) leakage from industrialized areas, including industrialized harbours and offshore oil and gas projects; and (6) marine shipping. Source: Based on information in Yeats (2000) and Stewart and White (2001).

## 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.

### 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.

### 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*).

### 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).

## 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.

### 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).

### 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).

### 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).

### 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).

### 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 chemi-



icals (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).

### 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, bio-accumulating 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 *Waste and Debris*.

# 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).

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

### **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 (Burrige 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).

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 6** as well as CCME (1999); CFIA (2005); Health Canada (2011).

### 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  $\Sigma$ DDT) are among the most

well known and ubiquitous examples of organochlorine compounds in the environment. DDE accounts for most of the  $\Sigma$ DDT 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  $\Sigma$ DDT and less so by PCBs. Data on concentrations of PCBs in marine biota indicate a declining trend, while data on  $\Sigma$ DDT in marine biota are conflicting (Addison and Stobo 2001; Hooker et al. 2008; DFO 2009a). There are no specific studies of PBDEs on 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.

### 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  $\Sigma$ DDT and 1 to 100 ng/L for PCBs (Addison 1984a). Concentrations of both residues in the surface micro-layer may be 5 times higher.

### 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

**Table 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	SOURCE	YEAR	AREA	TISSUE	TISSUE CONCENTRATION (µg/g) (WET WEIGHT)		
					TOTAL DDT	DDE	PCB
Groundfish (cod, hake, plaice & ocean perch)	Zitco (1971)	1970	NS banks	Muscle	-	< 0.02	< 0.02
Pelagic (Atlantic herring)	Zitco (1971)	1971	Chedabucto Bay	Muscle	43	24	54
Atlantic herring	Zitco 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, yellowfish, redbtail)	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	Zitco (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

this study contained high levels of  $\Sigma$ DDT; 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 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 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  $\Sigma$ DDT in samples of blubber from grey seals collected from Sable Island declined from 12 to 0.5 micrograms per gram ( $\mu\text{g/g}$ ) 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  $\Sigma$ DDT 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  $\Sigma$ DDT 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*-non-a-chlor 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.

**Seabirds:** Several perfluorinated compounds (PFCs) were detected in herring gull eggs collected from Sable Island in 2008 (Geb-bink 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.

### 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 2**). Anthropogenic sources of hydrocarbons in the marine environment include oil spills, discharges during marine transportation, ocean dumping, leakages from drilling

**Table 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
<b>Total:</b>	<b>1 245 200</b>

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,

## 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 8 000 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 to 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 7 000 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 1 500 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.

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).

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.

### 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).

### 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

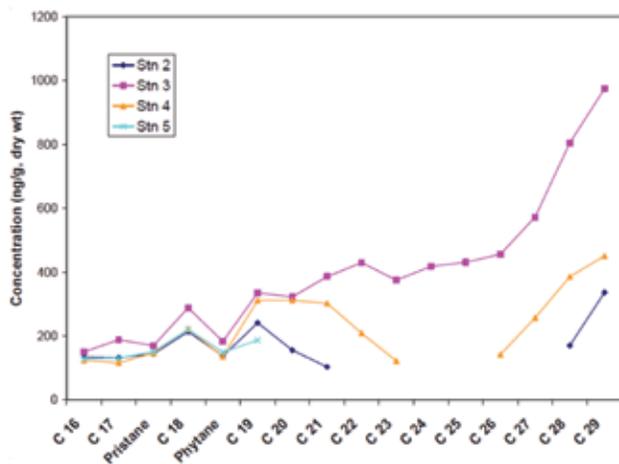


Figure 3. Concentration of various hydrocarbons (i.e., C16-C29, pristane, phytane) in sediment samples taken from the Gully MPA in 2006. Source: Yeats et al. (2008).

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 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.

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.

### 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).

### 3.3 METALS

Heavy metals are natural constituents of the marine environment and normally occur at low concentrations (Ray and Bowers 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 Bowers 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 anti-fouling 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 3**.

Concentrations of metals throughout the marine waters of the Northwest Atlantic do not vary widely (Ray and Bowers 1984). Lead and cadmium are considered to be the major metal contaminants in all the world's oceans, including the Northwest Atlantic (Ray and Bowers 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).

**Table 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

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 Bowers 1983; Ray and Bowers 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.

### 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 (Bowers et al. 1976; Stoffyn 1984). Zinc, nickel, copper, cadmium and aluminum have low levels in the upper 30 m of the water column

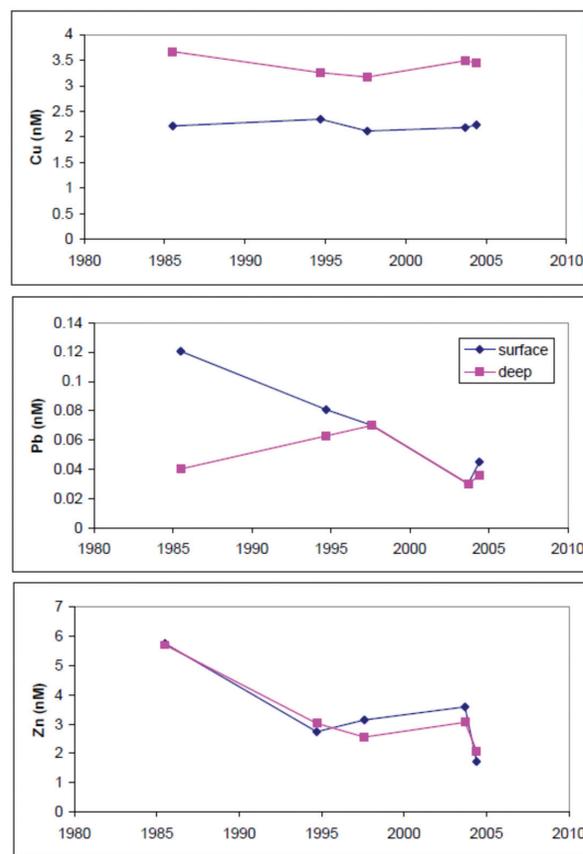


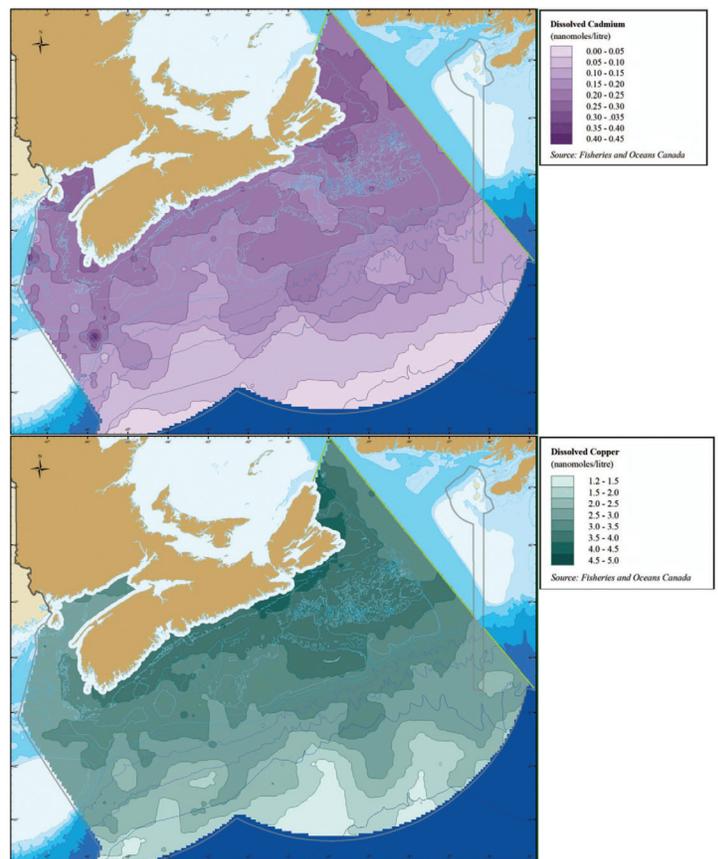
Figure 4. Levels of dissolved copper (Cu), lead (Pb) and zinc (Zn) in seawater on the Scotian Shelf, 1985–2005. Source: Yeats et al. (2008).

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 Bowers 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 (Bowers 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 near-shore (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 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 detection 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



**Figure 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).

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 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.

### 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 pre-drilling 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 on-

ward. 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 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

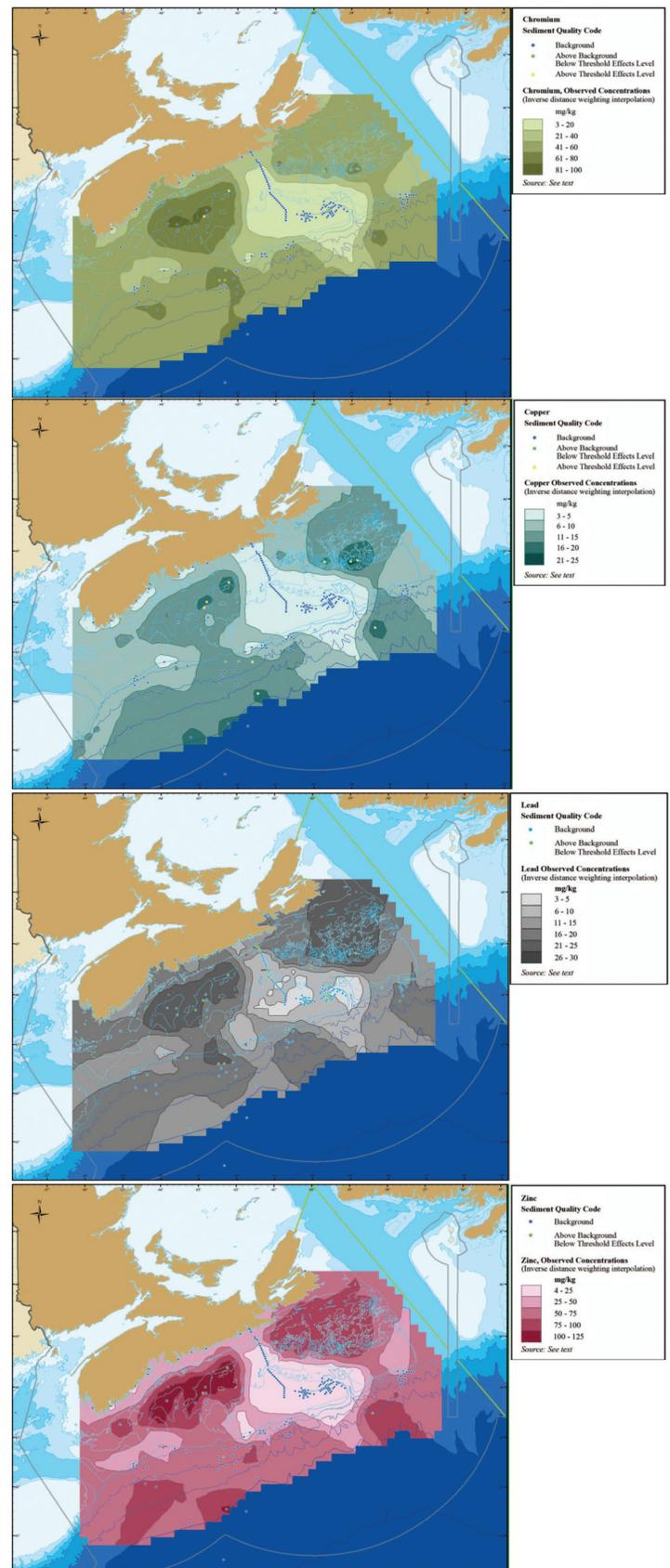


Figure 6. Concentrations of chromium, copper, lead and zinc in sediments of the Scotian Shelf (1970–2005). Source: Breeze and Horsman (2005).

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.
- **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.

### 3.3.3 Marine biota

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 µg/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.

# 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 4**).

### 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,

**Table 4: Potential biophysical and socio-economic impacts of pressures on the marine water and sediment quality of the Scotian Shelf.**

ELEMENT	POTENTIAL IMPACTS
<b>BIOPHYSICAL</b>	
<b>Biodiversity and Ecosystem Function</b>	<ul style="list-style-type: none"> <li>• Contaminants can cause a variety of lethal and sublethal effects in marine organisms including invertebrates, fish, seabirds, marine mammals, and species at risk.</li> <li>• Direct exposure to some contaminants can be lethal to some organisms (e.g., smothering and suffocation of seabirds during an oil spill).</li> <li>• 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.</li> <li>• 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.</li> <li>• Environmental impacts may emerge as a result of the combined effects of multiple contaminants and other stressors on the Scotian Shelf ecosystem (cumulative impacts).</li> </ul>
<b>SOCIO-ECONOMIC</b>	
<b>Human Health</b>	<ul style="list-style-type: none"> <li>• Contaminated fish and fish products can pose a serious health risk to humans if consumed.</li> </ul>
<b>Economic Activities</b>	<ul style="list-style-type: none"> <li>• Economic losses to the fishing industry associated with market restrictions or consumption advisories for fish and fishery products.</li> <li>• 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.</li> <li>• Contaminants may impact the health and productivity of commercially valuable fish stocks (<i>Fish Stock Status and Commercial Fisheries</i>).</li> </ul>

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.

- ***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 clean-up 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 form 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 methylmer-

cury 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 5** 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).

## 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 5**. Seafood con-

taminated 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 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 mea-

sured 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).

## 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.

# 5

## ACTIONS AND RESPONSES

Management actions and responses to marine water and sediment quality include legislation and policy, and scientific research and monitoring.

### 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 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

**Table 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
<b>INTERNATIONAL CONVENTIONS</b>		
<b>Stockholm Convention on Persistent Organic Pollutants (2004)</b>	<ul style="list-style-type: none"> <li>International treaty to protect human health and the environment from POPs</li> </ul>	Signed and ratified by Canada in 2001.
<b>Geneva Convention on Long-range Transboundary Air Pollution (1979) and associated protocols</b>	<ul style="list-style-type: none"> <li>Limit and gradually reduce and prevent air pollution including long-range transboundary air pollution</li> <li>Specific protocols to address POPs, heavy metals, and volatile organic compounds</li> </ul>	Canada signed the convention in 1979 and ratified it in 1981.
<b>International Convention for the Prevention of Pollution from Ships (MARPOL) (1973)</b>	<ul style="list-style-type: none"> <li>Main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes</li> </ul>	Managed through the International Maritime Organization. Canada has been a member since 1948.
<b>International Convention on the Control of Harmful Anti-fouling Systems on Ships</b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Managed through the International Maritime Organization. Canada has been a member since 1948.
<b>FEDERAL AND PROVINCIAL LEGISLATION AND REGULATIONS</b>		
<b><i>Fisheries Act</i></b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Section 36 of the Act is administered by Environment Canada.
<b>Pulp and Paper Effluent Regulations (Fisheries Act)</b>	<ul style="list-style-type: none"> <li>Regulates the discharge of effluent from pulp and paper operations</li> </ul>	Administered by Environment Canada.
<b>Metal Mining Effluent Regulations (Fisheries Act)</b>	<ul style="list-style-type: none"> <li>Regulates the discharge of effluent from metal mining operations</li> </ul>	Administered by Environment Canada.
<b>Petroleum Refinery Liquid Effluent Regulations (Fisheries Act)</b>	<ul style="list-style-type: none"> <li>Regulates the discharge of liquid effluent from petroleum refineries</li> </ul>	Administered by Environment Canada.
<b><i>Canadian Environmental Protection Act (CEPA)</i></b>	<ul style="list-style-type: none"> <li>Controls substances determined to be "toxic" and specifies time frames for developing and implementing preventive or control measures</li> <li>Requires the "virtual elimination" of releases of the most dangerous toxic substances to the environment</li> <li>Provides the authority to issue non-regulatory objectives, guidelines and codes of practice to prevent and reduce marine pollution from land-based sources</li> </ul>	Administered by Environment Canada and Health Canada.
<b>Disposal at Sea Regulations (CEPA)</b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Administered by Environment Canada and Health Canada.
<b>Persistence and Bioaccumulation Regulations (CEPA)</b>	<ul style="list-style-type: none"> <li>Outlines criteria for determining whether a substance is "persistent" and "bioaccumulative" under CEPA</li> </ul>	Administered by Environment Canada and Health Canada.
<b>Prohibition of Certain Toxic Substances Regulations (CEPA)</b>	<ul style="list-style-type: none"> <li>Prohibits and/or regulates the manufacture, use, sale, and import of certain toxic substances including DDT</li> </ul>	Administered by Environment Canada and Health Canada.
<b>Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations (CEPA)</b>	<ul style="list-style-type: none"> <li>Prohibits the release of dioxins/furans in effluent from pulp and paper operations</li> </ul>	Administered by Environment Canada and Health Canada.

LEGISLATIVE OR POLICY INSTRUMENT	PURPOSE/FUNCTION	COMMENTS
<b>FEDERAL AND PROVINCIAL LEGISLATION AND REGULATIONS</b>		
<b>PCB Regulations (CEPA)</b>	<ul style="list-style-type: none"> <li>Regulates the use and release of PCBs into environment</li> </ul>	Administered by Environment Canada and Health Canada.
<b>Canadian Environmental Assessment Act (CEAA)</b>	<ul style="list-style-type: none"> <li>Outlines requirements and process for environmental assessments in Canada</li> </ul>	Administered by the Canadian Environmental Assessment Agency.
<b>Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Acts (Accord Acts)</b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Administered by the CNSOPB. Administered by Transport Canada.
<b>Canada Shipping Act</b>	<ul style="list-style-type: none"> <li>Regulates shipping and navigation</li> </ul>	Administered by Transport Canada.
<b>Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals (Canada Shipping Act)</b>	<ul style="list-style-type: none"> <li>Establishes regulations to prevent the release of pollutants (e.g., oil, TBT) from ships into the marine environment</li> </ul>	Administered by Nova Scotia Environment.
<b>Nova Scotia Environment Act</b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Administered by Nova Scotia Environment.
<b>Nova Scotia PCB Management Regulations (NS Environment Act)</b>	<ul style="list-style-type: none"> <li>Regulates the use, storage and disposal of PCBs in the Province of Nova Scotia</li> </ul>	Administered by Nova Scotia Environment.
<b>Nova Scotia Pesticides Regulations (NS Environment Act)</b>	<ul style="list-style-type: none"> <li>Regulates the sale, use, storage, and disposal of pesticides; and restricts the use of non-essential pesticides in the Province Nova Scotia</li> </ul>	Administered by Nova Scotia Environment.
<b>Nova Scotia Emergency Spill Regulations (NS Environment Act)</b>	<ul style="list-style-type: none"> <li>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.</li> </ul>	Federal and Provincial Policies, Plans, Strategies and Guidelines
<b>FEDERAL AND PROVINCIAL POLICIES, PLANS, STRATEGIES AND GUIDELINES</b>		
<b>Canada's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants</b>	<ul style="list-style-type: none"> <li>Plan to inform the public about how the obligations of the Stockholm Convention will be implemented in Canada</li> </ul>	Administered by Environment Canada.
<b>Chemicals Management Plan</b>	<ul style="list-style-type: none"> <li>Immediate action on chemicals of high concern</li> <li>New regulatory activities for chemicals</li> <li>New investment in research and monitoring</li> </ul>	Administered by Environment Canada and Health Canada
<b>Toxic Substances Management Policy (TSMP)</b>	<ul style="list-style-type: none"> <li>Requires the "virtual elimination" of releases of the most dangerous toxic substances to the environment</li> </ul>	Administered by Environment Canada.
<b>Canadian Council of Ministers of the Environment (CCME) Environmental Quality Guidelines</b>	<ul style="list-style-type: none"> <li>Provide nationally endorsed science-based goals for the quality of atmospheric, aquatic, and terrestrial ecosystems</li> </ul>	Administered by the CCME.
<b>CNSOPB Offshore Waste Treatment Guidelines</b>	<ul style="list-style-type: none"> <li>Guidelines for operators in the management of waste material associated with petroleum drilling and production operations in offshore areas</li> </ul>	Administered by the CNSOPB.
<b>National Policy on Oiled Birds and Oiled Species at Risk</b>	<ul style="list-style-type: none"> <li>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</li> </ul>	Administered by the CWS.

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).

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<sup>2</sup> 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 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-

<sup>2</sup> 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).

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 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.

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.

## 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

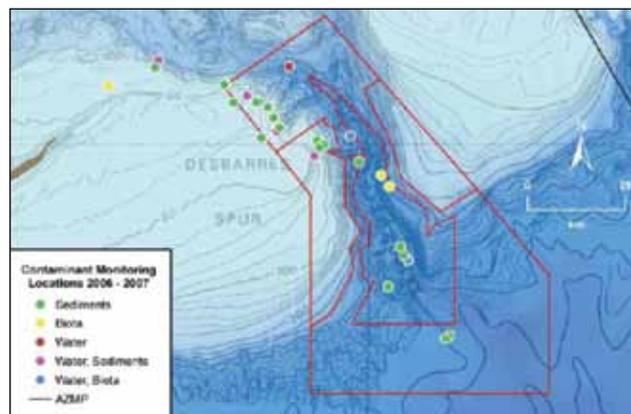


Figure 7. Map showing contaminant sampling locations in the Gully MPA. Source: DFO (2009a).

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 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.

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.

## INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	ASSESSMENT <sup>1</sup>	TREND <sup>2</sup>
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	+

<sup>1</sup>Assessment: assessment of the current situation in terms of implications for the state of the environment. Categories are poor, fair, good, unknown.

<sup>2</sup>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.

### Data Confidence:

- Reliable data on the concentrations of some organochlorine compounds (i.e.,  $\Sigma$ DDT, PCBs) in marine biota on the Scotian Shelf are 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.

### Key:

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

# 6

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