Marine Environmental Contaminants in the Scotian Shelf Bioregion: Scotian Shelf, Bay of Fundy and Adjacent Coastal and Offshore Waters—1995-present

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MARINE ENVIRONMENTAL CONTAMINANTS IN THE SCOTIAN SHELF BIOREGION: SCOTIAN SHELF, BAY OF FUNDY AND ADJACENT COASTAL AND OFFSHORE WATERS—1995-PRESENT

by

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Stewart, P.L., Kendall, V.J. and H.J. Breeze. 2019. Marine Environmental Contaminants in the Scotian Shelf Bioregion: Scotian Shelf, Bay of Fundy and Adjacent Coastal and Offshore Waters—1995-present. Can. Tech. Rep. Fish. Aquat. Sci. 3291: xiv + 152 p + Appendices.

Knowledge of marine contaminants is an important element of marine ecosystem management. This literature review covers post-1995 studies of levels and effects of contaminants of various kinds in the marine environment (water, sediments and biota) of the Scotian Shelf Bioregion—a biophysical subdivision of Canada's coastal and offshore waters in the Maritimes Region of Fisheries and Oceans Canada. Contaminant information is available for both coastal and offshore areas. Coastal areas include small inlets and harbours; the ports of Halifax, Sydney and the Strait of Canso, Nova Scotia, and Saint John, New Brunswick; and the inner and outer Bay of Fundy including the Quoddy Region. Offshore areas include the Scotian Shelf and Slope and adjacent abyssal waters, Cabot Strait, Laurentian Channel, eastern Georges Bank and the Gulf of Maine. Contaminants include metals; organic chemicals such as persistent organic pollutants (POPs); hydrocarbons from marine shipping, fossil-fuel combustion, and offshore hydrocarbon development; plastics and microplastics; organic enrichment (from sewage, fish plants, pulp and paper production and finfish aquaculture); nutrients; carbon-dioxide; radionuclides; and pharmaceuticals and endocrine-disrupting chemicals in sewage. Although levels of contaminants are not particularly high or likely to be harmful in most areas, all parts of the marine food chain are potentially affected. The amount of contaminant information available for management is relatively low, a reflection of limited resources in relation to the large ecosystem. The report recommends a coordinated approach to contaminants, involving maintaining or expanding existing research capabilities and adopting a risk assessment and planning approach to contaminants which includes long-term monitoring and a new focus on trophic studies.

RÉSUMÉ[2]

Stewart, P.L., Kendall, V.J. et H.J. Breeze. 2019. Contaminants du milieu marin dans la biorégion de la plate-forme Néo-Écossaise : plate-forme Néo-Écossaise, baie de Fundy et eaux côtières et extracôtières adjacentes — de 1995 à aujourd'hui. Can. Tech. Rep. Fish. Aquat. Sci. 3291: xiv + 152 p + Appendices.

La connaissance des contaminants marins est un élément important de la gestion des écosystèmes marins. La présente analyse documentaire porte sur des études postérieures à 1995 sur les concentrations et les effets des contaminants de divers

[1] The recommendations and conclusions found in the report are those of the authors and do not necessarily reflect the views of Fisheries and Oceans Canada.

[2] Les recommandations et conclusions formulées dans le rapport sont celles des auteurs et ne reflètent pas nécessairement les opinions de Pêches et Océans Canada.

types dans le milieu marin (eau, sédiments et biote) de la biorégion de la plate-forme Néo-Écossaise, une sous-division biophysique des eaux côtières et extracôtières du Canada dans la région des Maritimes de Pêches et Océans Canada. L'information sur les contaminants est disponible pour les zones côtières et extracôtières. Les zones côtières comprennent de petites baies et des ports : les ports de Halifax, de Sydney et du détroit de Canso, en Nouvelle-Écosse, et de Saint John, au Nouveau-Brunswick, et l'intérieur et l'extérieur de la baie de Fundy, y compris la région Quoddy. Les zones extracôtières comprennent la plate-forme Néo-Écossaise et le talus néo-écossais et les eaux abyssales adjacentes, le détroit de Cabot, le chenal Laurentien, l'est du banc de Georges et le golfe du Maine. Les contaminants comprennent les métaux, les produits chimiques organiques tels que les polluants organiques persistants (POP), les hydrocarbures provenant du transport maritime, de la combustion de combustibles fossiles et de l'exploitation d'hydrocarbures en mer, les plastiques et les microplastiques, l'enrichissement organique (provenant des eaux usées, des usines de transformation du poisson, de la production de pâtes et papiers et de la pisciculture), les nutriments, le dioxyde de carbone, les radionucléides, les produits pharmaceutiques et les perturbateurs endocriniens dans les eaux usées. Bien que les concentrations de contaminants ne soient pas particulièrement élevées ou susceptibles d'être nocives dans la plupart des régions, tous les maillons de la chaîne alimentaire marine sont potentiellement touchés. La quantité d'information disponible sur les contaminants pour la gestion est relativement faible, ce qui reflète les ressources limitées par rapport au grand écosystème. Le rapport recommande une approche coordonnée en matière de contaminants, comprenant le maintien ou l'expansion des capacités de recherche existantes et l'adoption d'une approche d'évaluation et de planification des risques pour les contaminants, ce qui comprend une surveillance à long terme et une nouvelle orientation en ce qui concerne les études trophiques.

EXECUTIVE SUMMARY

Environmental contaminants arising from human activities in the waters and watersheds of the Eastern Canadian coastal zone occur in various environmental compartments of the ocean and have the potential to impact various functions in marine ecosystems. The present study reviewed and summarized recent (i.e., since approximately 1995) primary scientific literature as well as technical reports and other information sources to obtain information on the status of contaminants in the Scotian Shelf Bioregion—a scientifically based subdivision of the Canadian East Coast marine environment that lies within Fisheries and Oceans Canada (DFO) Maritimes Region and includes the Scotian Shelf, Bay of Fundy, and adjacent coastal and offshore waters. Studies of various kinds have improved the understanding of the distribution, behaviour, and effects of contaminants, building upon and adding to earlier knowledge. Overall, the body of information available on contaminants in waters, sediments and biota of the bioregion is not large, consisting in the most part of studies focused on particular contaminant issues and important organism groups, but in synthesis it presents a view that is useful in assessing conditions in the bioregion. Most ecosystems and environments have been exposed to substances considered to be contaminants to some degree; in most cases the exposures are low and the effects, where they can be determined, are subtle. Questions remain as to the potential for long-term effects on ecosystems and the physiology and populations of animals of various kinds, including fisheries species. In most cases recognition of the presence of contaminants has led to appropriate regulation and reduction of releases into the environment. To better understand the effects of contaminants on the marine ecosystem of the bioregion requires a continued commitment to existing science; coordination of information generated by existing government programs involved in monitoring and managing contaminants; and a new focus on transfer of contaminants through the ecosystem, to complement existing activities.

The long list of contaminants includes types which society has identified for some time such as heavy metals with potentially toxic effects (e.g., mercury); new, emerging industrial compounds created for specialized applications, but which prove to be harmful in the environment (e.g., chlorinated and brominated compounds used as flame retardants); chemicals whose production and use has been phased out but which persist in the environment (e.g., chlorinated pesticides, tributyltin); as well as many others.

Some of the more prominent contaminants which have been studied in the bioregion include metals such as mercury and organometallic compounds such as methyl mercury and butyltins—in particular tributyltin; and a wide range of compounds based on carbon, so-called organic compounds. These include cyclic and polycyclic organic compounds such as polycyclic aromatic hydrocarbons (PAHs), benzene, toluene and xylene found in fuels and as residues from fossil fuel combustion; long-chain hydrocarbons which make up fuels, oils and lubricants; carbon-ring-based phenols and nonylphenols; chlorinated and brominated organic compounds, the former once widely used in stable industrial chemicals such as polychlorinated biphenyls (PCBs) and pesticides (e.g., DDT, hexachlorocyclohexane, chlordane). Polybrominated diphenyl ethers (PBDEs)

widely used as flame retardants, flame retardants such as polybrominated cyclododecane, and widely-used perfluorochemicals (PFCs) are other emerging contaminants which reach the ocean and accumulate in the environment there. Chemicals in pharmaceuticals and consumer products in everyday use which are released into sewage enter the marine environment in the bioregion and impact waters in cities and ports, forming a new category of chemicals of emerging concern (CECs). Other physical/structural contaminants which are a problem include marine debris and litter and microplastics. Sewage in many areas is a source both of fecal coliform and viral contamination of coastal waters, and also of the wide range of chemicals and substances which are released into the waste stream in urban environments.

Sources of contaminants in the marine environment of the bioregion are not unlike those in other industrialized parts of the world, including various human industrial and resource-based activities, urban and port development, natural resource exploitation, forestry, agriculture, offshore hydrocarbon development, shipping and marine transportation, as well as natural sources, often which are unexplained, which lead to elevated concentrations in particular locations. Sources are both local and distant, the latter including long-range atmospheric transport primarily from industrialized areas of Quebec and Ontario and the northeastern U.S. as well as other regions of the western hemisphere, and transfer via St. Lawrence River and Estuary to the Gulf of St. Lawrence, which is one of the sources of water masses on the Scotian Shelf.

Inshore waters, which include the inlets and harbours along the coasts of the bioregion, are influenced most strongly by the land and its natural processes, as well as by the associated human activity. Levels of contaminants in waters of the bioregion, both in nearshore areas and offshore, are frequently low; but levels in biota (invertebrates, fish and higher organisms such as marine mammals and birds) may be elevated in these areas to harmful levels and organisms may show subtle effects. Such is the case in Halifax, the bioregion’s largest harbour, where many studies have shown the presence and subtle influence of contaminants arising in sewage, which include contaminants as diverse as human hormones, and chemicals released from industrial and ship maintenance activity. Many of these substances in sewage are not removed by improved treatment and so continue to potentially affect marine organisms. When improvements to releases of contaminants have occurred, however, natural processes such as “capping” by the deposition of clean sediment, have often isolated them and reduced the risk of further exposure to marine organisms. A large-scale cleanup of a steel mill property and an associated contaminated settling pond—the Sydney Tar Ponds—located alongside the major harbour of Sydney on Cape Breton Island, as well as improvements to sewage treatment in the City of Sydney, have led to substantial improvements in contaminant levels there. Although persistent organic contaminants including PAHs and PCBs continue to reside in sediments in Sydney Harbour, they are isolated from the waters by capping. Similar processes are likely to be occurring in Halifax Harbour. Other large harbours, such as the Port of Saint John, have had instances of contamination in the past, but with effective management of municipal sewage and other sources, are generally free of significant examples of contamination in the marine environment there.

Sediments and biota are the main repositories of significance for contaminants, the former because of the association of contaminants of various kinds with fine organic and inorganic particles which leads to elevated concentrations in muddy sediments; and the latter because of the tendency of some metals and persistent organic chemicals to accumulate in tissues of higher organisms in the food chain—a process known as bioaccumulation. Sediments in harbours throughout the bioregion frequently contain elevated levels of contaminants of various kinds. Harbours—both large, such as Halifax Inlet and Sydney Harbour, Nova Scotia and Saint John Harbour, New Brunswick—and smaller harbours, including those used by fishing vessels throughout the bioregion, are affected to varying degrees. Ship and tanker traffic and fishing vessels contribute hydrocarbons and metals from equipment operation and engine exhaust; operation of offshore oil and gas platforms contribute low levels of various contaminants from routine operations and produced water to the marine environment. In some coastal areas, fish farms have been shown to add certain contaminants, including metals and some organic contaminants to the environment and sediments in the vicinity of sites. The contributions of all these inputs to the bioregion, however, are localized and, as a whole, are small.

Persistent chemicals have been shown to accumulate in tissues of fish and higher organisms such as marine mammals (seals, porpoises and whales), as well as seabirds. The number of research studies on contaminants in these organisms is generally small; but the research has shown that most contaminants of concern, including emerging contaminants, can be found in these organisms throughout the bioregion. While contamination can often be shown to be linked to occurrences due to associations of particular species with coastal areas which are known sources of certain contaminants (e.g., the contaminant loads in Harbour Seals along the southern New England coast of the Gulf of Maine), some, such as the occurrence of elevated levels of perfluorinated chemicals (PFCs) in eggs of Herring Gulls from Sable Island, remain unknown. Many studies of a wide range of persistent organic compounds show regional variation in levels in contaminants in organisms ranging from mussels to Harbour Porpoise in the Gulf of Maine, with generally lowest levels found in the bioregion compared to other areas.

Important contaminant issues in the bioregion include the role of sewage and stormwater in contributing contaminants to the marine environment; identification of releases of contaminants such as metals and other chemicals entering the environment through feed and other activities associated with the growing fish farming industry; releases of mercury and arsenic associated with former gold mining activity; industrial inputs of chemicals associated with ship maintenance and repair; hydrocarbons released from shipping and transportation; marine debris and in particular plastics released into the environment; dynamics of mercury in the marine environment of the bioregion; and bioaccumulation of persistent organic compounds in higher organisms. Offshore hydrocarbon exploration and development has resulted in releases of various contaminants to the environment, although monitoring has not demonstrated significant changes or effects. The ubiquitous occurrence of hydrocarbons—although at low levels in sediments in the marine environment of the bioregion—presumed to be both through releases from shipping and other transportation, as well as marine spills and natural releases, marine debris including plastic debris, and the emerging issue of microplastics in the marine environment are important concerns for the future.

Limitations imposed by the different jurisdictional responsibilities—marine mammals and fish through DFO; seabirds through the Canadian Wildlife Service, Environment and Climate Change Canada (ECCC); food quality and contaminants in fish and shellfish through Health Canada and the Canadian Food Inspection Agency (CFIA)—currently do not contribute to a broader focus on the dynamics of contaminants in the ecosystem. As well, the recent approach of monitoring contaminants in water and sediments only as related to particular industrial projects has contributed to a fragmented view of contaminants. In order to achieve a broader view, research expertise within government that would focus wholly on ecosystem- or trophically-based studies of contaminant dynamics should be developed, and thus could address some of the important questions on ecosystem dynamics of contaminants. Such a capability would use and help to focus the capabilities of these agencies to assist in answering some of the important questions concerning impacts of contaminants on the ecosystem of the bioregion. The lack of an overall management plan and risk assessment process for contaminants in the ecosystem of the bioregion, including suitable databases and monitoring, are also important gaps. It is suggested that a lead coordination role would be within DFO's overall responsibilities to manage fisheries and protect fish, as well as its requirement to take an ecosystem approach to management as mandated by the *Oceans Act*.

A challenge will be to not lose sight of the role of basic research on the biological, physical and chemical processes in the bioregion, but to use existing knowledge to best advantage and to carefully assess where contributions to the knowledge of effects of contaminants can be made.

1.0 INTRODUCTION

1.1. BACKGROUND

Canada's *Oceans Act* set the stage for adopting ecosystem-based management in Canada's coastal and exclusive economic zones. Ecosystem-based management has many facets, involving interactions between organisms which make up the marine ecosystem, and in turn their relationships with the physical and chemical environment, but also involves the interplay of human activity and resulting effects on the environment. Humans use the ocean in many ways, affecting natural processes almost at every step—from eutrophication and organic enrichment of harbours, to ocean warming and acidification, to the introduction of artificial chemicals as contaminants. These processes are known to disrupt food chains and have wide reaching, global effects. Ecosystem-based management requires not only knowledge of natural systems, but also an understanding of the effects and interactions of those systems with human activities. Marine Environmental Quality (MEQ), a collective assessment of the uses and functions both biological and by humans (Wells and Ralston 1991), has become an integral component of ecosystem-based management requiring an understanding of ecoregions, ecosystem processes, physical environments, and change, and particularly those human activities that may impact environmental quality. Contaminants released from point sources or introduced to the environment from diffuse processes represent significant threats to MEQ in coastal waters (Johannsen et al. 2007) and therefore an understanding of their dynamics is important in achieving ecosystem-based management objectives.

Fisheries and Oceans Canada (DFO) Maritimes Region occupies the Scotian Shelf Bioregion, an area defined by physical and biological characteristics extending from the mid-Laurentian Channel north of Nova Scotia, through the deep ocean bathyal depths south of Newfoundland, to the deep ocean off the U.S. continental shelf, and back in Canadian waters over Georges Bank through the Gulf of Maine and Bay of Fundy (DFO 2009b) (Figure 1). The ecosystem over this vast area of ocean includes physical elements—such as the ocean currents and sediments—and the biota, which encompasses a spectrum from microscopic organisms, such as phytoplankton and bacteria, to larger organisms, including large macrophytes, seabirds, sea turtles, sharks and whales. Environments in this region include the open ocean deep water and continental shelf areas, and coastal tidal environments of shallow water, each with different suites of organisms. Patterns of contamination vary, ranging from the open ocean conditions of relatively low and widespread levels of many contaminants, to concentrated contamination in nearshore areas such as inlets, harbours and ports, directly influenced by human activities.

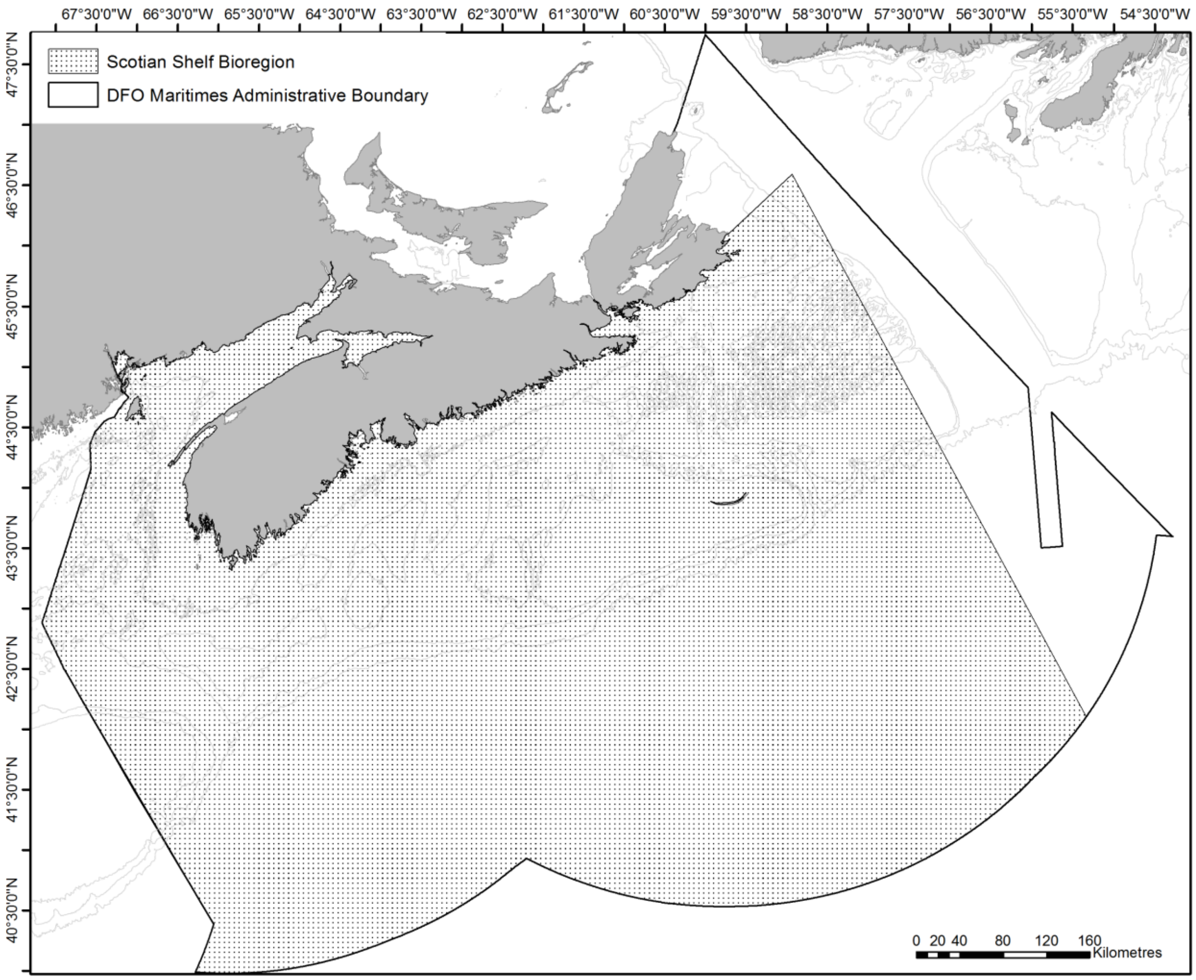

Figure 1. Scotian Shelf Bioregion (shaded) and DFO Maritimes Region Administrative Boundary. Study area for this review is all areas in DFO Maritimes Region.

Contaminants are defined as introduced chemical substances of various kinds, which are new to the environment or change the natural levels found in the environment, and potentially can be harmful at some level of concentration. The EU Water Framework more formally defines them: *“substances (i.e., chemical elements and compounds) or groups of substances that are toxic, persistent and liable to bio-accumulate and other substances or groups of substances, which give rise to an equivalent level of concern”* (EU Water Framework Directive, Article 2(29)). Contaminants in the marine environment are indicators of potential harm to biological organisms in the physical marine environment; contaminants in biota indicate immediate potential effects and concerns. A generalized list of chemical contaminants of concern expected in the marine environment of the bioregion is shown in Table 1, taken from a review for the Gulf of Maine by Harding (2013).

Table 1. Primary chemical contaminants in the Gulf of Maine (from Harding 2013).	
Polycyclic Aromatic Hydrocarbons (PAHs)	*Perfluorinated Chemicals (PFCs)*
Polychlorinated Biphenyls (PCBs)	*Organophosphorus flame retardants*
Polychlorinated Bornanes (e.g., toxaphene)	*Organophosphorus pesticides*
PCDDs/PCDFs (dioxins and furans)	*Pyrethroids/Pyrethrins*
∑DDT and metabolites	*Antibiotics*
Chlorobenzenes	*Pharmaceuticals*
Hexachlorocyclohexane	*Steroidal hormones*
Chlordanes	*Butyltins*
Mirex	*Mercury/methyl mercury*
Aldrin/Dieldrin	*Trace metals*
Organobromines (e.g., PBDEs)	
Abbreviations**:** Polychlorinated dibenzo p dioxin (PCDD); Polychlorinated dibenzofuran (PCDF); Dichlorodiphenyltrichloroethane (DDT); Polybrominated diphenyl ethers (PBDEs).	

In some cases, substances created by humans become contaminants after release into the environment through human activities. The contaminants DDT and polychlorinated biphenyls (PCBs) released into the environment have had significant negative impacts on ecosystems through bioaccumulation. Plastics, both through their persistent presence and physical alteration of the environment, as well as their tendency to attract certain contaminants as well as through the release of their component chemicals during weathering, have harmful effects on marine organisms. In particular plastic marine litter and microplastics—both manufactured and found as breakdown products of larger plastic litter—are physically and chemically altering the environment in which marine animals live (Mattalon and Hill 2014, David 2016).

Levels of contaminants in the marine environment vary depending on proximity to their sources—which include point sources such as smokestacks of industrial facilities and urban sewage outfalls—but also with proximity to shore, in particular in relation to the influence there of more diffuse and broadly-distributed non-point sources such as rivers and the atmosphere which also carry pollutants to the ocean. Inshore waters including inlets and harbours along the coast are influenced most strongly by the land and its natural processes, as well as by the associated human activity. The land is a source of water-borne sediment and dust, air-borne particulates from forest fires and industrial activities, input of organic detritus and nutrients, both arising naturally through runoff and groundwater, and from industrial wastewaters and sewage, which are typically most concentrated near the source. Coastal waters, sediments and biota of the Scotian Shelf Bioregion have levels of metal and organic contaminants which are elevated compared to expected baseline levels and are locally highest in areas experiencing human activity (Stewart and White 2001, Lotze and Milewski 2002, McCullough et al. 2005, CBCL 2009, Harding 2013, Bundy et al. 2014). In particular, activities in major coastal urban centres contribute to contaminant loads. In Nova Scotia, these include the Halifax-Dartmouth metro area on Halifax Inlet, the Strait of Canso and Port Hawkesbury; and the port of Sydney and the Port of Yarmouth. In the Bay of Fundy, Saint John and its important harbour and industrial centre is the most important urban centre, but the coastline from Saint John to the St. Croix River including Passamaquoddy Bay also forms an important area of coastal activity—the Quoddy Region. In more remote coastal areas of the bioregion, contaminants associated with fishing vessel maintenance and operation including hydrocarbons and combustion-derived contaminants as well as constituents of paints can be important contributors, while fish plant effluents are an important source of conventional contaminants, including ammonia, dissolved organic carbon and organic particulate matter.

Offshore waters, although remote from many of the industrial and human sources of contaminants, are not immune from human influences. On the Scotian Shelf, offshore oil and gas development and production is one of the more obvious industrial sources of contaminants of various kinds, including metals and hydrocarbons, although high dilution due to the vast and highly energetic Atlantic Ocean waters typically reduces concentrations to minimal levels (Lee 2005, Niu et al. 2010). Other important sources of contaminants in offshore areas include shipping and fishing activity and consequent accidental and operational releases of hydrocarbons (Lucas and MacGregor 2006), and other contaminants such as antifouling chemicals. Marine military operations including naval training and ordinance testing can contribute materials and wastes, and contaminant releases occur from shipwrecks both recent and past found around the coasts (CBCL 2009). As well, materials of various kinds such as plastic and other debris can be a source of contaminants. Marine debris can move from the ocean to shore, or vice versa when released in coastal areas of Nova Scotia and New Brunswick, and can be transported thousands of miles across oceans from distant locations. Other contaminants of concern arise in offshore areas after long-range transport via the atmosphere or in water masses. These include pesticides and persistent organic pollutants (POPs). Although they are not so much a concern in water and sediments of offshore areas, their presence is ubiquitous, including in tissues of wide-ranging and migratory marine mammals and seabirds.

Levels of contaminants measured in the marine environment must be viewed against a backdrop both of gradual improvements in infrastructure and management of contaminant use in human society; and the rise of more stringent standards for releases of wastes into the ocean and other receiving waters which began in the last half of the twentieth century. An example of regulatory control of the release of a chemical is the banning by the Canadian government of the antifoulant chemical tributyltin on vessels smaller than 25 m which removed one source of that chemical in the environment (Maguire 2000). Management of sewage—which is an important contributor to contamination of coastal waters—has also improved significantly over that time period. Most recently, the Canadian government developed the Wastewater Systems Effluent Regulations which were implemented under the *Fisheries Act* in 2012[1] which has provided additional impetus for communities to make improvements to the level of

[1] The *Wastewater Systems Effluent Regulations* under the *Fisheries Act (2012)* regulate levels of "carbonaceous BOD matter," suspended solids, total residual chlorine and un-ionized ammonia, and legislate reporting requirements for disposal of wastewaters including sewage in natural waters.

wastewater treatment in advance of the proposed implementation. As a result of these efforts, a minimum standard of advanced primary treatment was achieved for all sewage entering Halifax Harbour for all areas of Halifax-Dartmouth, Bedford, Eastern Passage and Herring Cove in the 2007-2009 period[2] with the completion of the Halifax, Dartmouth and Herring Cove Wastewater Treatment Plants (WWTFs), the latter which have diffuser outfalls located away from the shore. Similar developments in municipal waste treatment took place in other major population centres of the bioregion. The City of Saint John, New Brunswick completed consolidation of its wastewater system in 2014 which now comprises three WWTFs and ensures that all sewage entering Saint John Harbour receives a secondary level of treatment. The City of Sydney, Cape Breton, completed the Battery Point WWTF on the east side of Sydney Harbour in 2004. Construction of a treatment system in the Sydport area is currently (2018) underway. The Strait of Canso, Port Hawkesbury-Port Hastings WWTF was constructed in 2005. Many, although not all, smaller coastal communities throughout the bioregion have improved wastewater treatment and releases of certain contaminants over the same period.

This report documents a literature review of information on contaminants and contaminant levels in the marine environment in the Scotian Shelf Bioregion in the Maritimes Region of DFO, covering roughly the 1990s to the present. Measurements of contaminants in waters, sediments and biota of nearshore and offshore areas come from research studies of natural background and geochemistry; studies of industrial effects; environmental baseline information for assessment of coastal projects; and information required for routine regulatory assessments. The body of information available on contaminants in waters, sediments and biota of the bioregion is not large—many of the studies are focused on particular locations such as major ports and industrial harbours, oil and gas development sites, or harbours requiring dredging; however research has also focused on emerging issues such as contamination of the marine environment by former gold mining sites, and occurrence and significance of contaminants such as mercury and various persistent organic contaminants on wildlife, including seabirds and marine mammals. Some measurements of contaminants in sediments in DFO Small Craft Harbours came from routine sampling to determine suitability for harbour dredging and construction projects. The time frame of studies covers most of the survey period. Prior to this study, other reviews were conducted by DFO covering information on the Scotian Shelf and coastal areas before 1995 (Stewart and White 2001); and in the Bay of Fundy up to 1998 (White 1998) to assist in assessing the environmental quality of the region—the current review focuses on later information only. It identifies a comprehensive list of contaminants for use in ecosystem-based management of the region, and supplies information on levels of contaminants in various environmental compartments—waters, sediments and biota—to provide a "report card" for input to an assessment of marine environmental quality of the bioregion.

[2] Mill Cove WWTF and Eastern Passage WWTF both have had secondary treatment since 1969 and 1974 respectively, with continued upgrades and improvements along the way.

1.2. ENVIRONMMENTAL GUIDELINES

The primary motivating factor for determining the presence of contaminants and levels in the marine environment—apart from purely scientific and regulatory ones—is to alert society to their occurrence and to allow us to assess risk of exposure and potential impacts on the various uses, both by the organisms and the ecosystem, as well as by humans, and in particular, in terms of human needs and values (Wells and Rolston 1991, Harding 1992). As in many of the studies we reviewed which examined contaminants in the marine environment, this survey refers to various environmental quality guidelines used in some of the studies to assess the relative degree of contamination in different environmental compartments and situations, and their significance. An example of a set of guidelines is the Canadian Council of Ministers of the Environment (CCME) sediment quality guidelines (CCME 1999) presented in Table 2. Such guidelines or reference levels have been developed which indicate the level of hazard or potential for harm—so-called “safe” levels—of contaminants in the marine environment. The process of developing guidelines is a highly scientific and technical one and the reader is referred to sources such as CCME (1995, 1999) for explanations of the process. A brief discussion of guidelines and a collection of guideline levels, many of which continue to be applicable, is also presented in an earlier review of marine contaminants—Stewart and White (2001). Guidelines mainly referred to in this document and in the literature for contaminants in the bioregion include the Canadian Council of Ministers of the Environment (CCME) environmental quality guidelines (CCME 1999);[3] the regulated permissible levels of contaminants in sediments to be disposed at sea under the ocean disposal provisions of the Canadian Environmental Protection Act (CEPA); and fish and seafood quality guidelines of Health Canada and the Canadian Food Inspection Agency (CFIA) (CFIA 2018) which present acceptable levels of a suite of contaminants in saleable fish. The CCME (1999) guidelines include acceptable levels of contaminants found in water for both freshwater and marine and estuarine waters, as well as sediment guidelines. Some abbreviations for guidelines used frequently in our discussion include SQGs (Sediment Quality Guidelines) and occasionally ISQGs (Interim Sediment Quality Guidelines—those for which the availability of supporting scientific information is less, and which are under review). Probable Effects Levels (PELs) have a complex scientific basis, but simply put indicate some level of certainty about the likelihood and nature of effects. Readers are advised to consult the respective guideline sources noted above for levels and for a further explanation of the process of guideline development.

[3] Because contaminant levels in sediments are commonly measured for various purposes, in particular dredging and for ocean disposal, the main guidelines used in this report are the CCME marine sediment quality guidelines (SQG) which are found in the CCME Environmental Quality Guidelines (CCME 1999) and the CEPA Ocean Disposal limits.

Table 2. Summary of marine sediment quality guidelines for the protection of marine aquatic life. Interim Sediment Quality Guideline (ISQGs) and Probable Effects Levels (PELs) (CCME1999).		
Parameter		
Metals (µg/g dry weight)	**ISQG**	**PEL**
As	7.24	41.6
Cd	0.7	4.2
Cr	52.3	160
Cu	18.7	108
Hg	0.17	0.70
Pb	30.2	112
Zn	124	271
Organics		
Total PCBs (ng/g dry weight)	21.5	189
PAHs (ng/g dry weight)		
2-Methyl-Naphthalene	20.2	201
Acenaphthylene	5.87	128
Acenaphthene	6.71	88.9
Fluorene	21.2	144
Phenanthrene	54.1	86.7
Anthracene	46.9	245
Fluoranthene	113	1494
Pyrene	153	1398
Benzo*(a)* Anthracene	74.8	693
Chrysene	108	846
Benzo*(a)*Pyrene	88.8	763
Dibenzo*(a,h)* Anthracene	6.22	135

1.3. CONTAMINANT TYPES

Many types of contaminants occur in the marine environment, reflecting the wide range of activities and interests in human society, and also the long timeframe over which contaminants have been studied, monitored and managed. Some contaminants occurring in the environment such as heavy metals (e.g., lead, copper, zinc, etc.) are the by-product of human activities which have extracted and concentrated them from geological sources, and then released them at higher-than-natural concentrations into the environment when they are used and when materials containing them are discarded. Many, such as organic chemicals (the wide array of chemicals based on carbon, including many of the toxic and bioaccumulative chemicals such as DDT and PCBs), as well as organometallic compounds (in which a metal and organic compound are combined, for example the antifoulant chemical tributyltin) are synthesized and have no natural source. Some contaminants have been a concern for a long time—for example lead, which affected not only the Roman civilization but may have impacted marine environments as well, is a *classical* contaminant—while others which only recently have appeared and become a concern because of their harmful characteristics and widespread distribution in the environment (e.g., the fire retardants polybrominated diphenyl ethers, and the plasticizer, bisphenol A (BPA)) are known as *emerging* contaminants. Topics of recent interest include environmental pathways and fate of classical (dioxins/furans, PCBs) and emerging contaminants including polybrominated and polychlorinated diphenyl ethers (PBDEs and PCDEs), nonylphenol and nonylphenol ethoxylates (NPEs), and endocrine disruptors (EDCs) (DFO 2017a). Classical contaminants can be categorized based on chemistry (e.g., metals, organic compounds), type (e.g., bacterial contamination), and phase (e.g., water, sediment, and biota) in which they are found. Some contaminants may also arise and reach potentially harmful levels naturally. For example arsenic enters the marine environment from rock formations particularly along the Nova Scotian Eastern Shore, and is known as *geogenic* (Walker and Grant 2015); PAHs, as well as coming from human activities, arise from natural sources such as soot from forest fires and natural hydrocarbon seeps on land and in the ocean. In addition, some non-chemical physical contaminants of the environment such as plastics found in marine litter and microplastics, as well as other materials found in marine debris, are important in the bioregion.[4] Contaminants considered in this review specifically include:

- Metals, including in particular the heavy metals—arsenic, cadmium, copper, lead, mercury and zinc;
- Organic or organometallic compounds, e.g., PAHs, PCBs, DDT and congeners, tributyltin, dioxins, hydrochlorocyclohexane (HCHs), nonylphenol ethoxylates (NPEs), PBDEs and PCDEs, perfluorinated chemicals (PFCs), etc.;
- Pharmaceuticals, artificial hormones, drugs, endocrine disrupting chemicals, etc.;
- Consumer products such as cleansers, detergents, and skin care products, typically released in sewage;
- Physical/structural contaminants (e.g., marine debris, microplastics).
- Others, such as bacterial and viral contaminants of coastal waters and organic enrichment, are included in passing, where this is specifically the focus of research studies or programs.

1.4. METALS

Metals in the marine environment are found in various forms: dissolved; in suspended particulate matter in which they are both constituents of particles and found adsorbed to their surfaces; in flocs, the loose aggregations of both fine inorganic and organic particles which are a dominant form of suspended matter in coastal waters; in marine and estuarine organisms; and in sediments. Metals tend to be most concentrated in coastal areas such as harbours, where they are released by coastal industries including

[4] Nutrients are important contaminants which lead to eutrophication of coastal waters but they have not been included in this review.

shipbuilding and maintenance, pulp mills, thermal generating stations etc. among others, as well as through urban runoff, municipal sewage, and litter, which are associated with population centres. Many harbours are found at the mouths of rivers which frequently bring contaminants from urbanized and industrialized areas upstream. Estuarine conditions lead to enhanced flocculation and deposition of transported sediments, and often the occurrence of elevated metal levels in sediments. Metals in the ocean also arise from natural sources such as coastal erosion. As components of particles of various kinds, metals tend to be distributed with sediment particles with which they are deposited in depositional areas, such as harbours along the coast and in basins offshore. Overall, much of the particulate matter with which metals are associated winds up deposited on the continental shelf through various processes which include trapping by sediment particles and flocculates and when subsequently concentrated by depositional processes (Milligan and Loring 1997, Milligan and Law 2013, Smith et al. 2014).

Carter et al. (2004) provide an example of how industrial activities associated with harbours as well as routine operations and maintenance activities in various industries can lead to locally-elevated contaminant concentrations. The study found that shipyards and other vessel maintenance facilities in several of the main port cities in Atlantic Canada caused elevated heavy metal concentrations in adjacent environments. Small Craft Harbours also frequently have elevated levels of metals in sediments, owing to the maintenance and operation of vessels of various kinds (see Section 4.1.1). An example of an artificial source of a metal associated with an industry in coastal areas is tributyltin, a compound with various industrial applications, but in particular as an antifouling coating on sea-going vessels. Tributyltin continues to be found in Atlantic Canadian harbours and is an environmental concern, despite a Canadian ban on its use for marine applications on vessels less than 25 m in 1989 (Maguire 2000, Ernst et al. 1999, Carter et al. 2004) and a requirement that all ships remove or encapsulate TBT coatings by 2008 (Transport Canada 2018). The compound is harmful as an endocrine-disrupting chemical (Prouse 1996, Prouse and Ellis 1997, Carter et al. 2004, Titley-O'Neal et al. 2011a) and for its bioaccumulative properties, and has been found in major harbours in the Atlantic Region (Halifax Harbour, Saint John Harbour and St. John's Harbour) (Chau et al. 1997, Carter et al. 2004, Coray and Bard 2007, Titley-O'Neal et al. 2011b). Tributyltin is expected to occur in the marine environment of other industrial harbours and marinas with shipbuilding and maintenance activities. Other metals released into the marine environment include arsenic from bedrock formations, mercury from abandoned gold mining tailings and atmospheric releases, and lead from industrial activies and ship maintenance.

1.5. ORGANIC CHEMICALS

Chemicals of most concern as contaminants in the marine environment are often those which humans have synthesized or manufactured, and among those, most are built on chemical frameworks consisting largely of carbon and are termed "organic."[5] Upon

[5] The term *organic* in relation to compounds derived from carbon relates to the predominance of carbon and nitrogen in the composition of living matter, compared to non-living components of the physical

release, these compounds spread throughout the environment following a multitude of pathways which are also shared by other types of contaminants. Organic chemicals in widespread use or which involve heavy applications over large areas of land, such as agricultural or forestry pesticides and herbicides, typically arrive in marine areas through atmospheric transport or in river flow, although others, such as hydrocarbons and derivatives produced in smaller amounts but where use is concentrated, such as in coastal cities, may be found in relatively high concentrations in urban runoff where they are channeled to the ocean through storm sewers and sewage.

As an important source of organic compounds and other contaminants in the marine environment, sewage and stormwater releases into harbours and coastal waters in the Scotian Shelf Bioregion add a suite of largely organic chemicals derived from human wastes in sewage. They also add a range of chemicals whose composition mirrors the substances found and used in the diverse activities carried out by our industrial society—metals from wear and tear on machines and equipment, hydrocarbons from lubricants and fuels, combustion-derived byproducts including PAHs and polycyclic aromatic compounds (PACs), pesticides, etc. Ammonia, chloramines, nonylphenol (NP) and its ethoxylates (NPEs)—four substances placed on the Canadian Environmental Protection Act (CEPA) Priority Substances list in 1995—frequently occur in treated municipal wastewater effluent. Ammonia, NPs and NPEs are routinely discharged from sewage outfalls, and chloramines are discharged from facilities where chlorine is used to disinfect drinking water and wastewater such as sewage plants and fish plants (Lotze and Milewski 2002). In the Atlantic Region, approximately 130 municipalities have a population of 1,000 or more connected to some type of sewage treatment (Environment Canada 2005 from Brun et al. 2006). Municipal sewage also contains organic chemicals such as pharmaceuticals as well as other compounds which can pass through wastewater treatment plants into aquatic environments. The hundreds of these compounds of various kinds—collectively known as chemicals of emerging concern (CECs)—include pharmaceuticals (e.g., antibiotics, blood pressure regulators, hormonal contraceptives), additives in personal care products (i.e., shampoos, soaps, lotions, cosmetics), and cleaners (Kidd and Mercer 2012). Although not released in exceptional amounts, these chemicals may be potent even at low concentrations and have side effects which potentially impact marine organisms, the most worrisome effect being endocrine disruption.

Kidd and Mercer (2012) reviewed 31 CECs used by humans and presumed to be released in sewage in assessing potential impacts on marine organisms in the Bay of Fundy. Few studies have been done of the fate and effects of CECs in the marine environment of the bioregion (Kidd and Mercer 2012); however a risk assessment conducted in that study, based on the limited data available, suggested that levels of CECs do not threaten the health of aquatic organisms in surface waters or marine areas

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environment. "Most of the chemical components of living organisms are organic compounds of carbon, in which the carbon is relatively reduced or hydrogenated. Many organic biomolecules also contain nitrogen. In contrast…carbon and nitrogen are not abundant in nonliving matter and occur in the atmosphere and the earth's crust only in simple inorganic forms, such as carbon dioxide, molecular nitrogen, carbonates, and nitrates" (Lehninger 1970).

of the Bay of Fundy (Kidd and Mercer 2012). Brun et al. (2006) also provide an overview of the issue, in a study of pharmaceuticals released from a sewage treatment plant into waters at the head of Halifax Inlet on the Atlantic coast of Nova Scotia. Other contaminants enter the marine environment from sewage, including surfactants which have been found in waters in Nova Scotia harbours including Halifax Inlet and Northwest Arm, Lunenburg, Chester and the LaHave River estuary at Bridgewater (Gagnon 1983). In Halifax Harbour, levels of anionic surfactants were mostly in the range of 3 to 15 µg/L with peak concentrations of 50 to 60 µg/L. Levels in selected smaller harbours ranged from 17.0 to 20.0 µg/L, with low levels (0.0 to 1.0 µg/L) at remote sites. Levels of anionic surfactants are reduced by sewage treatment and levels are expected to be at the low end of the range reported throughout the bioregion. Other compounds arising in sewage include perfumes, which contain nitro and polycyclic musk compounds (Gatermann et al. 1999 from McCullough et al. 2005).

Crude oil is a widespread organic contaminant of offshore waters, either through releases during normal use in operations of fossil-fuel fired equipment or through catastrophic releases such as oil spills. Coastal intertidal and subtidal sediments exposed to crude oil are likely to be present throughout the Scotian Shelf Bioregion; a small proportion of the oil adrift in the ocean in the bioregion shows up in seabirds washed ashore on Sable Island (Lucas and MacGregor 2006), but little information is available on the overall occurrence and extent. Crude oil in sediments in sites which have received a major oiling event, such as the Arrow tanker spill in Chedabucto Bay in 1970, have degraded to a degree and lost some of their toxicity and biological effects, but are still detectable (Lee et al. 2003). Stranded oil elsewhere in the bioregion is expected to have experienced extensive biodegradation and physical removal, including by bacterial populations capable of degrading hydrocarbons.

A comparatively recent source of organic chemicals to the coastal marine environment is the aquaculture industry, in particular feed additives such as emamectin benzoate, an organic feed additive used to control sea lice in farmed salmonids (Waddy et al. 2002).

1.6. BACTERIA AND PATHOGENS

Various human activities in coastal areas can lead to releases of bacteria and other pathogenic organisms into the ocean. Treated and untreated municipal sewage is a common source of contamination by human disease organisms such as infectious bacteria and viruses, which affect recreational use of coastal waters, as well as potentially contaminating aquacultural products such as mussels and oysters as well as commercial fisheries species. Fish farming itself has also shown a potential to harbour organisms pathogenic to fish—the infectious viral disease Infectious Salmon Anemia (ISA) brings a naturally-occurring organism into elevated concentrations in fish farms where nearby natural fish populations can be affected. Coastal waters are also exposed to ship traffic from around the world which can carry pathogens as well as invasive species into waters of the bioregion.

Harbours such as Halifax Inlet formerly had high levels of bacteria arising from mainly untreated sewage, which prevented various uses of the harbour such as swimming and shellfish harvesting. Improvements to sewage treatment in many of the coastal communities and major harbours of the bioregion over the past two decades, including Sydney Harbour and Saint John Harbour, have led to improvements in water quality, with resulting changes such as the opening of beaches to swimming and recreational fishing. Improvements in bacterial conditions in coastal areas have generally helped to maintain water quality needed for fisheries, fish processing, and activities such as shellfish harvesting.

Waters in bays and coastal inlets along Canada's ocean coastlines are monitored for levels of fecal coliform bacteria (*E. coli*) for management of shellfish harvesting under the Canadian Shellfish Sanitation Program (CSSP), a federal food safety program jointly administered by the CFIA, Environment and Climate Change Canada (ECCC), and DFO. The goal of the program is to protect Canadians from the health risks associated with the consumption of contaminated bivalve molluscs such as mussels, oysters and clams. Coastal areas are designated as safe or unsafe for shellfish harvesting depending on microbiological criteria in each coastal area. Although the extent of coastal waters closed to shellfish harvesting was known to be increasing in the early 1990s (Stewart and White 2001), by 2006 to 2010 the percentage of approved and conditionally approved growing area had stabilized (Figure 2) (ECCC 2018). Over this time period, there has been an improvement in management of effluents such as municipal sewage, industrial effluents and fish plant wastes, which is likely responsible for overall recent stability in shellfish closures areas. Another measure is the number of shellfish closures in the Atlantic Region (which includes the Scotian Shelf Bioregion) which, however, increased rapidly from 1985 to 2000 (Wilson 2000, CBCL 2009) (Figure 3), with the trend continuing from 2001 to 2004 (Environment Canada 2000 from CBCL 2009). Although important, bacterial contamination is one of the environmental quality issues (along with eutrophication and organic enrichment) which was not reviewed in this report.

1.7. PHYSICAL/STRUCTURAL CONTAMINANTS

Marine debris includes a wide range of materials discarded by humans which reach the ocean and can occur most obviously on shorelines, but are found throughout the oceans of the world. It arises from many sources including recreational littering and mismanagement of solid waste, sewage outfalls, inland waterways, and shipping activities. Marine litter has various environmental and socioeconomic impacts, aside from the aesthetic impact experienced when the public encounters it on beaches or in coastal waters. Grieve (2013) provides a summary of impacts with special reference to the Scotian Shelf, including effects of entanglement of marine animals and harm through ingestion of plastics and other debris, facilitated movement of invasive species, and disturbance of habitat. Some of the socioeconomic effects include damage to fishing boats and recreational vessels from entanglement and encounters with floating debris, reductions in catch through harm to fisheries species, and negative tourism impacts (Grieve 2013).

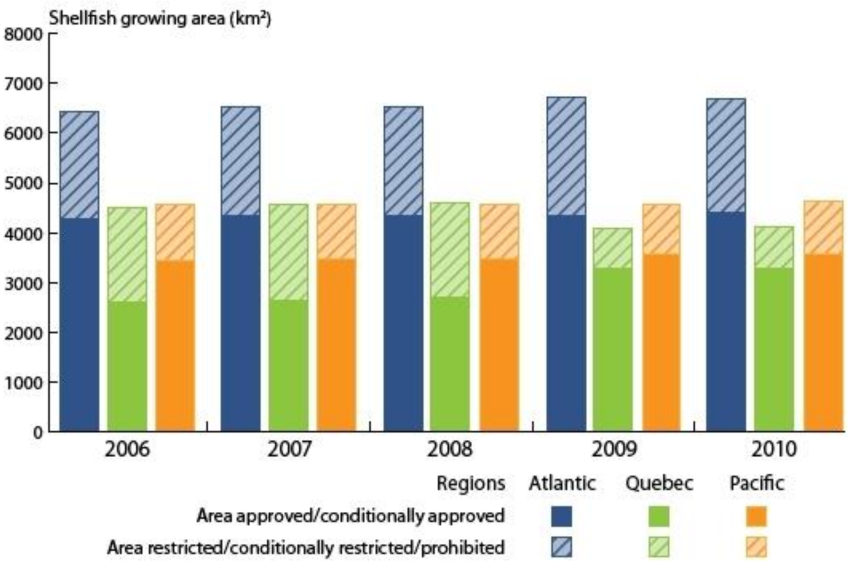

Figure 2. Shellfish growing areas which are approved or restricted in Canada (2006-2010) (Source: ECCC 2018).

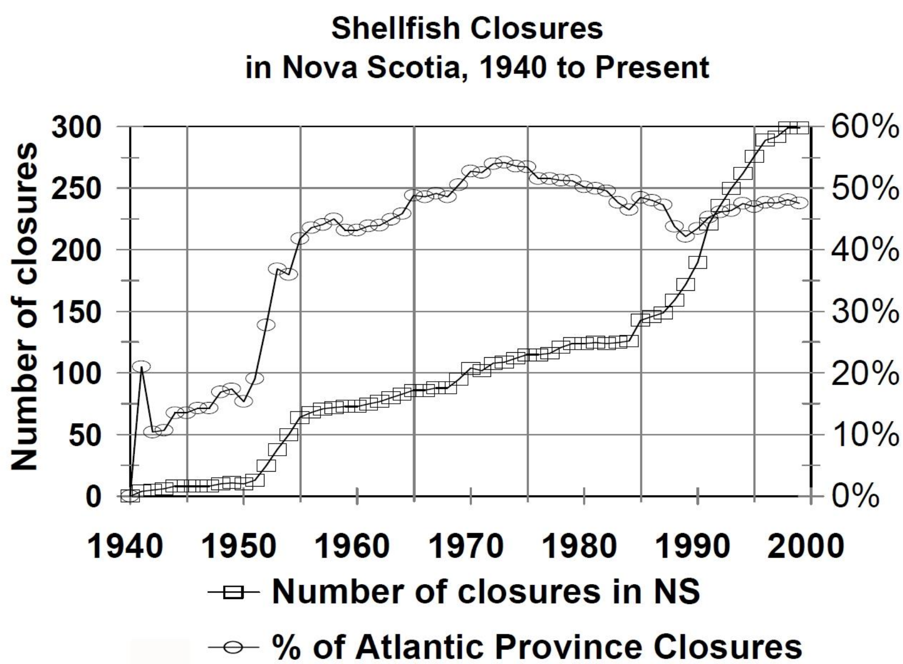

Figure 3. Trend in shellfish closures in the Atlantic Region and Nova Scotia, 1940-2000 (Source: Wilson 2000). Percent of closures represents the number of closures in Nova Scotia as a percentage of all Atlantic Canada closures.

Beach surveys and community-organized beach clean-ups attest to the variety and volume of debris found along shorelines in Nova Scotia. Volunteer shoreline cleanups in Nova Scotia and New Brunswick have long been a source of information on marine litter and debris composition and trends in the Scotian Shelf Bioregion. From 2003 to 2009, the composition of waste collected in the Atlantic Provinces mirrored national profiles in a national volunteer cleanup program[6] but was highly variable between provinces (Grieve 2013). The dominant source categories were shoreline and recreational activities; waterway activities; smoking-related activities; dumping activities; and medical, personal and hygiene activities (Grieve 2013). Shoreline cleanups conducted along the New Brunswick coast of the Bay of Fundy in the 2010s and coordinated by the Huntsman Marine Sciences Centre (Southwest New Brunswick Marine Debris Program) found predominantly plastic items (bottles, pieces of plastic, bags, cigarette filters and food wrappers) but also commonly fishing- and aquaculture-related items such as lobster traps, ropes and nets. (R. McIver, Aquatic Science Biologist, DFO, Dartmouth, N.S., Personal Communication, 2017).

A beach survey conducted in Halifax at Point Pleasant Park and Black Rock Beach from April to September 2005 found 10.8 kg of debris (2129 items), of which 86 percent was low-density plastic material. Over half of this debris was identified as land-based and recreationally sourced (i.e., littering). Shipping and fishing activities accounted for 6.7 percent, sewage was 13.5 percent, and 27.5 percent was identified as “other” (Walker et al. 2006). Beach surveys of persistent litter deposited on Sable Island, between May 1984 and September 1986, recorded 11,183 items, of which 92 percent was plastic material (Lucas 1992). Typical debris items found in surveys and clean-ups include tampon dispensers, polystyrene cups and packing materials, plastic containers for food and confectionary wrappers, polyethylene bags and sheets, beverage bottles, and fishing equipment among others. Highest density of marine debris in annual Nova Scotia beach surveys carried out in Nova Scotia between 2006 and 2015, was 447 items and 102 kilograms per kilometre of survey (Figure 4) (David 2016). Litter included cigarette butts, common disposable goods (e.g., food wrappers, caps/lids, bottles, etc); and rope and strapping bands used in marine activities such as fishing and aquaculture (8.8 and 3.1 percent of items respectively). Most items were entirely or partially composed of plastic (David 2016). Halifax sites reported more than double the proportion of other types of litter associated with smoking (principally cigarette butts) but had similar proportions of other categories of litter compared to sites in other coastal areas (David 2016). The high proportion of cigarette debris is consistent with shoreline cleanups around the world (David 2016).

[6] Annual summaries of marine debris and litter for volunteer shoreline surveys in the bioregion are compiled through The Great Canadian Shoreline Cleanup a national volunteer program coordinated by the Vancouver Aquarium (https://shorelinecleanup.ca/). Begun in Vancouver in 1994, the activity became a national conservation initiative in 2002. Results are presented for each Atlantic Province as a whole, and are not broken down for the Bay of Fundy or Scotian Shelf subareas of the bioregion.

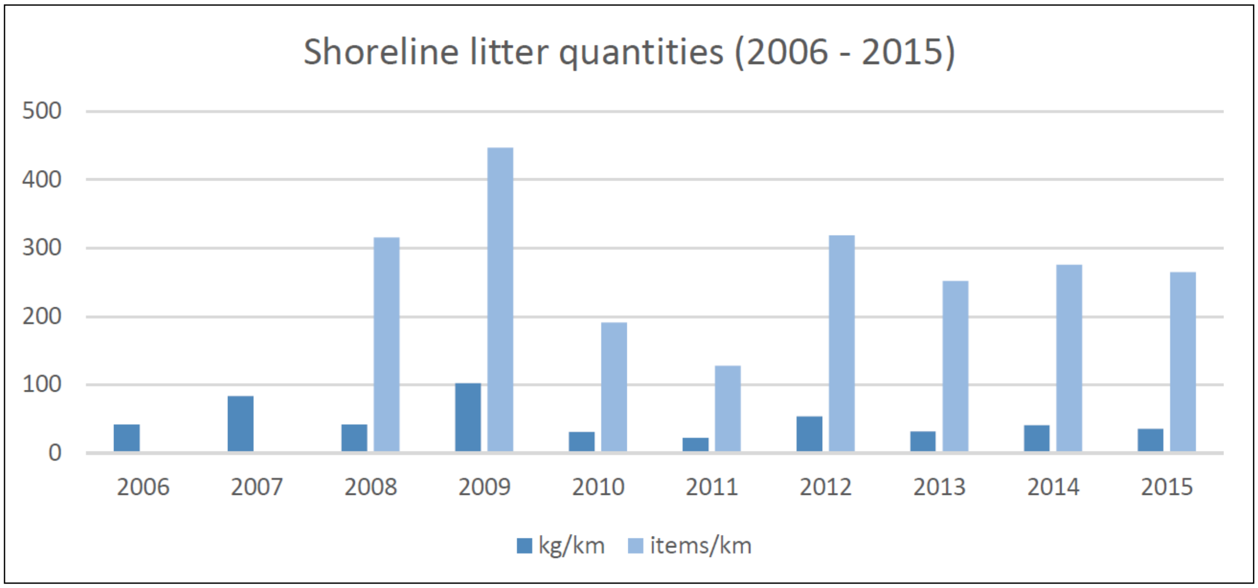

Figure 4. Quantities of litter in recent Nova Scotia shoreline surveys (Source: David 2016).

1.8. ORGANIC ENRICHMENT

The physical and chemical structure of all living organisms is based primarily on the chemistry of carbon in combination with nitrogen, oxygen and hydrogen,[7] as well as other minor constituents. Compounds containing carbon (i.e., "organic" material, see Section 1.4) produced by living organisms are released when they die or when they are consumed and metabolized by other organisms, or excreted into the marine environment. There they are further decomposed by bacterial and chemical processes in waters and sediments, reducing those that are readily decomposed to simple carbon compounds such as carbon-dioxide, and leaving the more refractory compounds such as cellulose and lignin to accumulate in sediments. When the availability of organic compounds is high, as it often is in many coastal waters, the utilization of carbon-containing compounds becomes a factor in oxygen balance, often leading to depletion or complete loss of oxygen in near-bottom waters and accumulation of organic material and its contained carbon compounds in sediments (Karlson et al. 2002, Gray et al. 2002, Hargrave et al. 2008). Reduced oxygen in coastal waters and organic contamination of sediments has become a major global issue where increased eutrophication combined with increasing ocean temperatures has led to the occurrence of extensive areas of the ocean with anoxic conditions, known as "dead zones" (Biello 2008). Dead zones are not a regular feature of the bioregion; however anoxic conditions have occurred periodically in some harbours, for example Sydney Harbour (Stewart and White 2001, Stewart et al. 2002a).

Sources of organic enrichment in the bioregion include releases of sewage; high primary production associated with nutrient inputs to coastal waters—i.e.,

[7] Many phytoplankton use silicon as a structural material.

eutrophication; as well as releases of fine particulate organic debris associated with industries such as pulp and paper, fish processing, and sea farming, all of which lead to organic carbon accumulation in sediments and potentially to localized occurrences of oxygen depletion in near bottom waters and sediments. Eutrophication as a result of nutrient input is not a particular problem in coastal environments in the bioregion but could be if nutrient inputs are not managed (Strain et al. 1995; Strain and Yeats 1999, 2002). Liebman et al. (2012) provided an overview of the eutrophication issue for the Gulf of Maine, while the Gulf of Maine EcoSystem Indicator Partnership (ESIP) had a component which focused on monitoring eutrophication indicators including concentration of nitrogen, phosphorus, chlorophyll *a* and Secchi Depth (a measure of transparency) which have been measured in the Bay of Fundy since 2015 (ESIP 2017). No studies assessing organic enrichment in the bioregion except for those relating to aquacultural impacts were identified in this review although it has been highlighted as a potential issue in the Quoddy Region of New Brunswick (Lotze and Milewski 2002, Milewski and Lotze 2004). DFO is targeting research on organic enrichment associated with aquaculture through an internal Program of Aquaculture Regulatory Research (PARR) which includes several research themes relating to the topic of organic enrichment caused by sea farms (http://www.dfo-mpo.gc.ca/aquaculture/parr-prra/index-eng.html). Monitoring of aquaculture sites for indicators of enrichment (e.g., dissolved oxygen and sulfide measurements) is routinely carried out under provincial permitting in Atlantic Canada, and controls on effluents (e.g., biochemical oxygen demand, BOD) are in place for most industries which have aquatic discharges.

2.0 INFORMATION SOURCES AND REPORT ORGANIZATION

Parts of the bioregion were covered in several earlier overviews of marine environmental quality and contaminants including White and Johns (1997) (Gulf of St. Lawrence), Pierce et al. (1998) (eastern Canadian waters including the Bay of Fundy and Gulf of Maine), and Stewart and White (2001) (Scotian Shelf). Other reviews have characterized coastal conditions in general on the Nova Scotia Atlantic Coast (McCullough et al. 2005), in Nova Scotia coastal areas in general (CBCL 2009, Bundy et al. 2014), on the Scotian Shelf (Burbidge 2013), in the Bay of Fundy Quoddy Region (Lotze and Milewski 2002), and in the Gulf of Maine including the Bay of Fundy (various summary reports on marine environmental quality of the Gulf of Maine such as Chase et al. 2001, Harding 2013, and Harding and Burbidge 2013). In particular, Harding (2013) produced a review focusing on contaminants in sediments, waters and biota of the Gulf of Maine, a region which overlaps our study area, providing additional background on contaminants and issues. Our present review incorporates information from the Harding review to provide a complete picture of information on studies available from the area in the time window covered by our study, but we have not dealt as thoroughly with the background of some of the contaminant issues. Several monitoring studies which focused on particular environmental issues (e.g., contamination of water, sediments, and biota arising from coastal gold mining and the Sydney Tar Ponds Cleanup) (Walker et al. 2013a, 2013b, 2013c, 2013d; Walker and Grant 2015; MacAskill et al. 2016) provide compilations of environmental levels of various contaminants of concern for the region.

This report is organized by environmental compartments (e.g., waters, sediments and biota), subdivided geographically and within a nearshore/offshore breakdown. Degree of breakdown varies depending on availability of information. The two primary subdivisions are the Scotian Shelf and adjacent offshore and inshore waters, and the Bay of Fundy-Gulf of Maine. The two areas are frequently set apart for research, fisheries management, and ocean management purposes, and are presented in the above order, although the choice is arbitrary and does not reflect their relative importance. In addition, there are several levels of emphasis in terms of the information presented, with major focused studies on particular regions or topics being given more attention. Illustrative and representative contaminant data in various matrices—sediments, water, and biota—are presented in appendix tables (Tables A1-A3), but do not provide a complete inventory of information on contaminants in the region.

3.0 CONTAMINANTS IN THE SCOTIAN SHELF BIOREGION

3.1. FOCUS AREAS

Contamination of the marine environment in the Scotian Shelf Bioregion tends to be highest in certain coastal areas, in particular major harbours and ports with high urban populations where waters are used for release of municipal sewage and stormwater, and marine industrial activities such as shipbuilding, repair, and shipping are concentrated. Such areas also tend to be the focus of research studies into marine contaminants, and availability of information is often higher, and also the range of contaminant issues which can occur is greater. These “focus areas” include the Halifax-Dartmouth area on Halifax Inlet; the Strait of Canso industrial harbour which supports Port Hawkesbury and Point Tupper; the Port of Sydney in northern Cape Breton Island; the City of Saint John and Saint John Harbour; and the New Brunswick coastline and waters of the Bay of Fundy stretching from Saint John to Passamaquoddy Bay—the Quoddy Region. Apart from the focus areas, there are many mid-sized population centres in the bioregion which have local impacts on contamination of the marine environment. Such smaller centres include the towns of Truro, Nova Scotia, situated on the Salmon River at the head of tide on Cobequid Bay, Bay of Fundy; St Andrews in the Quoddy Region of New Brunswick; Parrsboro, Nova Scotia; Yarmouth, Nova Scotia, in the outer Bay of Fundy; Sackville, New Brunswick on Cumberland Basin; and Wolfville, Kentville and the Windsor-Falmouth-Hantsport area on the Southern Bight of the Minas Basin, all of which are closely connected with, and impact, the local marine and estuarine environment. In the context of general coastal contamination, changes include improvements in sewage treatment which have occurred over recent decades, shifts in the mix and intensity of coastal industries, and degree of treatment of industrial effluents regulated by provincial and municipal government in coastal areas, which have led to reductions in contaminant loading of coastal waters. Examples of decreased or managed inputs include the closure of coal mines along the coast of northeastern Cape

Breton, reduction in the number of fish plants all along the coast, pulp mill closures such as the Bowater Mersey plant near Liverpool, Nova Scotia, and the remediation of the Sydney Tar Ponds in 2009-2011 in Sydney. In particular, the Sydney Tar Ponds remediation project removed significant sources of contaminants and has led to reductions in contaminant levels—in particular PAHs—occurring in water, sediments and biota there. As part of the broader picture of contaminants in the marine environment of the bioregion, however, these major centres and their associated human activities and contaminant sources remain particularly important. Background on these focus areas is presented in the following sections.

3.1.1. Halifax Harbour

Halifax-Dartmouth in the Halifax Regional Municipality is the largest urban and industrial centre in the bioregion, and Halifax Inlet the largest harbour. The contaminant issues experienced here illustrate those likely to be found in the other coastal industrial and population centres and major coastal harbours in the bioregion including Saint John and Moncton, New Brunswick, and Sydney and the Strait of Canso industrial area of Port Hawkesbury-Port Hastings on Cape Breton Island. Halifax Inlet, like most major harbours and coastal cities worldwide, has experienced higher inputs of contaminants than other coastal areas due to its long history of urban and industrial development. As a result, contaminants in the environment represent a legacy of past use and abuse of its waters. While waters and biota have generally shown levels of contaminants which are not acutely harmful, sediments in particular have become highly contaminated with organic carbon, petroleum hydrocarbons, including PAHs, and metals, as they are areas of deposition where many contaminants have accumulated, forming a lasting record and a hazard, particularly if the sediments are disturbed (Buckley and Winters 1992; Buckley et al. 1995; Hellou et al. 2002a, 2002b; Stewart and White 2001). Recent sediment accumulation arising from processes of erosion on land can “cap” or contain earlier sediments beneath cleaner sediments; however even most recent surface sediments in Halifax Inlet contain suites of contaminants which reflect conditions in the environment, including new contaminants, which may be currently produced and released into the environment in the area (King et al. 2002, Metcalfe et al. 2003a, Brun et al. 2006).

Environmental conditions in Halifax Harbour have been extensively studied, as summarized in earlier reviews (Stewart and White 2001, McCullough et al. 2005). In particular an intensive oceanographic research effort was conducted by federal government and local researchers and consultants in the late 1980s and early 1990s to characterize conditions there in support of efforts to improve sewage treatment in the harbour (e.g., Halifax Harbour Task Force 1990, Buckley and Winters 1992, Fader and Buckley 1997). In the late 1990s this effort was renewed by DFO scientists to look at organic contaminants, as well as metals and other compounds found in sewage, to assess pathways through which they reach and affect the biota (Hellou et al. 2000, 2002a, 2002b, 2003, 2005b; Yeats et al. 2008). In particular the most recent studies targeted metals, PCBs and polycyclic aromatic hydrocarbons (PACs), which include PAHs and other associated compounds such as dibenzothiopenes. Many arise in the environment as byproducts of combustion of hydrocarbons and wind up in sediments and waters of coastal harbours. The studies focused on the role of these and other environmental contaminants in affecting the physiology of the common intertidal mussel, Blue Mussel (*Mytilus edulis*). In general, various studies have shown that concentrations of heavy metals, PAHs and PCBs in biota in Halifax Harbour are similar to those reported for other industrialized inshore waters, with some instances of elevated concentrations (Yeats et al. 2008). Levels of some contaminants in the harbour are likely to have improved since the period covered by these studies, in particular after the installation of improved sewage treatment but also improved environmental regulation of many industrial activities taking place there.

Levels of organic and metallic contaminants in waters, sediments and biota of Halifax Harbour, and corresponding levels of environmental concern, vary significantly with location. For example harbour waters do not generally show excessive concentrations of contaminants, but exceptions such as high concentrations of lead and zinc in seawater near sewage outfalls and spikes in concentrations of particular PCBs (Dalziel et al. 1991 and King et al. 2002 respectively from Yeats et al. 2008), have occasionally occurred (Yeats et al. 2008). Sediments in depositional areas have been, and continue to be contaminated—in many parts of the harbour exceeding Canadian Environmental Quality Guidelines PELs (CCME 1999) for PCBs, PAHs, copper, lead, mercury and zinc (Yeats et al. 2008).

3.1.2. Sydney Harbour

Sydney Harbour became the focus in the 1980s and subsequent decades of studies to assess environmental contamination which arose from the operation of the Sydney Steel Corporation mill and coke ovens, which included atmospheric releases, site runoff, disposal and management of waste streams and ash, all of which affected nearby areas of the land and water (Vandermeulen 1989, Barlow and May 2000, Stewart and White 2001, Griffiths et al. 2006). The South Arm of Sydney Harbour is most contaminated; the other main industrial and urban input is the port of North Sydney in outer Sydney Harbour, but it has a comparatively small contaminant footprint in the marine environment. Contaminant levels in Sydney Harbour are influenced by the presence of the City of Sydney and its associated urban development and contamination sources, sewage, industrial development and shipping activity associated with the Port, as well as human activities in the watershed of the Sydney River estuary at the head of South Arm of the harbour (Stewart and White 2001). The main contributors to environmental contamination of the harbour, however, have been a combination of the presence of the Sydney Steel Mill and, subsequent to its closure, the presence of the settling pond, known as the Sydney Tar Ponds, which accumulated large quantities of contaminants, particularly PAHs, as well as wastes and sewage from Sydney which have entered the harbour by various means.

Environmental characterization of the loading of contaminants in Sydney Harbour took place beginning in the early 1980s involving DFO and Environment Canada, as well as private companies and consultants, after lobster in the harbour were shown to be unfit for human consumption based on high levels of PAHs in tissues (Sirota et al. 1984, Uthe and Musial 1986, Vandermeulen 1989). Various harbour studies of contaminant levels in water, sediments, and biota (Blue Mussels, Horse Mussels and Lobster) continuing up to approximately the year 2000 monitored changes after the closure of the mill, summarized in Vandermeulen (1989) and Stewart and White (2001). A major multidisciplinary research initiative was undertaken in 1999-2001 to study metals and conventional organic contaminants (e.g., PAHs, PCBs) and their distribution in Sydney Harbour, as well as potential for microbial degradation, funded by the federal government under Health Canada's Toxic Substances Research Initiative (TSRI) (Lee 2002, Smith et al. 2009). In addition to confirming the presence of high loadings of contaminants such as PAHs, PCBs and heavy metals in older sediments, the study showed reduced levels of metals and organic contaminants in surficial sediments indicative of improving conditions; as well as hotspots of PCB contamination arising from urban combined sewer outfalls at various sites which verified the results of an earlier study (Ernst et al. 1999). Efforts to remediate the mill settling pond—known as the Sydney Tar Ponds and located on Muggah Creek which flows into the harbour near the mill site—were begun in the early 1990s. After a long public process which lasted almost two decades, a remediation project was completed in 2011 which finally ended contamination reaching the harbour (Griffiths et al. 2006, Walker et al. 2013a). During the mill's operation, runoff from the site and from wastes from the coking process, as well as wastes from the City of Sydney, entered the Tar Ponds and accumulated there, from which contaminants—in particular PAHs—were slowly released via Muggah Creek into Sydney Harbour. Walker et al. (2013a, 2013b, 2013c, 2013d, 2015; Walker and MacAskill 2014) conducted studies on Sydney Harbour during and following the Sydney Tar Ponds clean-up and remediation as part of an environmental monitoring program overseen by Public Works and Government Services Canada (reviewed in DFO 2010, 2012). Information on contaminant levels in water sediments and biota (caged mussels and local rock crab) around the harbour as well as in the adjacent, relatively uncontaminated Northwest Arm, demonstrated levels of metals and organic contaminants which were similar to natural levels although occasionally higher at reference sites. The large-scale cleanup of the steel mill property and the Sydney Tar Ponds, as well as improvements to sewage treatment, has led to substantial improvements in contaminant levels in Sydney Harbour.

3.1.3. Strait of Canso

The coastal towns of Port Hawkesbury and Port Hastings form a second core area—next to Sydney—of industrialization and urban development in a coastal area of Cape Breton Island. The communities' natural harbour and adjacent coastline of the Strait of Canso were affected by construction of a causeway across the Strait in 1968 that effectively blocked it, turning it into a second, much larger artificial harbour with oceanographic characteristics similar to an inlet. The environmental effects of a geo-engineering project on such a large scale became the focus of early Nova Scotia environmental geology research in the 1970s (Buckley et al. 1974, Stewart and White 2001) and later scrutiny by the ocean and fisheries science community to assess its impacts (McCracken 1979, Stewart and White 2001). While many of the same industrial impacts in the Strait of Canso were found as for other coastal ports and areas which have similar activities—including marine facilities, shipyards, fish processing, and municipal sewage—the main environmental concern discovered at the time was a build-up of wood fibre wastes from the Nova Scotia Forest Industries pulp mill (Buckley et al.

1974, Day 1979) and elevated levels in sediments of contaminants such as PCBs. Concern also emerged over the potential for contamination of the marine environment with mercury released from a chlor-alkali plant associated with the pulp and paper mill, later still over dioxins and furans released to the environment by the chlorine bleaching process, and lastly over the effects of a significant oil spill—the tanker *Arrow* in 1970—which occurred in the outer entrance (Keizer et al. 1978; Lee et al. 1999, 2003).

Subsequently and to the present, additional industrial and urban development has taken place in Port Hawkesbury and Port Hastings, as well as in coastal communities located on the Strait such as Mulgrave. Some recent industrial activities include an ocean terminal for natural gas and condensate pipelines from the offshore developments around Sable Island, a shore facility for demobilizing the Sable Island Offshore Energy project, a liquefied natural gas (LNG) terminal project at Bear Head at the Atlantic entrance to the Strait, and a proposed container terminal at Melford.

Apart from environmental measurements summarized in Stewart and White (2001), only Parrott et al. (2005) (a geology survey) and Tay et al. (2010) (which summarizes studies conducted by Environment Canada in connection with monitoring of an ocean disposal site in the area)[8] were identified as containing recent scientific information on contaminants in the Strait of Canso.

Elevated cadmium had been a feature of sediments in the Strait of Canso based on earlier studies (Stewart and White 2001). Cadmium levels above the Disposal at Sea guidelines of 0.6 mg/kg (up to 1.82 mg/kg) were detected along the industrialized east side of the Strait in 2004 (Tay et al. 2010). Similarly, elevated levels of PAHs and PCBs in sediments, which also had been a feature of industrialized areas of Canso Strait (Stewart and White 2001), showed high PCB concentrations (up to 535 µg/kg) near the shoreline closest to the industrial areas within the Strait (Tay et al. 2010). At the time, levels of PAHs in sediment samples in central Canso Strait in 2004 occasionally exceeded the ocean disposal guideline of 2.5 µg/g (Tay et al. 2010) (Table A1). Consistent with the elevated cadmium levels, both cadmium and mercury concentrations in sediments in Canso Strait do not correlate well with lithium concentration, suggesting that the concentrations of these elements are mainly controlled by factors other than grain size (Parrott et al. 2005), reflecting an unnatural (i.e., human) origin. At the time, levels observed were an improvement over those observed in the 1980s (Tay et al. 2010).

3.1.4. Saint John Harbour

Like other harbours in Atlantic Canada, the harbour in Saint John—the largest city in New Brunswick and one of Canada's major ports—experienced pollution and environmental degradation through its long history of development as one of the region's oldest cities. Contamination has arisen from major uses of the harbour,

[8] Environment Canada, Ocean Disposal Section, investigates and designates ocean sites which are suitable for disposal of sediments and other material from harbour dredging and coastal construction projects, fish wastes, etc.

including its role in servicing a major population centre and port, serving for a time as a repository for untreated sewage, and supporting industrial activities including oil refining, brewing, and pulp and paper production as well as the cumulative effects of those activities (Environment Canada 2003, Kidd et al. 2014, Van Geest et al. 2015). Problems with environmental conditions in the harbour, including contamination of harbour sediments and waters with hydrocarbons and metals as well as sewage and associated contaminants, were present long before awareness and concern over the need for environmental controls and management emerged (Washburn and Gillis Associates 1993, Land and Sea 2001, Environment Canada 2003, Kidd et al. 2014). Some of the current industries include, in addition to the Saint John waterfront and wharf facilities, the Irving pulp mill and Moosehead Brewery at Reversing Falls, the Irving oil refinery and associated Canaport Monobuoy tanker offloading facility and LNG terminal at Mispec Point, and municipal sewage outfalls (Environment Canada 2003, Hung and Chmura 2006, Van Geest et al. 2015).

3.1.5. The Quoddy Region

The Quoddy Region, which encompasses the St. Croix River estuary, Passamaquoddy Bay, L'Etang Inlet and the various islands and inlets of southwestern New Brunswick, has been a focus of human activity and settlement for hundreds of years (Lotze and Milewski 2002, Milewski and Lotze 2004). The pulp and paper industry and several pulp mills on the shores and in the watershed had an important impact in terms of wastes and mercury releases throughout the years. The presence of the Coleson Cove thermal generating station and the Point Lepreau nuclear generating station in the vicinity, the important fishing industry, the rapid development of salmonid aquaculture, as well as growing coastal towns and tourist centres have all focused attention on environmental quality—and particularly concern over contaminants—in the region.

4.0 CONTAMINANTS IN SEDIMENTS

4.1. SCOTIAN SHELF AND ADJACENT OFFSHORE WATERS

4.1.1. Metals in Sediments – Coastal and Nearshore

The Scotian Shelf and adjacent waters makes up the largest part of the bioregion, extending from the western extent of Nova Scotia and the Northeast Channel to northern Cape Breton. Contaminants in coastal areas are strongly influenced by the adjacent land-based sources of sediments through upland and coastal erosion and by contaminants derived from human activities, particularly those associated with the coast, including wharves and marinas, ship repair facilities, and sewage releases from coastal communities. Atmospheric transport is a comparatively minor contributor to contaminant levels in sediments in coastal areas. Once in the ocean, metals and other surface-active contaminants such as persistent organic compounds are associated with fine particles and aggregations of fine organic and inorganic particles known as flocs, which become the main transfer mechanism to the food chain and sediments (Milligan and Loring 1997, Milligan and Law 2013, Law et al. 2014). Elevated levels of metals can often be found in sediments in the bioregion in depositional areas such as harbours where flocculated mud accumulates (Bundy et al. 2014).

Trace metal levels in a representative sample of coastal inlets and smaller coastal harbours in Nova Scotia (including Annapolis Basin and Pubnico Harbours from the Bay of Fundy-Gulf of Maine) are often low—many are at levels considered to represent natural background (i.e., measurements in areas without human influences determined from the literature) (Loring et al. 1996, Tables 3-5).[9] Most (9 of 10) of the inlets surveyed, however, showed at least some likely contamination, based on average concentrations of one or more metals which exceeded a guideline[10] for arsenic, cadmium, copper, lead, mercury, tin and zinc (Loring et al. 1996). Forty percent (4 of 10) of inlets failed for arsenic; 90 percent failed for cadmium; 30 percent for copper; 60 percent for mercury; 40 percent for lead; 30 percent for tin; and 10 percent for zinc (Loring et al. 1996).

Nearshore coastal sediments often have low levels of contaminants. Uncontaminated well-sorted fine to medium sand at the mouth of Lunenburg Harbour had low levels of heavy metals and petroleum hydrocarbons (Envirosphere Consultants 1996) (Table A1). Samples were taken around a naval frigate sunk as an artificial reef in 1995. Levels of arsenic and mercury in New Harbour, Nova Scotia, intertidal sediments (an uncontaminated reference site) were below detection at <2 and <0.02 mg/kg dry weight respectively (Doe et al. 2017).

[9] Studies reviewed are often not consistent in noting or reporting the extraction method used for metals in sediments. Geochemical studies (e.g., Loring et al. 1996) typically use the most aggressive sediment digestion using hydrofluoric acid (Loring and Rantalla 1977, 1992) to provide estimates of total metals. Early measurements prior to about 1990 produced by commercial labs (e.g., for offshore measurements and coastal monitoring) would have used either hydrofluoric acid digestion or *aqua regia* (a nitric/hydrochloric acid combination). After 2000 most commercial labs would have used the latter analysis (S. MacKnight, OCL, Dartmouth, N.S. pers comm., C. MacGregor, MacGregor and Associates, Halifax), unless specifically requested. The less aggressive digestion results in slightly lower measurements of metals, which are adequate for most purposes. Baseline levels measured for Sable Island Bank, Nova Scotia coastal inlets and the Bay of Fundy (Loring 1979, Carter et al. 1985, Loring et al. 1996) used the more aggressive digestion and provide a truer estimate of total metals.

[10] Guideline levels to indicate possible contamination of sediments are: arsenic, 20 mg/kg; cadmium, 0.3 mg/kg; copper, 40 mg/kg; mercury, 0.1 mg/kg; lead, 40 mg/kg; tin, 5 mg/kg; and zinc, 150 mg/kg (Loring et al. 1996).

Table 3. Baseline and background guideline metal and organic contaminant levels in sediments from the Bay of Fundy and coastal areas of Nova Scotia (Loring 1979; Loring et al. 1996, 1998; Bugden et al. 2000).

	Bay of Fundy					***Nova Scotia***	
	Offshore[d] (Loring 1979) n=83 (mg/kg)	**Passamaquoddy Bay** (Loring et al. 1998)[b] (mg/kg)	**Passamaquoddy Bay** (Bugden et al. 2000) (mg/kg)[e]	**St. Croix Estuary**[c] (Loring et al. 1998) (mg/kg)	**L'Etang Inlet** (Bugden et al. 2000) (mg/kg)[e]	**Coastal Areas** (Loring et al. 1996) (mg/kg)	**Background Guideline Level**[a] (Loring et al. 1996) (mg/kg)
Metals							
As	8 (4-15)	11.67 (11-13)	8-16	9-27	<1-19	2-42	20
Cd	0.22 (0.03-	0.06 (0.05-0.07)	0.04-0.12	0.03-0.18	0.02-0.54	0.02-2.16	0.3
Cr	57 (15-352)	71.33 (71-72)	63-83	44-72	36-83	3-226	
Cu	15 (5-32)	18	13-18	8-22	7-41	2-44	40
Zn	51 (18-104)	98.33 (98-99)	76-106	55-99	52-130	8-304	150
Pb	20 (8-42)	32.33 (31-33)	21.5-28		17-31.5	6-80	40
Co	12 (4-27)	14	13.4-18.2		8.2-17		
Ni	15 (3-46)	35	32.6-47	22-41	19.4-45	5-73	
V	70 (27-136)	110	91-119	73-110	63-113	8-115	
Ba	310 (150-540)	406.67 (400-410)	340-420	290-420	320-420		
Hg	30 (20-90)		<10-40		10-520	10-390	100
Se	0.17 (0.11-						
Be	1.6 (0.8-2.9)		2-2.55		1.95-2.75		
Al		20-35	6.59-7.87	5.1-6.6	6.04-7.62	2.88-6.99	
Fe		9-15	3.26-4.03	2.7-4.0	2.37-3.87	0.56-4.84	
Li		54 (53-55)	48.6-67.4	36-52	31.2-67.8	13-75	
Mn		500 (480-540)	455-505	450-860	375-565	0.024-0.236	
Sn						1-13	5
Sr		98 (97-100)	116.5-156	91-120	111.5-237		
Ti		0.63 (0.6-0.7)	0.54-0.66	0.6-0.7	0.52-0.7		
U		2.3 (2.2-2.4)	2-2.6	1.4-2.2	1.4-3.6		
Organic Contaminants							
PAH		1429.67 (961-		61-3144			

a. Background Guideline Level is the level above which it can be reasonably assumed that a site is contaminated (i.e., having levels exceeding what would be expected when compared to natural levels and known measurement variability for the same type of sediment based on previous studies) (Loring et al 1996). For most metals, the factor used in estimating the guideline is 1.5-2. A higher factor (5) was used in estimating the guideline for tin because of measurement variability and a factor of 2 was used for arsenic (Loring et al. 1996).

b. Sites in central Passamaquoddy Bay

c. Sites in St. Croix Estuary upstream of St. Andrews.

d. Outer Bay of Fundy roughly from Cape Chignecto to Brier Island-Grand Manan.

e. Includes: Back Bay, Bliss Harbour, Lime Kiln Bay, L'Etang Harbour, Upper L'Etang, Black's Harbour, Deadman's Harbour.

Table 4. Contaminant metals in several inlets on the Nova Scotian Eastern Shore (from Loring et al. 1996).				
Location	**Country Harbour**	**St. Mary's River Estuary**	**Ship Harbour**	**Petpeswick**
Potential Contamination	Gold mining wastes and tailings circa 1900; aquaculture	Agriculture, Town of Sherbrooke, leaching of mine wastes and tailings from circa 1900	Residences and aquaculture activities	Cottages and permanent residences
Metal	**Concentration (ug/g)**			
Aluminium	5.52	4.34	4.49	4.29
Arsenic	14.7	9.1	10.8	8.4
Cadmium	0.41	0.20	0.81	0.41
Chromium	58.9	31.6	64.3	52.5
Copper	18.1	9.6	23.3	15.7
Mercury	0.05	0.04	0.06	0.03
Manganese (%)	0.049	0.043	0.044	0.050
Iron	2.55	1.74	2.68	2.25
Lithium	49.0	30.5	39.1	33.1
Nickel	21.3	12.7	26.9	19.7
Lead	25.4	14.9	31.6	18.9
Vanadium	67.3	38.4	60.9	58.6
Zinc	70.2	48.6	71.0	57.4
Tin	2.4	1.9	2.3	2.7

Major Harbours: Both Halifax Inlet and Sydney Harbour have shown elevated levels of contaminant metals in sediments in the past, often above CCME Sediment Quality Guidelines (SQGs) for the protection of marine aquatic life (Stewart and White 2001); however with improved management of sources and natural capping in recent years, surface sediments are expected to be approaching more moderate levels. Halifax Harbour sediments at one time were exceedingly high in contaminant metals, typical of harbours around the world, and often above CCME SQGs—resulting from the long period of industrialization (Buckley and Winters 1992, Stewart and White 2001). Recent sampling studies have demonstrated that many parts of the harbour continue to have elevated—although lower than in past—levels of metals (Hellou et al. 2003). The lack of more recent studies of distribution of metals in surface sediments of Halifax Harbours is an important data gap.

Table 5. Contaminant metals in several inlets on the Nova Scotian South and Southwest shores and the Bay of Fundy (from Loring et al. 1996).						
Location	**Annapolis Basin**	**Pubnico Harbour**	**Shelburne Harbour**	**Liverpool Harbour**	**LaHave Estuary**	**Lunenburg Harbour**
Potential Contamination	Municipal and residential sewage, agriculture, wharves and coastal marine transport-ation	Fish wastes, fishing vessel activity, coastal residences	Shipbuilding and repair, fish processing, coastal infra-structure, municipal and residential sewage	Shipbuild-ing, pulp and paper, fishing and fish pro-cessing, municipal and residential sewage	Agricultural, urban and industrial discharges; municipal and residential sewage; fishing and fish processing	Agricultural, urban and industrial discharges; municipal and residential sewage; fishing and fish processing
Metal	**Concentration (ug/g)**					
Aluminium	4.26	5.04	4.66	4.35	6.25	6.24
Arsenic	5.4	5.7	13.7	3.7	21.0	14.1
Cadmium	0.04	0.19	0.48	0.30	0.27	1.31
Chromium	76.4	43.0	28.4	30.2	74.9	NR
Copper	11.8	8.9	15.8	6.7	NR	NR
Mercury	0.02	0.02	0.06	0.05	0.12	0.22
Manganese (%)	0.054	0.060	0.062	0.073	0.066	0.061
Iron	2.10	2.14	1.80	1.22	3.46	3.45
Lithium	23.5	28.9	32.5	22.2	56.0	55.1
Nickel	17.1	17.7	16.4	12.3	21.7	26.7
Lead	16.3	19.8	29.3	14.8	45.3	NR
Vanadium	55.3	46.6	43.1	26.7	85.5	80.5
Zinc	39.3	42.3	44.5	32.3	96.0	158.6
Tin	1.7	2.0	3.9	1.6	NR	NR

NR= Not Reported

Among metals and compounds found in sediments in Halifax Harbour, tributyltin is a metallic compound having a wide range of applications, in particular as an ingredient in anti-fouling coatings for ships and other vessels. Levels in sediments in Halifax Inlet are elevated, particularly in the vicinity of ship repair facilities (Carter et al. 2004) and elevated levels are likely to occur in harbours and marinas throughout the bioregion. Levels of tributyltin in Halifax Harbour sediments, sampled in central Bedford Basin and in the vicinity of ship-repair yards and large-vessel docks in 2002 (Carter et al. 2004), had a wide range (42-46,267 ng/g tin dry weight)[11] but reached highest concentrations near vessel maintenance facilities; compared with samples collected at the same locations in 1988 and 1994, concentrations in about half the samples were higher in 2002 (Carter et al. 2004). The highest level observed was near a major shipbuilding facility. Concentrations in sediments in Halifax Harbour were lowest (56.9 and 42.1 ng/g tin dry weight) in Bedford Basin and at a berthing site near the military base at

[11] The results were highly skewed with highest TBT level of 46,267 ng/g Sn dry weight more than 200 times the next highest concentration. A mean (SD) and range for the remaining five sites sampled in 2002 was 886 (989) (42.1-1985 ng/g tin dry weight), and for the high site in 2003, 5638 (5427) (1440 to 13,400 ng/g tin dry weight).

Shearwater respectively compared to a reference site (Chezzetcook Inlet) which had levels of 1-3 ng/g tin. Levels in sediments in two small craft marinas in Mahone Bay, southwest of Halifax (Oak Island Marina and South Shore Marina in Chester, 43.3 and 212 ng/g tin respectively) were comparable to some of the lowest levels observed in Halifax Harbour though higher than the Chezzetcook reference site (Carter et al. 2004). Levels in Halifax Harbour in 2002 (Carter et al. 2004) are comparable to levels found in the harbour in 1993-94 (range of 40-1909 ng/g tin dry weight) (Chau et al. 1997), and to measurements from Saint John Harbour at the time (21-3212 ng/g tin dry weight) (Chau et al. 1997), but are higher than those in St. John's Harbour in Newfoundland (Carter et al. 2004). Extremes reported in Halifax Harbour sediments also appear to be high compared to levels observed in other parts of the world (Carter et al. 2004).

Most sediments near recreational and industrial shipyards (Dartmouth Marine Slips, Halifax Synchro Lift, and Halifax Shipyard) exceeded SQGs for all of the principal heavy metals (arsenic, cadmium, chromium, copper, lead and zinc) (Carter et al. 2004). Many exceeded the PELs and some extreme values were observed (Carter et al. 2004) (Table A1). Levels were comparable to or above mean values reported by Buckley and Winters 10 years earlier (1992).

Levels of various metals in recently deposited sediments in Sydney Harbour, at least in the early 2000s, continue to demonstrate contamination, some due to current contaminant sources such as sewage and industrial activity, and some derived from earlier contamination (Loring et al. 2008). Various metals including silver, arsenic, bismuth, cadmium, copper, mercury, molybdenum, phosphorus, lead, antimony, and zinc are at levels which are above natural background, and are presumably influenced by anthropogenic inputs.

Concentrations of heavy metals such as cadmium, copper, lead and zinc in Sydney Harbour sediments were similar to those found in other developed harbours in Nova Scotia such as Halifax and Lunenburg when sampled in 2001 (Loring et al. 2008). Metals measured in surface sediments (0-1 cm) in the 2009-2012 period in shallow nearshore waters around the margin of Sydney Harbour show a similar distribution pattern to earlier studies—with highest levels in the vicinity of Muggah Creek and the Sydney waterfront, and lowest in Northwest Arm—but the maxima are lower (Walker et al. 2013a). Levels of various contaminants including heavy metals in sediments sampled by Environment Canada in 1997 to develop toxicity test protocols (Zajdlik et al. 2001) and by Tay et al. (2003), to be used in histopathology studies of effects of contaminated sediments, were similar to those found in other studies in the 1999-2001 period (Table A1). Different studies of sediments in Sydney Harbour have sampled different time frames of deposition because of different sampling depths they used. In the TSRI project (Lee 2002; Stewart et al. 2002a, 2002b; Tay et al. 2003), samples included deeper and older sediments (up to 10-15 cm) while surface samples taken by King and Lee (2004) and A.R. Stewart et al. (2001) summarized in Loring et al. (2008) and Walker et al. (2013b) are recently-deposited (i.e., <1 cm) sediments. Sediment cores in the TSRI project (Lee 2002), in addition, show the transition from older to recent sediments and demonstrate capping of the most contaminated sediments by newly deposited, less contaminated sediments (Smith et al. 2009). Nonetheless surface sediments in Sydney Harbour in some cases show potentially harmful concentrations, particularly in areas such as the central harbour, which were most contaminated initially. Sediments around the margins are at less harmful levels (Walker et al. 2013b). Recent sediments at most of the sites were above CCME SQGs for many metals (CCME 1999, Loring et al. 2008) (Table 2). More recently, Walker et al. (2013a) found that most metals were above CCME SQGs in South Arm, but only copper, lead and zinc occasionally exceeded the CCME PEL levels. Levels of metals overall are lower than other industrial harbours in North America (Walker et al. 2013a).

Sydney Harbour also likely has high concentrations of tributyltin in sediments in industrialized parts of the harbour, particularly in shipyards, marinas and maintenance facilities, as shown by an indicator of contamination by this compound—the occurrence of a biological condition known as imposex in intertidal whelks, *Nucella lapillus.* All female whelks sampled from Sydney Harbour in 1995 showed the condition in a survey of Atlantic region harbours (Prouse and Ellis 1997). Updates to measurements of tributyltin in sediments in Halifax Harbour and nearby coastal areas showed that levels there—and by inference in other harbours such as Sydney which have similar marine activities—had not decreased appreciably by the early 2000s (Carter et al. 2004).

<u>Legacy of Gold Mining:</u> Processing and waste disposal activities (e.g., tailings) used in gold mining have caused elevated levels of mercury, which was used in gold extraction, along parts of the Nova Scotia Atlantic Coast, and as well have led to release of arsenic, which occurs in associated rock formations in terrestrial, freshwater, and nearshore coastal marine environments. Several studies in response to a Natural Resources Canada initiative to examine the dispersion, speciation and fate of mercury and arsenic in gold mining areas have shown arsenic and mercury contamination of terrestrial and shallow marine environments in the vicinity of abandoned gold mines and associated processing facilities on Nova Scotia's Eastern Shore (Wong et al. 1999, Parsons et al. 2012, Little et al. 2015, Walker and Grant 2015, Doe et al. 2017). The Environment Canada study (Doe et al. 2017) in particular showed that locations in three harbours on the Nova Scotian Eastern Shore (Seal Harbour, Wine Harbour, and Harrigan Cove) are highly contaminated by arsenic—in the case of Seal Harbour the levels of arsenic in softshell clams has led to the closure of the flats at the mouth of West Brook to shellfish harvesting (Doe et al. 2017). Doe et al. (2017) looked at nine sites on the Atlantic coast of Nova Scotia from Gold River to Seal Harbour and a reference site (New Harbour) in sampling conducted in 2004-2005.[12] The intertidal sites in Seal Harbour sampled in 2004 had sediment levels of arsenic ranging from 457 to 688 mg/kg dry weight at the mouth of West Brook, a stream whose watershed was previously contaminated by gold extraction activities. Arsenic levels exceeded CCME PELs by 11.0 to 18.4 times (Doe et al. 2017), and were considered to be at hazardous levels. Later sampling in Seal

[12] From west to east, Gold River, Cow Bay, Lawrencetown, Pope’s Harbour, Harrigan Cove, Gegogan, Wine Harbour, Seal Harbour, and New Harbour (reference site). Seal Harbour was selected for sampling in 2004 because of previously identified contamination issues; the remaining sites were selected based on criteria which included relatively high annual ore throughput when in operation (>10,000 t), location within 5 km of a marine receiving environment, exposure to tailings and where shellfish might be harvested, accessibility, potential for species at risk, and suitable sediments (Doe et al. 2017).

Harbour (2005) confirmed high levels of arsenic at the West Brook source (i.e., ~680 mg/kg dry weight) and concentrations declined with increased distance away (Doe et al. 2017). Mercury levels were elevated in the same sediments, ranging from 0.21 to 0.49 mg/kg dry weight in 2004 (Table A1), exceeding the CCME ISQG but below the PEL, and in 2005 showed similar mercury levels and a pattern of decreasing concentrations with increased distance from the source (Doe et al. 2017). Mercury levels in sediments in Seal Harbour had previously been shown to be elevated (Parsons et al. 2004).

A wide range of concentrations of both arsenic (4-568 mg/kg) and mercury (444-320,000 mg/kg) also occurs in sediments in Wine Harbour, on the Eastern Shore of Nova Scotia (Little et al. 2015). The area is in one of Nova Scotia's historical gold mining districts and experienced coastal disposal of tailings as well as freshwater input exposed to gold mining processing operations, which for a time used mercury as a primary means of gold extraction. Levels of arsenic and mercury are above Canadian Interim Marine Sediment Quality guidelines (CCME 1999) while pre-mining background levels estimated from sediment cores (arsenic = 4-6 mg/kg and mercury = 5-17 μg/kg) are below the guidelines (Little et al. 2015, Table A1). Levels of other heavy metals measured in sediments (cadmium, copper, lead, chromium and zinc) were all below applicable sediment quality guidelines (Table A1).

Within Isaacs Harbour, one of the inlets west of Seal Cove, and in the same gold mining area, arsenic and mercury levels in sediment cores continue to be elevated over background levels although not above SQGs, long after mining ceased (Parsons 2005 MS). Surface sediment concentrations of both metals are reduced by an order of magnitude at the mouth of Isaacs Harbour, although even the highest levels are lower than maximal levels achieved during the peak period of gold mining in the area. Surface concentrations of arsenic ranged from about 30 mg/kg in central inner Isaacs Harbour to about 15 at the mouth; mercury ranged from about 100 μg/kg to 40 μg/kg. Surface levels in the vicinity of Red Head (the proposed site of an LNG terminal) were < 15 mg/kg for arsenic and about 15 μg/kg mercury (Parsons 2005 MS) (Figure 5). Recent measurements (2008) of levels of arsenic and mercury in surface sediments (i.e., the top 1 cm) in Isaacs Harbour and outer Country Harbour as well as in the vicinity of the proposed LNG berthing facility (Table A1) show similar levels to those obtained in the other studies (Walker and Grant 2015) (Table A1) and exceed CCME SQGs not only for arsenic and mercury, but also for cadmium, copper and lead, but were below CCME PELs (Walker and Grant 2015).

Arsenic and mercury levels in sediments are also occasionally elevated in former gold mining areas along the coast between Seal Harbour and Gold River on the Nova Scotia South Shore (Doe et al. 2017). Many of the sites[13] exceed SQGs for arsenic and mercury, including having levels of arsenic above PELs in Wine Harbour, Harrigan Cove and Gegogan, and exceedances of CCME sediment quality guidelines (SQGs) in Popes Harbour and Port Dufferin, with unexpectedly elevated levels of arsenic in Gold River (22 mg/kg) and mercury levels above PELs in Wine Harbour and Harrigan Cove (Doe et

[13] See previous footnote for list of areas.

al. 2017). Acceptable levels of both metals in sediments occur in both Lawrencetown and Cow Bay (levels of arsenic <2.2-3 mg/kg dry weight and mercury <0.02 mg/kg) (Doe et al. 2017).

Levels of metals in sediments in outer parts of the combined Isaacs Harbour/Country Harbour inlet, including arsenic and mercury, are lower than inside Isaacs Harbour. Levels of major metals in surface sediments measured during surveys for the second pipeline to the Encana Deep Panuke development near Sable Island, were comparable to baseline levels for similar types of coastal sediments found in Loring et al. (1996) (see also JWEL 2006, 2008) (Tables 6 and 7).

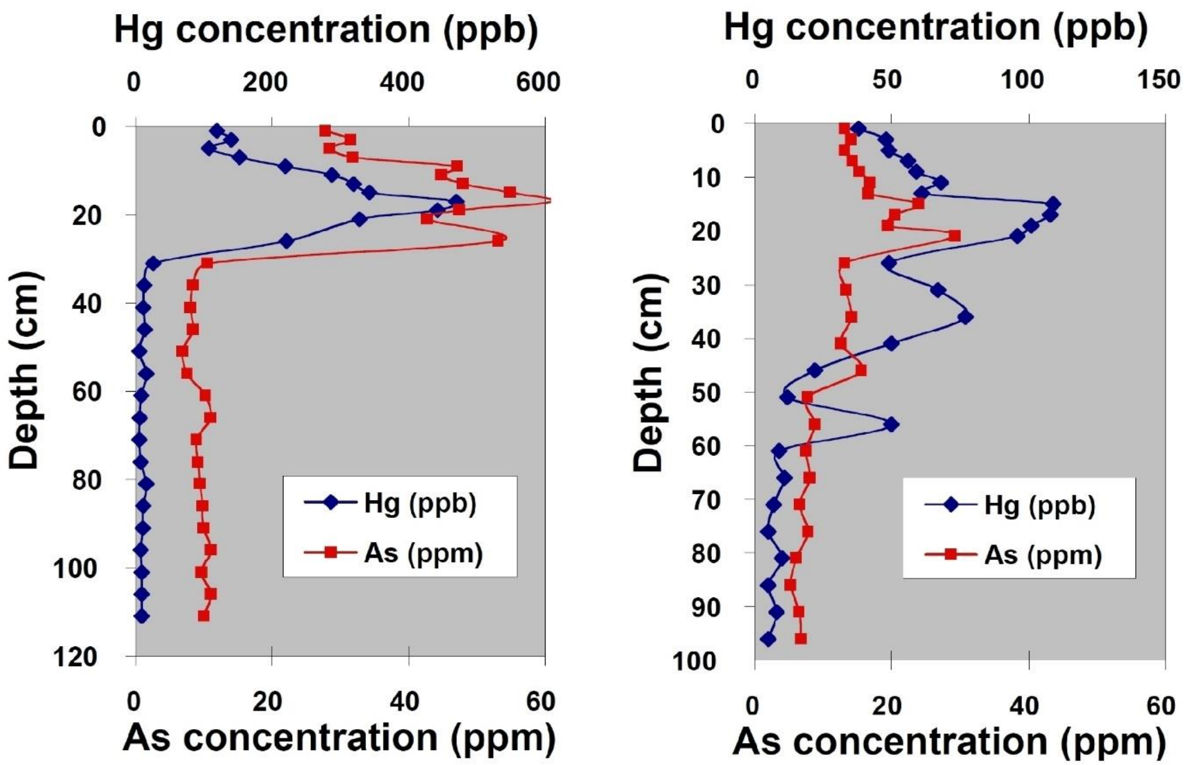

Figure 5. Profiles of arsenic and mercury in sediments in Isaacs Harbour (left) and at the mouth (unpublished data, Dr. M. Parsons, NRCAN, 2005).

Aquaculture: Fish farms are a source of metals and other contaminants such as pesticides to the marine environment, and concentrations of some metals have been found to be elevated in sediments in the vicinity of aquaculture sites (Hargrave et al. 2005, Smith et al. 2005, Loucks et al. 2012, Law et al. 2014). Copper and zinc as well as other metals can be found in feed and antifouling treatments for nets, and are dispersed through uneaten feed and fine particles and flocs. On the Nova Scotia South Shore (Port Mouton Bay), Loucks et al. (2012) found copper was also transported from a salmon cage site after being concentrated in the sea surface microlayer through an association with gas bubbles generated by the organic waste. Monitoring of sediments around the same sea farm over 3 years showed copper levels in sediments ranging from 32-42 mg/kg at the cage site to 6-7 mg/kg up to 400-2000 m away and concentrations persisted for 27 months after the farm was fallowed (Loucks et al. 2012). Copper concentrations on the farm site usually exceeded the 18.7 mg/kg CCME sediment quality guideline for the protection of marine life, although they were all below the CCME PEL (108 mg/kg). Monitoring of metals in sediments at fish farms is likely to be included in a proposed DFO monitoring program to assist in aquaculture management.[14]

Table 6. Metal Concentrations (mg/kg) in sediments between Sable Island and Nova Scotia Eastern Shore, 2001 (Jacques Whitford Environment Limited, 2001).[a] Number of samples shown in brackets.

Metal	Sand		Sand with Clay		Silty Sand		Gravel with Silt	
	Range	Mean (14)	Range	Mean (8)	Range	Mean (7)	Range	Mean (2)
Aluminum	8800-17000	12307	10000-35000	17750	9800-38000	23971	36000-38000	37000
Antimony	<2	<2	<2	<2	<2	<2	<2	<2
Arsenic	2-19	5.3	2-8	4.9	2-7	3.9	3-6	4.5
Barium	140-270	194	140-310	224	180-340	260	270-310	290
Beryllium	<5	<5	<5	<5	<5	<5	<5	<5
Cadmium	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Chromium	3-12	6.1	6-28	13.5	6-31	17.7	28-34	31.0
Cobalt	1-2	1.1	2-6	2.8	1-5	3.0	4-6	5.0
Copper	3-4	3.5	2-11	4.9	2-14	6.6	6-12	9.0
Iron	2600-10000	5443	5300-15000	9675	4000-15000	9957	13000-17000	15000
Lead	3.8-11	5.6	6.2-17	9.2	6.5-15	10.3	9.30-18	13.7
Manganese	29-320	88.6	77-400	164.3	59-650	314.1	460-530	495.0
Molybdenum	<2	<2	<2	<2	<2	<2	<2	<2
Nickel	2-3	2.2	3-15	6.00	3-16	8.0	10-17	13.5
Selenium	<2	<2	<2	<2	<2	<2	<2	<2
Strontium	40-67	52.8	37-86	56.3	33-140	80.3	92-170	131.0
Thallium	0.1-0.2	0.13	0.1-0.4	0.21	0.1-0.4	0.27	0.3-0.4	0.35
Tin	<2	<2	<2-2	<2	<2	<2	<2-2	<2
Uranium	0.2-0.4	0.26	0.3-1.3	0.60	0.4-1.6	0.9	1.2-1.6	1.40
Vanadium	6-40	14.3	10-44	23.0	13-44	26.9	38-53	45.5
Zinc	7-22	10.7	11-44	19.9	14-48	26.6	34-49	41.5

a. Sediments from route of Encana Deep Panuke natural gas pipeline from Sable Island to Country Harbour.

[14] DFO is initiating a national monitoring program and framework for aquaculture (Aquaculture Monitoring Program, AMP) which will potentially include trace metals, organic content, sulfides, and other contaminants including drugs, pesticides, and antibiotics in the vicinity of aquaculture sites. The program will be aimed at detecting aquaculture impacts and provide information to support aquaculture policy and regulatory decision-making (A. Lacoursiére, Research Scientist, DFO, St. Andrews, N.B., Personal Communication, 2018).

Table 7. Metal Concentrations (mg/kg) in sediments, outer Country Harbour, Nova Scotia Eastern Shore, 2001[a] and background levels from inner Country Harbour (Jacques Whitford Environment Ltd 2008).				
Parameter	**2001**		**Background [b]**	
	Range	**Mean**	**Mean**	**Background**
Aluminum	37000-38000	37500	55200	
Antimony	<2	<2		
Arsenic	5	5	15	20
Barium	230-240	235		
Beryllium	<5	<5		
Cadmium	<0.3	<0.3	0.41	0.3
Chromium	22-23	22.5	59	
Cobalt	3	3		
Copper	8	8	18	40
Iron	12000	12000	25500	
Lead	9.9-10	9.95	25	40
Manganese	570-610	590	486	
Molybdenum	<2	<2		
Nickel	9	9	21	
Selenium	<2	<2		
Strontium	110	110		
Thallium	0.3	0.3		
Tin	2	2	2.4	5
Uranium	1.3-1.4	1.35		
Vanadium	32-33	32.5	67	
Zinc	34	34	70	150

a. Samples from along natural gas pipeline route to Encana gas plant at Goldboro. b. Background levels are from Loring et al. (1996).

DFO Small Craft Harbours: Coastal fishing and recreational harbours are significant though localized sources of contamination of various kinds to the marine environment. Wastes are discharged from vessels and associated maintenance activities, as well as from weathering of infrastructure (e.g., treated wharf pilings), litter, releases from support facilities, fish plants, and sewage. Conditions have been improving over the past decades through improved environmental management (PWGSC 2010) although unmanaged releases of contaminants such as untreated sewage discharged directly into harbours continue to occur.

Recent contaminant information on sediments in harbours in the Scotian Shelf Bioregion is available from reports of routine sediment sampling (Marine Sediment Sampling Programs (MSSPs)) coordinated by the federal government Public Services and Procurement Canada (PSPC, the replacement for PWGSC) in ongoing management and maintenance of harbour facilities. Fisheries and Oceans Canada, Small Craft Harbours Branch (DFO-SCH) is responsible for the operation, maintenance and development of many recreational and fishing harbours in Atlantic Canada. Harbour facilities such as wharves, breakwaters and vessel launching ramps, and activities such as dredging harbour channels and basins to ensure safe navigation are included in DFO-SCH responsibilities (PWGSC 2010). Sediments dredged from harbours in the Scotian Shelf Bioregion are mostly disposed using various forms of land-based disposal (PWGSC 2010). Of 54 SCH harbours in the region which had been dredged in the

2000-2010 period, 49 (91 percent) used land-based disposal, and only 5 (9 percent) used disposal at sea (PWGSC 2010).

PSPC and DFO SCH maintain a database containing reports of sediment sampling and contaminant measurements conducted for harbour maintenance, which was accessed for this project. Reports of surveys carried out since approximately 2000—and in some cases as early as 1990—were selected for review from this database, providing information on 121 Nova Scotia harbours/facilities and 19 in New Brunswick. Some harbours had been sampled several times in the study period, and some harbours which are not currently active but for which sediment information was available in the survey period were also included. These represent a subset of the 187 Small Craft Harbours in Nova Scotia and 87 in New Brunswick (PWGSC 2010), of which 146 in Nova Scotia and 33 in New Brunswick are in DFO Maritimes Region (M. Cormier, DFO SCH, Moncton, N.B., Personal Communication, 2018) (Figure 6). A consistent standard protocol for sediment sampling has been carried out over the period, usually including random selection of sample locations within the harbours involved. It should be noted that many harbours likely retain a legacy of contaminants from earlier times, and so results of recent sampling may not necessarily reflect improvements in environmental management over the years. Changes such as better control of releases of engine oil and use of non-creosoted timbers in wharves to remove a source of PAH contamination, have likely led to improvements (i.e., reduced contaminant levels), although the effects of such improvements have not been monitored, which forms a data gap.

Most harbours sampled in the period reviewed did not meet sediment quality guidelines for some metal or PAH;[15] however none failed in terms of levels of DDT or PCBs, which were never detected (Table 8). We did not assess, however, the degree to which guidelines were exceeded for metals or PAHs, although for most cases the contamination is not expected to be especially severe.[16] The harbours are also localized, and probably do not form a significant source of contamination to coastal environmnents as a whole. Overall the proportion of harbours not meeting the guidelines was similar in both provinces, with a total of 79.3 percent of harbours having failures of the CEPA or CCME sediment quality guidelines for one or more contaminants (Table 8). However, New Brunswick harbours had a lower rate than Nova Scotia in terms of exceedances of PAHs or metals.

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[15] Individual PAHs and total PAH analyzed in sediments from DFO Small Craft Harbours were for the 16 U.S. Environmental Protection Agency (EPA) priority PAHs which are routinely analyzed by commercial analytical laboratories.

[16] A recent survey of PAH levels and composition in sediments, based on MSSP reports for 31 of the Small Craft Harbours in Nova Scotia from 2001 to 2017, showed few sediments with concentrations likely to impair biota based on sediment quality guidelines although occasionally potentially harmful levels were encountered (Davis et al. 2018). High molecular weight PAHs dominated samples following global trends (Davis et al. 2018).

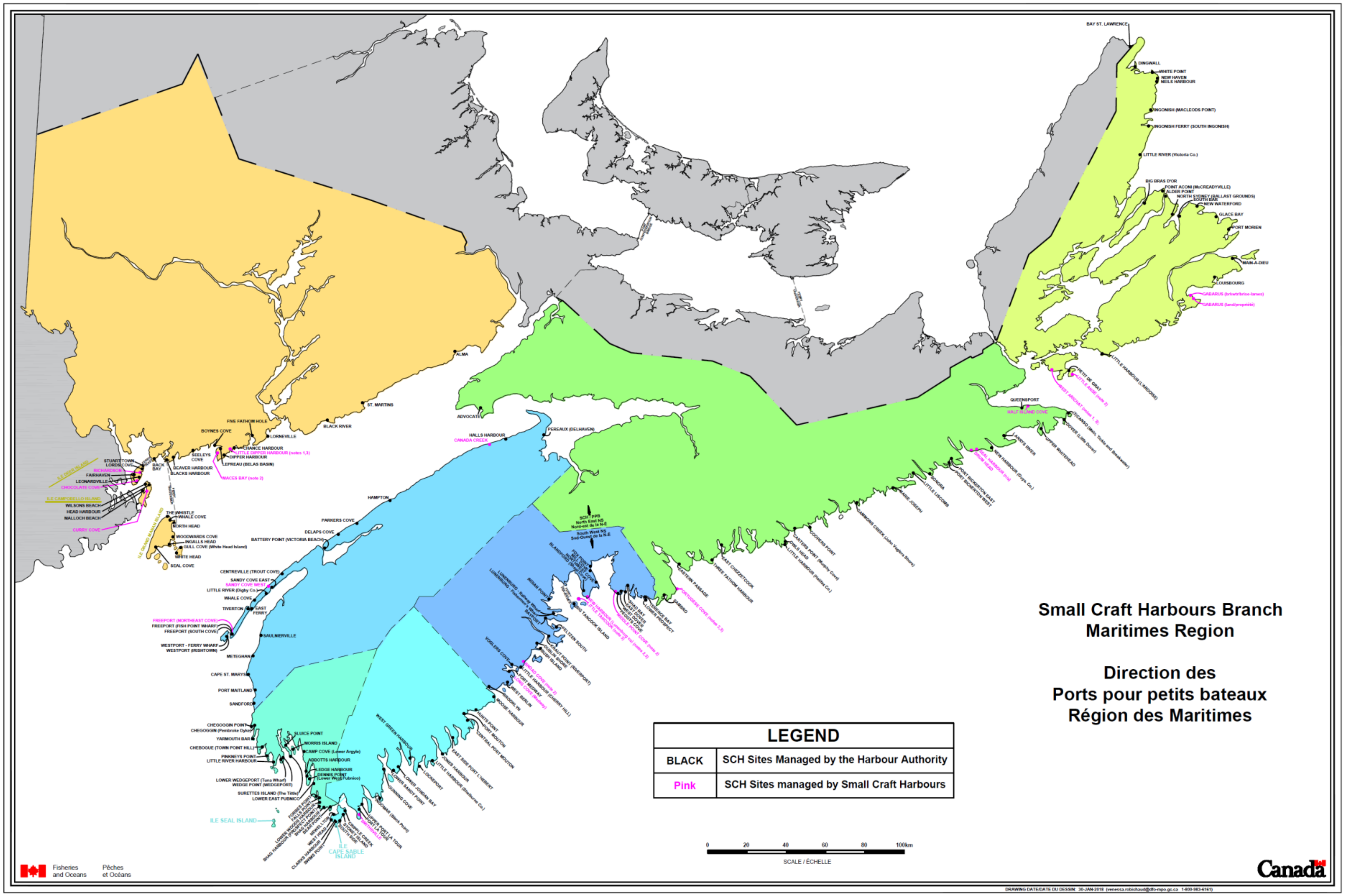

Figure 6. Locations of active Small Craft Harbours in the Scotian Shelf Bioregion. Includes harbours managed by DFO (pink) and by local Harbour Authorities (Source: DFO Small Craft Harbours Branch, Moncton, February 2018).

About as many harbours did not meet the guideline overall for metals as for PAHs (Table 9). Metals having one or more exceedances for any of the criteria used were aluminium, arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, tin, vanadium, and zinc, summarized in Table 9.[20] Cadmium had the highest number of exceedances in Nova Scotia, followed by arsenic, selenium and copper. Arsenic followed by copper and zinc exceeded the guidelines most often in the New Brunswick harbours (Table 9). In all cases, the sources of exceedences, and whether they are local or regional, artificial or natural, are not known.

Table 8. Sediment quality guideline exceedences for recent[a] contaminant levels in sediments in Nova Scotia and New Brunswick Small Craft Harbours in the Scotian Shelf Bioregion, for which recent sediment quality information is available. SQGs (Sediment Quality Guidelines) used are CEPA Ocean Disposal criteria and CCME SQGs.

Province	Number of Harbours	Number of Harbours Exceeding Guideline						Reports examined per Harbour ± (S.D.)
		Exceeds Any SQG	CEPA Ocean Disposal	CCME PAH	CCME Metal	CCME DDT	CCME PCB	
New Brunswick	19	16 (84.2%)	15 (79.0%)	9 (47.4%)	7 (36.8%)	0	0	1.95 (1.2)
Nova Scotia	121	95 (78.5%)	71 (58.7%)	74 (61.2%)	84 (69.4%)	0	0	1.98 (0.8)
Total	140	111 (79.3%)	86 (61.4%)	83 (59.3%)	91 (65.0%)	0	0	1.98 (0.9)

a. Includes mainly harbours for which sediment quality information was available after 2000.

Table 9. Major metals exceeding any environmental guideline for levels in sediments in DFO Small Craft Harbours marine sediment sampling studies (2000 to present).

Metal	Nova Scotia (n=121)	New Brunswick (n=19)
Arsenic	33 (27.3%)	5 (26.3%)
Cadmium	45 (37.2%)	3 (15.8%)
Chromium	8 (6.6%)	3 (15.8%)
Copper	31 (25.6%)	5 (26.3%)
Lead	24 (19.8%)	3 (15.8%)
Mercury	6 (5.0%)	1 (5.3%)
Molybdenum	28 (23.1%)	3 (15.8%)
Selenium	32 (26.4%)	3 (15.8%)
Zinc	16 (13.2%)	4 (21.0%)

[20] PAHs for the DFO SCH data were not summarized in the present project because of the complexity of the mixtures, number of compounds, and time constraints for preparing the report.

4.1.2. Metals in Sediments – Scotian Shelf Offshore

Pre-1990s research studies on hydrocarbons in the environment conducted by the federal government (e.g., Keizer et al. 1978); and occasional background measurements of hydrocarbon and metal contaminants in marine sediments and waters in connection with offshore hydrocarbon development (e.g., Carter et al. 1985) were the only sources of information on background levels of these contaminants in the offshore. The advent of hydrocarbon production on the Scotian Shelf, centred on Sable Island Bank near Sable Island, and associated environmental monitoring activities; research by the federal government on fate of contaminants arising from production facilities (e.g., Yeats et al. 2008, Muschenheim et al. 2010, Niu et al. 2010, Yeung et al 2011); and continued interest in exploration and eventual production in deepwater areas on the Scotian Slope have provided a more extensive picture of contaminants in these areas.[21] Numerous measurements of metals and organic contaminants concentrations have been made on the Scotian Shelf and Slope in connection with hydrocarbon exploration and development (Figure 7). Even though the measurements are nearly two decades old, they likely continue to be relevant and to provide background levels for the assessment of current exploratory activities on the Scotian Slope.

Oceanographic research studies have shown low, natural levels for cadmium and manganese in clay surface sediments in LaHave Basin on the Scotian Shelf and Laurentian Channel off southwest Newfoundland (cadmium 0.5 to 1.8 µg/g and 0.18 to 1.3 µg/g; and manganese < 1 mg/g and up to 5 mg/g) respectively (Gobeil et al. 1997). Lead concentrations in Emerald Basin, one of the basins on the inner Scotian Shelf, decreased from the surface (32 µg/g) to 20 µg/g below 40 cm, while copper was 34 µg/g and declined by less than 10 µg/g at 40 cm (Smith et al. 2014). These levels are below background levels for Nova Scotia coastal inlets (Loring et al. 1996).

Offshore surveys in support of exploratory drilling activities have shown that trace metal concentrations in sediments on the Scotian Slope, Shelf and the Laurentian Channel (Tables 10 and 11) are at natural (uncontaminated) baseline levels, with local variation induced by sediment type and the association of higher concentrations with finer sediments, such as are found on the continental slope and basins on the Scotian Shelf, as well as local geochemical processes. Heavy metals including chromium, copper, lead and zinc based on these and other available samples are low and below sediment quality guideline levels over broad areas (Breeze and Horsman 2005), but copper levels exceed the threshold effects guideline for a subset of samples taken in basins, where the presence of fine sediments and geochemical processes may be affecting them (e.g., Gobeil et al. 1997).

[21] Reports on offshore exploratory surveys are available from the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB), Halifax, Nova Scotia.

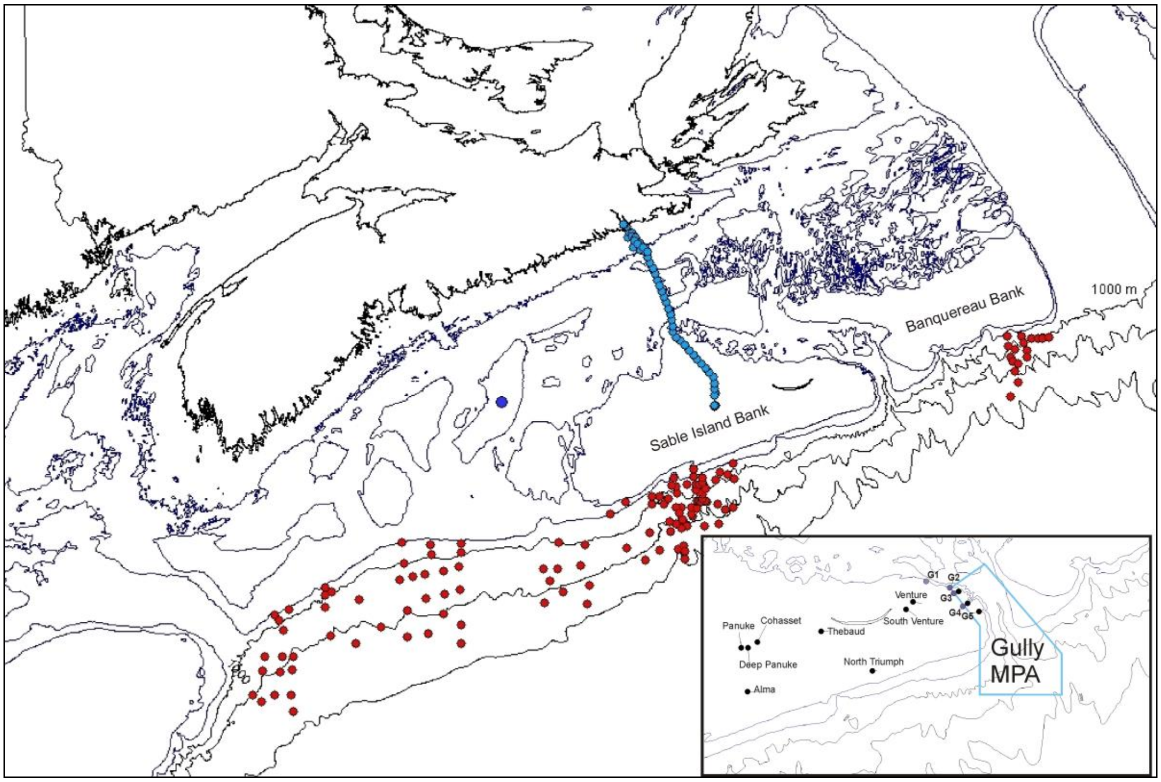

Figure 7. Locations of recent hydrocarbon exploration, development and monitoring activities on the Scotian Shelf and Slope, for which contaminants information has been obtained and is included in this report. G1 to G5 are monitoring locations to verify lack of effects of the nearby Venture and South Venture wellsites. Red dots are locations sampled for exploratory drilling on the continental slope. Blue dots are locations of baseline sampling for Sable Offshore Energy Project or Deep Panuke. The sample for Gobeil et al. (1997) is the blue dot in centre of shelf (Emerald Basin). Dots in the inset are locations for wellsites.

Metal concentrations for the Nova Scotia continental slope are often higher than for the Scotian Shelf due to the prevalence of finer sediments (silts and clays) there (JWEL 2002a, 2002b, 2002c, 2003a, 2003b, 2003c); however, they are within known ranges observed for marine sediments on the Scotian Shelf and Grand Banks (Table 10) (Mobil Oil Canada 1983, Carter et al. 1985, HMDC 1994) with some higher values reflecting higher mud content in the Scotian Slope sediments (JWEL 2001a, 2001b, 2002a, 2002b 2002c, 2003a, 2003b, 2003c) (Table 10). Other differences of slope sediments from the Scotian Shelf, such as higher concentrations of aluminum, chromium, cobalt, iron, strontium, thallium and vanadium on the slope versus other areas (Table 10) reflect the finer sediment composition of slope sediments, although coarser sediments associated with localized surficial sediment features in some areas (Piper and Campbell 2002) may also affect concentrations and composition. Levels are not high enough to harm marine organisms; however their local distribution and sources are not known. Low (background) levels of metals in sediments have been observed in the Gully (DFO 2009a, Yeats et al. 2008) and on its western edge.

Table 10. Contaminant levels (metals and hydrocarbons) in sediments on the Scotian Slope[a] and Cabot Strait[c] compared with previous measurements. Number of samples in brackets.						
Parameter	**Unit**	**Scotian Shelf and Slope**			**Cabot Strait and Laurentian Channel[c]**	
		EQL	**Scotian Shelf and Grand Banks[b]**	**Scotian Slope (n = 129)**	**EQL**	**McGregor Geoscience (n = 19)**
Aluminum	mg/kg	10	300-22900	7100-69000	10	4200-18000
Antimony	mg/kg	2	<2-3	<2-4	2	<2
Arsenic	mg/kg	2	<2-13	<2-7	2	<2-9
Barium	mg/kg	5	0.5-690	110-610	5	30-200
Beryllium	mg/kg	5	<5-0.4	<5	2	<2
Cadmium	mg/kg	0.3	<0.3-0.4	<0.3-5	0.15	<0.15
Chromium	mg/kg	2	<2.0-39	4-70	2	10-51
Cobalt	mg/kg	l	<1.0-9.6	1-15	1	3-12
Copper	mg/kg	2	<2.0-47	<2-31	2	3-25
Iron	mg/kg	20	50-18000	2400-35000	500	9200-39000
Lead	mg/kg	0.5	<2.0-15.3	3.8-24	0.5	2.7-22
Lithium	mg/kg	2.0		8-56		4-32
Manganese	mg/kg	2	<2.0-630	62-2100	2	150-1400
Mercury	mg/kg	0.01		<0.01-0.03	0.01	<0.01-0.2
Molybdenum	mg/kg	2	<2.0-6.0	<2-2	2	<2
Nickel	mg/kg	2	<2.0-28	<2-44	2	8-37
Selenium	mg/kg	2	<2.0-34	<2-4	2	<2
Strontium	mg/kg	5	3-160	<5-470	50	17-100
Thallium	mg/kg	0.1	0.1-0.3	0.1-0.7	0.1	<0.1-0.2
Tin	me/kg	2	<2.0-4.0	<2-9	2	<2
Uranium	mg/kg	0.1	<0.1-0.8	0.3-3.2	0.1	0.4-1.4
Vanadium	mg/kg	2	2.0-40	6-110	2	22-140
Zinc	mg/kg	2		8-84	5	14-82
Total Carbon	g/kg	0.1		1.1-44		
Total Inorganic Carbon	g/kg	0.1		0.5-18		
Total Organic Carbon	g/kg	0.1		0.7-28		
Benzene	mg/kg	0.025	<0.025	0.012-<0.025	0.001	<0.001
Tolune	mg/kg	0.025	<0.025	<0.025	0.001	<0.001
Ethylbenzene	mg/kg	0.025	<0.025	<0.025	0.001	<0.001
Xylene	mg/kg	0.050	<0.025	<0.050-<0.05	0.001	<0.001
C6-ClO	mg/kg	2.5		<2.5	0.05	<0.05
Cl0-C21	mg/kg	0.250		<0.250-5.32	0.05	<0.05
C21-C32	mg/kg	0.250		<0.250-7.73	0.1	<0.1-57
TPH (Total of C6-C32)	mg/kg	3.0	1-26	<3-13	0.1	<0.1-57
Moisture	%	-		19-67		

Source: a. Jacques Whitford Environment Limited (JWEL 2001a, 2001b, 2002a, 2002b 2002c, 2003a, 2003b, 2003c). b. Carter et al. (1985). c. McGregor Geoscience (2012).

Measurements of trace metals on Sable Island Bank made in association with the Sable Offshore Energy Project (SOE Project) natural gas development are presented in Table 11. Metal levels were also low and comparable to those on the Scotian Shelf and Slope in sediments in the Laurentian Channel and nearshore areas along a transect across the Cabot Strait between Point Aconi and Port aux Basques, Newfoundland (McGregor Geoscience 2012). Levels of antimony, beryllium, bismuth, cadmium, molybdenum, selenium, silver and tin were below detection limits; other metals were low and below

CCME Sediment Quality Guidelines (Table 10). Based on sampling conducted for DFO, levels of metals in sediments in the St. Anns Bank Marine Protected Area are below CCME sediment quality guidelines and comparable to background levels (B. Law, Research Scientist, DFO, Dartmouth, N.S., Personal Communication, 2018).

Trace metal levels sampled in 2001 and 2008 in sediments west of Sable Island at the Deep Panuke well site, and in inshore areas along the pipeline route of both the SOE Project and the Encana Deep Panuke Project, were within baseline ranges found in other offshore studies of Scotian Shelf sediments (Martec Limited 1980, Mobil Oil Canada 1983, Carter et al. 1985), and were below background concentrations for Nova Scotia coastal inlets (Loring et al. 1996) (Tables 3-5).

Table 11. Baseline metal concentrations in sediments at wellsites of the Sable Offshore Energy Project and the western edge of Sable Island Bank at the Gully, June 1998-November 1999. Data from Jacques Whitford Environment Limited (2000).

	The Gully		**Venture**		**North Triumph**		**Thebaud**	
Metal (mg/kg)	**Mean (n=23)**	**Range**	**Mean (n=174)**	**Range**	**Mean (n=134)**	**Range**	**Mean (n=136)**	**Range**
Aluminum	6827.4	4700-15000	11116.7	5000-21100	10080.7	3400-17600	10387.4	3500-23000
Antimony	<2	<2	3.0	<2-3	<2	<2	<2	<2
Arsenic	2.0	<2-2	2.3	1-5	2	<2-2	2.5	<2-4
Barium	125.5	78-260	195.2	95-360	201.2	49-1900	195.7	80-760
Beryllium	<5	<5	<5	<5	<5	<5	<5	<5
Boron	<5	<5	<5	<5	<5	<5	7	<5-7
Cadmium	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.03	<0.03
Chromium	2.6	<2-8	8.5	2-38	5.8	2-13	7.8	2-21
Cobalt	1.0	<1-1	1.5	<1-5	1.1	1-2	1.3	<1-3
Copper	2.0	<2-2	2.5	<2-6	2.1	2-4	2.5	<2-15
Iron	1174.8	480-5000	5174.3	880-25000	3199.2	630-7400	4598.4	800-16700
Lead	3.0	2-6.6	6.0	2.3-7.9	4.8	1.4-7.7	4.7	1.8-9.1
Lithium	<5	<5	<5	<5-5	<5	<5	<5	<5-5
Manganese	17.7	6-100	146.4	8-1000	110.10	11-320	98.3	7-520
Molybdenum	2.0	<2-2	2.7	<2-3	<2	<2	<2	<2
Mercury	<0.01	<0.01-0.01	0.0	<0.01-0.05	<0.01	<0.01	0.0	<0.01-0.01
Nickel	2.0	<2-2	2.4	<2-4	2.2	2-4	2.5	<2-6
Selenium	<2	<2-2	3.0	<2-3	<2	<2	<2	<2
Silver	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Strontium	30.7	19-61	48.3	23-86	46.1	15-77	45.8	20-88
Thallium	0.1	0.1-0.2	0.1	0.1-0.2	0.1	0.1-0.2	0.1	0.1-0.3
Tin	<2	<2	2.0	<2-2	<2	<2	<2	<2-6
Uranium	0.2	0.1-0.3	0.3	0.1-1.1	0.3	0.1-0.6	0.4	0.1-5
Vanadium	3.7	2-13	12.7	2-52	8.5	2-17	10.9	3-37
Zinc	6.3	4-18	11.7	4-41	9.3	4-28	10.1	4-26

Barium is a primary constituent of marine sediments and occurs naturally at a wide range of concentrations, predominantly in barite mineral particles in sediments but also associated with other sediment fractions including carbonates, clays, organic matter and other minerals (Gonneea and Paytan 2006). It is of interest as a contaminant since it is a constituent of barite mineral, a component of drilling mud used in offshore exploration, and serves as a tracer of dispersal of drilling wastes from drill sites. Barium levels in sediments in areas of most active production drilling on Sable Island Bank have not changed over time (Carter et al. 1985, JWEL 2000, ExxonMobil 2017) except for occasional spot elevations attributed to drilling mud dispersed from well sites.[22] Levels on the continental slope have tended to be similar to those observed on the shelf (Table 10).

Drilling for development of offshore wells around Sable Island has not changed levels of trace metals, total petroleum hydrocarbons (TPH) or the organic contaminants PAHs in sediments in the vicinity of the well sites or nearby areas. Baseline levels are shown in Tables 10-11. In the SOE Project, one of the two main energy projects in the vicinity of Sable Island, drilling did not result in significant changes to metals in sediments near well sites—Venture, South Venture, North Triumph and Thebaud—which were monitored extensively (Figure 7) (JWEL 2000, 2004). Since 2000, levels of specific metals (barium and mercury) have been monitored at the site (ExxonMobil 2007). Monitoring of metal content in sediments during development and operation of the sites focused on specific metals which were associated with offshore hydrocarbon production—in particular mercury which can be found in produced water[23] and barium as a tracer of drilling muds.

Monitoring activities in parallel to those for production wells focused on a group of stations along the western edge of the Gully (Figure 7), which were positioned to detect long-distance effects of the activities (JWEL 2000, 2004). Beginning in 1999, monitoring included a full suite of metals and organic contaminants, which was reduced after 2000 to a list of contaminants more relevant to the development activities, including barium, mercury, TPH and PAH. Barium, a constituent and tracer of drilling mud, and TPH were occasionally found at elevated concentrations compared to background at some locations near drilling sites, but were not found or only occasionally detected later and were not found near the Gully (JWEL 2000, 2003a; ExxonMobil 2007). Ranges of levels of metals detected in the drilling period (1998-1999) are summarized in Table 11. Monitoring of sediment levels of barium, TPH and mercury during the production phase have shown consistently low levels (ExxonMobil 2017). DFO also surveyed sediments at stations on the western edge of the Gully in 2006 in a survey to produce background environmental information for the Gully Marine Protected Area (MPA) (Yeats et al. 2008), and found low levels of trace metals, in agreement with the industry monitoring program. In addition to being at low concentrations, the heavy metals chromium, copper, iron, vanadium and zinc found in sediments at the edge of the Gully are closely correlated with aluminum and lithium—an indication that they are naturally-occurring and not due to contamination (Yeats et al. 2008). Barium mostly shows the same

[22] Muschenheim et al. (2010) showed that coarse size fractions of barite minerals were incorporated in the shallow sediment column of sands in areas of higher concentration found near the Venture and Thebaud well sites.

[23] *Produced water* is the water found mixed with hydrocarbons in rock formations and brought to the surface during production. It is separated from the product and typically treated to remove hydrocarbons before release to the ocean.

pattern, except for a few cases which were suggested to represent barium originating from offshore drilling activities (Yeats et al. 2008).

Metal concentrations in sediments west of Sable Island and along the natural gas pipeline route to shore for the SOE Project and Encana Deep Panuke project (Figure 7) have shown a similar pattern of overall lack of influence of hydrocarbon production and development operations. Levels of metals in sediments measured from 2001-2008 in the SOE Project were at or below background levels and within ranges comparable to those observed previously for the Scotian Shelf (Tables 6, 7, 10 and 11) (JWEL 2004, 2008). Since production began, levels of metals in sediments within 2 km of the Encana production platform have been comparable to baseline levels (Encana 2017).

Sediments in the Gully MPA have low levels of trace metals, including barium, chromium, copper, iron, lead, vanadium and zinc (Yeats et al. 2008). For lead and barium, the correlation with aluminum and lithium suggest that some may have originated from non-natural sources (Yeats et al. 2008).

4.1.3. Organic Contaminants in Sediments – Coastal and Nearshore

<u>Organic Contaminants in Halifax Harbour</u>: The ports and urban centres of Halifax-Dartmouth and Sydney show high levels of contamination of various organic compounds considered to be contaminants. High levels of PCBs are among the suite of harmful contaminants occurring in Halifax Harbour sediments. Concentrations of PCBs, including in particular hexachlorobiphenyls 138/158/160/163 and 153/132/168 predominated in surface sediments throughout the harbour in 1999-2000, when levels reached 46.2 and 28.6 ng/g dry weight in the two groups respectively (Hellou et al. 2002a, 2002b). The results for total PCBs led to a conclusion that most sites sampled in the harbour at the time (14 of 18) exceeded a sediment quality guideline of 40 ng/g (MacDonald et al. 2000) while several sites exceeded PELs for sediment-dwelling organisms (Hellou et al. 2002a). There have been no efforts to remediate the sediments, although capping by natural deposition of clean surface sediments, in the absence of sources, such as production and use of PCBs, has likely led to an overall reduction.

Total PAH concentrations in sediments sampled in Halifax Harbour in the same study in early 1999 are high, although within ranges reported for harbours elsewhere (Hellou et al. 2002b) (Table 12). Most surface sediments exceed environmental quality guidelines for sediments for individual PAH compounds (CCME 1999), and also exceed the guideline of 2.5 µg/g for disposal at sea under CEPA (Hellou et al. 2002a, 2002b). Combustion-derived PAH compounds typically predominate in sediments, derived from burning of fossil fuels and in particular fossil fuel use in motor vehicles, but occasionally sediments have been contaminated by aliphatic hydrocarbons, which come from spills and other local sources. High concentrations of dibenzothiophenes which characterize pyrolytic sources (e.g., mature crude oils, coal, coke and diesel fuel) have commonly been found in association with high PAH levels (Hellou et al. 2002b).

Organic Contaminants in Sydney Harbour: Most of the sites sampled by King and Lee (2004) in 2001 throughout Sydney Harbour had levels of PAH congeners which exceeded the CCME PELs and the U.S. Effects Range Median (ERM) levels from Long and MacDonald (1998) (King and Lee 2004). PAH composition in sediments in the most contaminated parts of Sydney Harbour reflect coke oven emissions; those in outer reaches reflect petroleum sources such as crankcase oil (King and Lee 2004), while PAH composition in sediments at shallow depths (9-11 m) around the margin of South Arm and in Northwest Arm indicates fossil fuel combustion and coal dust from current coal offloading terminals as potential sources (MacAskill et al. 2016), although PAHs associated with coal often are not bioavailable (Bucheli and Gustafsson 2000). The MacAskill et al. (2016) and Walker et al. (2013a, 2013b, 2013c, 2013d) studies were all carried out to monitor the marine effects of the project that remediated the Sydney Tar Ponds in the 2009-2012 period. Levels of major contaminants measured by Walker et al. (2013b) around the margins of the harbour were not a concern.

Table 12. Concentration of PAH compounds which are particularly abundant in Halifax Harbour sediments (modified from Hellou et al. 2002b).

	Halifax[a]	**Saint John**[b]	**Sydney Harbour**[c]	**Boston**[d]	**Sydney Harbour**[e]
Phenanthrene	0.14-5.21	0.06-1.5	0.34-8.84	0.05-63.7	1.11 (1.34)
Fluorine	0.08-6.11	0.06-1.2	0.34-13.65	0.005-84.5	1.84 (2.74)
Pyrene	0.15-5.13	0.05-0.96	0.29-19.6	0.20-66.8	1.53 (2.32)
Chrysene	0.08-3.61	0.04-0.44	0.31-17.4	0.04-364.7	1.34 (1.95)
Benzo(*a*)pyrene	0.04-1.75	0.03-0.08	0.19-23.5	0.06-95.0	2.39 (3.58)

a. Hellou et al. (2002b). b. Zitko (1999). c. South Arm (Zajdlik et al. 2001). d. Shiaris and Jambard-Sweet (1986) from Hellou et al. (2002b). e. JWEL-IT (1995). Average and (standard deviation).

PCB levels in 2009-2012 around the margin of Sydney Harbour exceeded the Effects Range Median (ERM) (Long and MacDonald 1998) (which is similar to the CCME SQGs) in South Arm and Sydney River estuary (Walker et al. 2013a), reaching up to 3.8 ng/g dry weight; while total PAH concentrations in surface sediments were 1.4-73.8 μg/g (Walker et al. 2013a), lower than in earlier studies, but still above the ERM in many cases.

The South Arm of Sydney Harbour is a basin with a sill at the mouth (near South Bar), leading to reduced near-bottom currents and mixing, and resulting in deposition of fine sediments, including sewage, and detritus which reaches South Arm from the Sydney River estuary. These conditions create the potential for anaerobic conditions to occur, particularly in the vicinity of the City of Sydney waterfront where exceptionally high organic carbon levels and associated reduced/anoxic conditions in sediments have been observed (P. Lane and Associates cited in Stewart and White 2001, Stewart et al. 2002a, 2002b). Improvements to sewage treatment which have recently been completed in Sydney may reduce levels of organic carbon in sediments. Combined with the recent deepening of a shipping channel through the sill to serve the new container terminal at Sydney, water circulation may improve and lead to improved near-bottom oxygen levels.

4.1.4. Organic Contaminants in Sediments – Scotian Shelf Offshore

Offshore sediments on the Scotian Shelf and Slope invariably contain measureable but low levels of hydrocarbons. Hydrocarbons were detected in almost all samples from one study of six exploratory drilling leases on the Scotian Slope; when detected, the hydrocarbons were characterized as being typically in the C_{22}-C_{32} (lube) ranges (JWEL 2002b) (Table 10), but occasionally in the fuel (C_{11}-C_{21}) range. Low levels of hydrocarbons, but with some samples in the lube range, have also been found in some sediments in the Laurentian Channel and nearshore areas in Cabot Strait between Point Aconi and Port aux Basques, Newfoundland (McGregor Geoscience 2012). Most sediments had non-detectable levels of a suite of standard hydrocarbons (benzene, tolune, ethylbenzene, xylene and aliphatic hydrocarbons (C_6 to C_{32})), but some hydrocarbons in the C_{21}-C_{32} range were detected in about half of nineteen samples, at levels ranging from 33-57 mg/kg (McGregor Geoscience 2012) (Table 10). Based on sampling conducted for DFO, levels of organic contaminants in sediments in the St. Anns Bank Marine Protected area are below CCME sediment quality guidelines and comparable to background levels (T. King, Research Scientist, DFO, Dartmouth, N.S., Personal Communication, 2018). Petroleum hydrocarbons commonly are found in offshore marine sediments on the Scotian Shelf and Grand Banks—background concentrations range from 1.0 to 26 mg/kg (Keizer et al. 1978, MacLaren Plansearch 1981, Carter et al. 1985, HMDC 1994). Sources include primarily marine tanker traffic, but also other marine transportation and vessel operations, urban runoff, and atmospheric transport (Lucas and MacGregor 2006).

Petroleum hydrocarbon concentrations in sediments from the Scotian Slope in the early 2000s, measured in baseline surveys on exploration leases, are comparable to ranges typically observed for marine sediments on the Scotian Shelf and Grand Banks. Petroleum hydrocarbons (aliphatics) were detected in almost all samples (approximately 130 were collected in all), but at low levels (i.e., from below detection to up to 3.1 mg/kg with three samples from 8.3 to 13.0 mg/kg) (JWEL 2001a, 2001b, 2002a, 2002b, 2002c, 2003a, 2003b, 2003c) (Table 10). There were no detectable PAHs or BTEX hydrocarbons in any samples.

Drilling for development of offshore wells around Sable Island has not changed levels of TPH or the organic contaminants PAHs in sediments in the vicinity of the well sites or nearby areas. In the SOE Project, one of the two main energy projects in the vicinity of Sable Island, drilling did not result in significant changes to TPH or PAH in sediments near well sites—Venture, South Venture, North Triumph and Thebaud—which were monitored extensively (Figure 7) (JWEL 2000, 2003) and were typically at levels below detection. Since 2000, levels of TPH and PAHs have been monitored and similar results have been found (ExxonMobil 2007). Sediments in a group of four stations on the western edge of Sable Island Bank adjacent to the Gully, which have been monitored since 1998 to verify predictions that drilling wastes and hydrocarbon production from the SOE Project would not contaminate the Gully, similarly have shown low or non-detectable levels of TPHs and non-detectable PAHs. The nature of low-level concentrations of TPH were more precisely defined during a phase of the monitoring program which included measurements by DFO scientists—levels measured by the

SOE Project ranged from 0.56 to 5.45 µg/kg dry weight versus 0.97 to 6.49 µg/kg dry weight measured by DFO (Yeats et al. 2008). Ranges were consistent with hydrocarbon concentrations in mostly uncontaminated sandy shelf sediments elsewhere (Yeats et al. 2008), and the composition of component alkanes determined as part of the DFO study suggest that the hydrocarbons had both anthropogenic (i.e., human-related) and biogenic (e.g., phytoplankton) origins (Yeats et al. 2008).

Alkylphenols are known endocrine-disrupting chemicals which have various industrial sources, but also occur in produced water from oil and gas production platforms where they are released into the marine environment there (Lee 2005). The sediment monitoring program for the Encana Deep Panuke project included analysis targeting nonylphenols in the immediate vicinity of the well and at control locations, but rarely detected the compounds (1 sediment sample, 250 m from the Production Field Centre platform with a level of 4-nonylphenol of 0.686 ng/g in three years of monitoring) (Encana 2017). This level is below the provisional interim sediment quality guideline for nonylphenol and its ethoxylates of 1.0 ng/g (Environment Canada 2002).

4.2. BAY OF FUNDY/GULF OF MAINE AND ADJACENT OFFSHORE WATERS

4.2.1. Metals in Sediments – Bay of Fundy/Gulf of Maine Coastal and Nearshore

Metals in sediments in the Bay of Fundy and Gulf of Maine have been comparatively well-studied, in particular background levels and processes of metal accumulation determined in geochemical sedimentology studies by D.H. Loring since the late 1970s (Loring 1979, 1981; Loring et al. 1996 and 1998) and more recently oceanographic surveys of sediments in Passamaquoddy Bay and L'Etang Inlet (Bugden et al. 2000). A recent summary of metal levels in sediments is provided in Yeats and Dalziel (2005). Bothner et al. (1987) summarized levels of metals in sediments on Georges Bank. Various studies have focused on specific contamination issues such as mercury in sediments (Sunderland 2003) and environmental quality and monitoring of Saint John Harbour (Van Geest et al. 2015). Harding (2013) reviewed studies of metals as contaminants—including sediments—in the Gulf of Maine ecosystem. Our present review complements the Harding review.

Studies of metals in sediments in Saint John Harbour and approaches in the 1970s and 1980s showed low levels of sediment contamination by metals (e.g., Ray 1983, Ray and MacKnight 1984, Wildish and Thomas 1985) and organic contaminants such as PAHs and PCBs (Tay et al. 1997, Land and Sea 2001, Environment Canada 2003). A small fraction of sites sampled by Ray and MacKnight in Courtenay Bay in the central harbour, however, had elevated mercury (Ray and MacKnight 1984) as well as elevated concentrations of copper, lead, cadmium, and zinc (Ray and MacKnight 1984 from VanGeest et al. 2015). A recent analysis of levels of metals and organic contaminants (PAHs and PCBs) in sediments in the vicinity of wharves and berthing areas in inner Saint John Harbour (including the Saint John waterfront, Courtenay Bay and Rodney Terminal, Bay Ferries Wharf) in samples obtained by ECCC for disposal at sea permitting from 2007 to 2014, also showed the major metal contaminants to be low. Levels were below SQGs and cadmium and mercury were always below the detection limit (Envirosphere Consultants 2016 MS). Low levels of heavy metals were also found in nearshore sediments collected off Mispec Point at the mouth of Saint John Harbour in 2006 (Irving Oil 2009) (Table A1). Ray and MacKnight (1984) concluded that the harbour was well flushed by the Saint John River and the tides, leading to the lower concentrations of metals in sediments.

Various studies of contaminant levels in the outer harbour of Saint John have been conducted in relation to management of the Black Point Ocean Disposal Site, and are summarized in Tay et al. (1997) and Environment Canada (2003). The Black Point site is located in the approaches to Saint John Harbour and is the largest in Atlantic Canada, used primarily as a destination for sediments dredged from the harbour. Sediments are deposited continually in the port by the Saint John River, the largest river in the region. The disposal site has been operated since 1958, and although ocean conditions are dispersive, spoil has accumulated, some containing various contaminants and organic carbon (Environment Canada 2003). Concentrations of various contaminants are elevated at the disposal site—reflecting the characteristics of the source material from the inner harbour—but at levels which are below the guideline levels for disposal at sea under CEPA and concentrations of metals and organic contaminants drop off steeply with distance from the disposal site (Environment Canada 2003). Levels of metals and organic contaminants in the outer harbour only occasionally exceed sediment quality guidelines (Environment Canada 2003, Van Geest et al. 2015) (Table A1). In 2011-2013, only arsenic and nickel exceeded the CCME sediment quality guidelines at all of six sites sampled in the outer harbour (Van Geest et al. 2015). Levels were comparable to baseline (e.g., Loring 1979 and Loring et al. 1998), and both arsenic and nickel may be naturally elevated in that part of the Bay of Fundy.

Concentrations of trace metals in sediments in Passamaquoddy Bay and L'Etang Inlet, in the Bay of Fundy, New Brunswick, are typically at background except where elevated by local inputs such as municipal sewage and aquaculture sites. In 1999, a survey by DFO (Bugden et al. 2000) found levels of most metals in sediment were similar to concentrations observed in sediments from other Atlantic coastal embayments (e.g., Loring et al. 1996). Only chromium and nickel were markedly elevated with respect to background. Metal concentrations were consistent throughout the entire study area (Bugden et al. 2000), although the overall pattern showed a tendency towards higher concentrations in the north and west. In L'Etang Inlet, copper and zinc were both elevated in Lime Kiln Bay and in the northern section of Back Bay (Bugden et al. 2000).

Sunderland (2003) and Sunderland et al. (2004) measured mercury concentrations in sediments in the St. Croix Estuary, Passamaquoddy Bay, and outer Bay of Fundy, and found only localized elevation in mercury (See Section 6.2.1).

Low and natural levels of trace metals occur in sediments in central Annapolis Basin, across the Bay of Fundy from Saint John (Table 5) (Loring et al. 1996) with occasionally higher concentrations of chromium related to the local geology. Brylinsky (2005) found low levels of trace metals in sediments offshore of Digby Neck (Table A1).

Surface metal levels in a sediment core in a pristine salt marsh at Allen Creek, New Brunswick, at the head of Cumberland Basin were 12.5, 12, 15 and 60 ug/g dry weight for arsenic, copper, lead and zinc respectively (Kostaschuk et al. 2008) (Table A1). Levels of most heavy metals were comparable through the sediment column extending to the mid-nineteenth century (Kostaschuk et al. 2008). A peak in concentrations of some metals at sediment depths corresponding to the early to mid-twentieth century (i.e., 1939) has been suggested to be due to operation of foundries in Sackville, New Brunswick at that time (Kostaschuk et al. 2008).

Sediment levels of four trace metals (silver, copper, cadmium, zinc) determined in a study of tissue concentrations in lobster in the Bay of Fundy were within the range reported for the Maritimes region (Loring et al. 1996) with silver typically not detected (Chou et al. 2003). Sediment metal concentrations in the Musquash Estuary are within the range observed in sediments elsewhere in the Bay of Fundy (Chou et al. 2004). Sediments in Musquash Estuary were sampled recently for contaminants in support of the management of the Musquash Estuary Marine Protected Area. Levels of metals and other contaminants were at background levels and below sediment quality guidelines (B. Law, Research Scientist, DFO, Dartmouth, N.S., Personal Communication, 2018).

Levels of metals were analyzed in sediments sampled in 2015 in important embayments representative of major watersheds in the Gulf of Maine (Passamaqoddy Bay, Musquash Estuary, Outer Saint John Harbour/Saint John River and Chignecto Bay in New Brunswick; and Minas Basin and Annapolis Basin in Nova Scotia) (ESIP 2017). Of all the sites analyzed, sediments at Five Islands, Nova Scotia, and Lime Kiln Bay, New Brunswick were the most frequently elevated in terms of metal concentrations (ESIP 2017).

Locally elevated concentrations of metals and organic carbon occur around sea farms for Atlantic Salmon and other fish species. Salmon aquaculture sites are found in coastal areas throughout the Scotian Shelf Bioregion, particularly in the outer Bay of Fundy and southwest New Brunswick (Figure 8), but in coastal areas of Nova Scotia as well. Presently there are 94 licensed finfish operations in southwest New Brunswick and 34 licences in Nova Scotia although not all are active (NB Department of Natural Resources 2018, NS Dept of Fisheries and Aquaculture 2018). Fish farms are the primary local source of inputs of metals, which are found in feed and gear treatment chemicals in nets, and organic carbon, which reaches the seabed in the form of uneaten food and fish feces and may cause buildups and anoxic conditions if the deposits are not adequately dispersed.

Slight elevations of zinc and copper in surface sediments were detected and attributed to aquaculture sites in a wide area survey of sediments in the Quoddy Region (Bugden et al. 2000). Copper and zinc levels were elevated within 200 m of an abandoned New Brunswick salmon farm in Lime Kiln Bay (Smith et al. 2005) reaching more than 70 mg/kg copper and >250 mg/kg zinc beneath cages. Levels of zinc were usually, and copper occasionally, above the CCME sediment quality guidelines. Concentrations remained elevated over a period of 5 years, suggesting minimal remobilization of these metals from sediments after abandonment of farming activities (Smith et al. 2005).

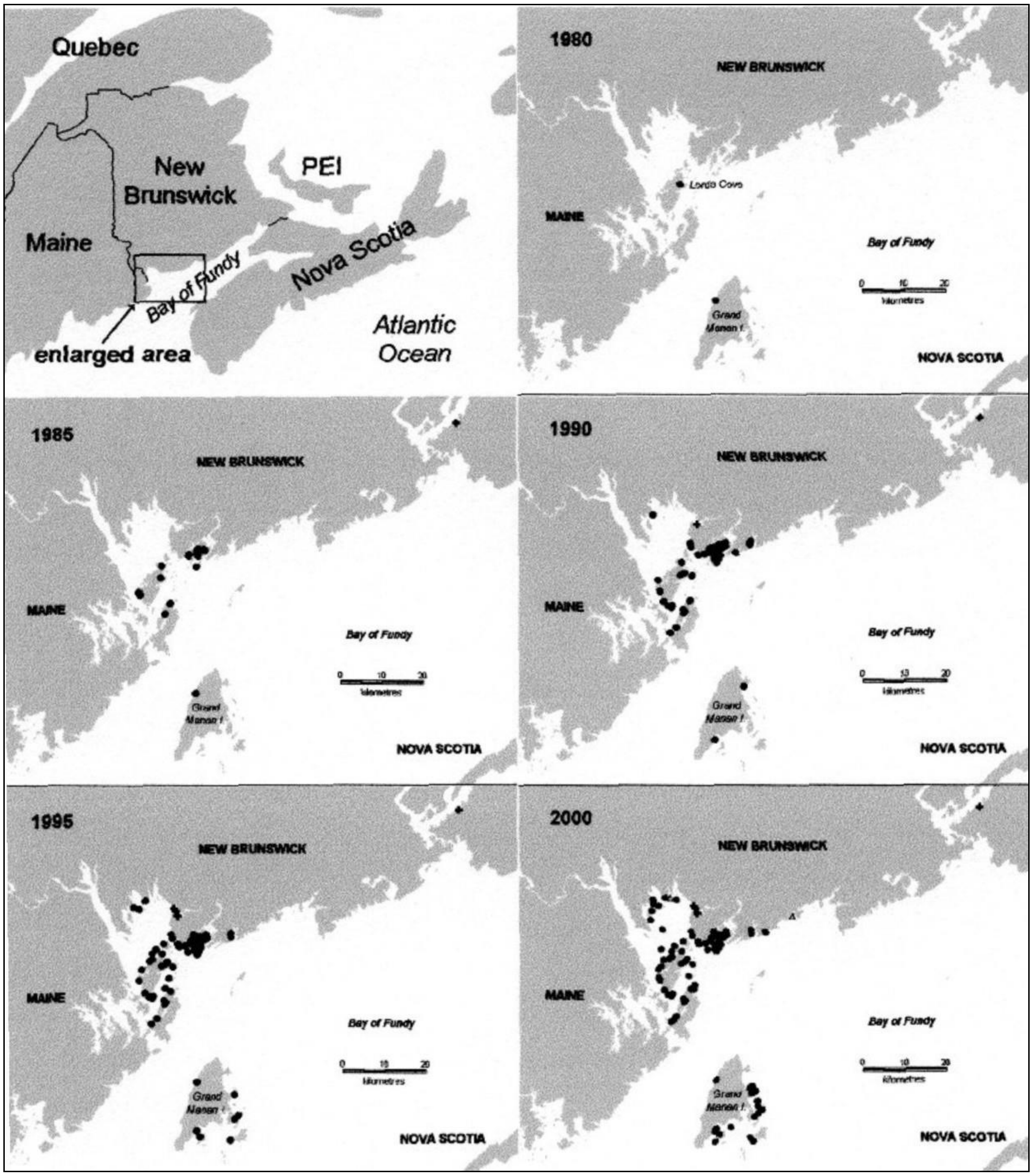

Figure 8. Expansion of salmon aquaculture grow-out sites licensed in the Quoddy Region (not including Cobscook Bay, Maine) 1980-2000. From Lotze and Milewski (2002).

Parker and Aube (2002) had earlier found elevated levels of copper and zinc beneath sea farm pens in Southwest New Brunswick sampled in 1999 to 2001, including some levels which were above the CCME SQGs and occasionally above the probable effects levels (PELs). Zinc exceeded the SQG in about 50% and copper 87.5% of samples, while cadmium and lead did not exceed the respective SQG levels. Reference samples even 100 m from the pens all exceeded the SQG for copper (Parker and Aube 2002). Cadmium concentrations were low, ranging from 0.12 µg/g to 0.94 µg/g (median 0.29 µg/g); cobalt was detected in all samples with a median concentration of 12.34 µg/g; copper ranged from 12.89 µg/g to 115.72 µg/g (median 21.95 µg/g); and the medians for lead and nickel were 25.80 µg/g and 31.10 µg/g respectively (Parker and Aube 2002).

In addition to accumulating metals such as copper and zinc from fish feed, sediments around fish farms contain pigments from feed and butyltins, including tributyltin (Burridge et al. 1999). Sediments at four net pen sites in southwestern New Brunswick (exact locations anonymous) all showed elevated metals and organic parameters compared to reference sites, in particular showing copper levels in sediments above the CCME SQG at all sites (Burridge et al. 1999). Butyltins including mono-, di- and tributyltin (TBT) were frequently detected with TBT present and at highest concentrations in sediments under salmon pens, and in one case at a reference site, at concentrations of 0.5 to 0.7 ng/g dry weight but otherwise not detectable along a gradient from the sites (Burridge et al. 1999). Monobutyltin and dibutyltin levels ranged from non-detectable to 1.8 ng/g dry (dibutyltin) at one site (Burridge et al. 1999).

There are multiple possible transport mechanisms of metals from sea farm sites. For example metals have been shown to be associated with fine inorganic and organic particles and flocs (Law et al. 2014) which are transported by water movements away from aquaculture sites. Metals also can migrate from sites in the sea surface microlayer (Loucks et al. 2012) after transfer from the sediments to the surface by means of bubbles. Dispersal from the aquaculture site can result in low levels at significant distances from the facility (Yeats et al. 2005); slightly elevated zinc levels in sediments have been found 1 km from sea farms in the area (Robinson et al. 2005). Particles and flocs provide a transfer mechanism of metals to suspension feeding organisms (Law et al. 2014).

Low levels of contaminant heavy metals from other sources, both natural and anthropogenic, have been measured in recently deposited intertidal and salt marsh sediments in the Bay of Fundy (Hung and Chmura 2006, 2007). In that study, recent sediment deposited in seven salt marshes along the New Brunswick coast of the Bay of Fundy (i.e., in a five-year period from 1997-2002) had low levels of some heavy metals (chromium, lead, mercury, nickel, vanadium, and zinc) but levels of arsenic and copper which were only occasionally near or slightly above sediment quality guidelines (Hung and Chmura 2006, 2007). Sediments are sinks for various contaminants which are associated with inorganic and organic particulate matter, and recent deposition reflects the immediate state of the combined natural and anthropogenic loading. The salt marshes were in coastal areas potentially affected by common industrial and municipal trace metal sources such as a thermal electric power plant, municipal wastewater discharges, scrap yards, pulp mills etc. (Hung and Chmura 2007) but incidences of elevated levels were not usually associated with areas having obvious sources. Chromium, lead, mercury, nickel, vanadium and zinc were within natural ranges, while copper and arsenic levels were near the CCME SQGs at sites in the outer Bay of Fundy of New Brunswick. Arsenic and lead were enriched over pre-industrial levels in Dipper Harbour in an outer Bay of Fundy salt marsh (Hung and Chmura 2007). Mercury levels ranged from 7 to 78 ng/g, lowest at the head of the Bay of Fundy (Cape Enrage) and highest at a marsh at Bocabec in Passamaqoddy Bay (low and high marsh averages of 56 and 59 ng/g respectively and two to seven times higher than other salt marshes)

(Hung and Chmura 2006) but all were below the CCME guideline level. Mercury levels were of the same order as the range of 4 to 71 ng/g previously reported by other studies that measured mercury in sediments in Bay of Fundy salt marshes (Sunderland 2003 and Bayer 2004 from Hung and Chmura 2006).

Surface sediments in a salt marsh in Dipper Harbour, New Brunswick, southwest of Saint John, have zinc, copper and lead concentrations above background, which have been attributed to recent pollution (Daoust et al. 1996). Levels of lead (18.2 to 66.3 ppm), copper (5.4 to 29.7 ppm) and zinc (23.7 to 54.7 ppm) were higher in the upper 30 cm of sediment column compared with averages for depths of from 30 cm to 3.5 m (22.7, 7.0, and 22.9 ppm) respectively (Table A1) (Daoust et al. 1996).

Subtidal gravelly sand sediments at 35-40 m below mean low water off Digby Neck in the Bay of Fundy have low levels of cadmium, copper, lead, mercury and zinc—at background levels and below CCME Sediment Quality Guidelines (Brylinsky 2005 MS) (Table A1).

4.2.2. Mercury in Sediments – Bay of Fundy

Anthropogenic releases of mercury from fossil fuel combustion and other sources have increased concentrations in the environment at a global scale. However levels of mercury in the sediments and waters of the Scotian Shelf and Bay of Fundy are relatively low. Hotspots where localized releases have occurred in the past—such as in waters influenced by effluents from chloralkali plants associated with pulp and paper production or releases at gold processing operations[24]—have been phased out in Atlantic Canada. Nonetheless, the chemical properties of mercury[25] which lead to the formation of organic derivatives such as methyl mercury have led to its accumulation in organisms at various trophic levels via the food chain in coastal areas of the bioregion, where it can be harmful (Evers et al. 2008, Chen et al. 2008).

Methyl mercury forms principally by bacterial activity in sediments both in freshwater and in depositional marine intertidal and subtidal environments, where it is passed through benthic invertebrates to wildlife at higher trophic levels such as fish, waterbirds, marine mammals and other wildlife. Methyl mercury is toxic to living organisms at high concentrations and there is widespread concern about its continued accumulation in the environment. Humans can be exposed through their food, particularly in diets high in fish, which typically accumulate methyl mercury and where most potentially toxic exposures occur (ECCC 2016).

Research on the dynamics of mercury in the marine and estuarine environment of the Bay of Fundy over the past two decades has made important contributions to the understanding of the processes of supply, cycling and trophic transfer of mercury both

[24] Approximately one ounce of mercury was used for every ounce of gold produced (Parsons et al. 2004).

[25] Bacterial activity, principally in sediments, can methylate mercury, resulting in alkylated forms such as methyl mercury, which are lipid-soluble and can bioaccumulate in organisms.

regionally and globally. Apart from natural sources, mercury enters the aquatic environment after being produced through human activities such as fossil fuel combustion, the chloralkali industry, paint containing mercury additives, pharmaceuticals, medical wastes, and gold mining and extraction (Doiron et al. 1998, Brewster and Stobo 2004). Because of improved environmental regulation and changes in industrial practices, most of these sources have been largely phased out, with fossil fuel combustion and waste disposal remaining as the most significant modern sources (Doiron et al. 1998; Sunderland and Chmura 2000a, 2000b).

Mercury enters the Bay of Fundy-Gulf of Maine system primarily via rivers and estuaries but does not principally concentrate in animals in the water column—rather the main route of exposure to higher organisms is through benthic food webs (Sunderland et al. 2010, 2012). Marine sediments are major reservoirs of inorganic mercury and focal points of transfer to organisms, in particular through methyl mercury production by sediment bacteria (Sunderland et al. 2004, Environment Canada 2016 and references therein). Inorganic mercury introduced into the environment accumulates in fine sediments through its affinity for organic and inorganic particles. In sediments, some is transformed to methyl mercury, a process which takes place continuously in the upper 10-15 cm of fine subtidal sediments such as occur in coastal inlets and bays such as Passamaquoddy Bay (Sunderland 2003, Sunderland et al. 2004) and in anoxic horizons of other sediments such as occur in mudflats and salt marshes (Sunderland 2003, O'Driscoll et al. 2011). Sufficient pools of mercury and methyl mercury remain in fine-grained sediments in the coastal and estuarine areas of the Bay of Fundy to continue to expose the marine ecosystem, even in the face of regulated reductions to releases from human activities (Sunderland 2003, Sunderland et al. 2004). Temporal patterns of mercury in tissues of various marine animals do not tend to show declining levels of mercury despite reductions of releases into the environment, reflecting the relatively large pool of the element already present in the marine environment (Sunderland et al. 2012).

Sediments throughout the Bay of Fundy have low total mercury levels compared with more contaminated waters elsewhere in Canada and the world (Environment Canada 2016). In Passamaquoddy Bay and the St. Croix Estuary the highest level of total mercury (and the highest for the Bay of Fundy as a whole) was 100 ng/g dry weight, at the head of the estuary, where historic releases of mercury from pulp and paper production had accumulated in sediments and are still at high levels (Sunderland et al. 2006, Sunderland et al. 2004). Elsewhere in the Bay of Fundy, concentrations of total mercury are lower, ranging from 20-90 ng/g (Environment Canada 2016). Concentrations are low in intertidal mudflats of Minas Basin, Bay of Fundy (0.5-24.0 ng/g) (O’Driscoll et al. 2011) and levels in Saint John Harbour approaches range from 2.4-24 ng/g dry weight total mercury (Van Geest et al. 2015). Compared with total mercury, methyl mercury levels have been measured infrequently, and in surface sediments of the Bay of Fundy average 0.3 ± 0.09 ng/g in Passamaquoddy Bay and 0.1 ± 0.02 ng/g at sites near Grand Manan and central parts of the Bay in that area (Sunderland 2003, Sunderland et al. 2012).

The Bay of Fundy, because it is semi-enclosed and is small enough to reflect the influence of coastal sediments and land-based inputs, lends itself naturally to modeling mercury budgets and flux at an oceanographic scale to develop an understanding of relative importance of various inputs (Dalziel et al. 2010, Sunderland et al. 2012). Based on a mercury budget for the Bay, which included information from airborne and land-based sources, as well as oceanographic sampling of sediments, plankton, and water, Dalziel et al. (2010) concluded that the Bay of Fundy is relatively uncontaminated by mercury. Levels in water used in the assessment were total mercury and methyl mercury 237 pg/L and 58 pg/L, respectively at the outer extent of the Bay (Dalziel et al. 2010).

4.2.3. Other Metals in Sediments – Bay of Fundy/Gulf of Maine Offshore

Loring (1979) identified low levels of a range of metals in sediments throughout the outer Bay of Fundy. Trace metal concentrations in sediments on Georges Bank which forms an outer boundary to the Gulf of Maine on the adjacent U.S. continental shelf are low (Table 13) and probably represent natural (uncontaminated) baseline levels, with local variation induced by sediment type and the association of higher concentrations with finer sediments (Bothner et al. 1987).

4.2.4. Organic Contaminants in Sediments – Bay of Fundy/Gulf of Maine Coastal and Nearshore

A wide range of organic contaminants common to Atlantic Canada as a whole are found in coastal areas of the Bay of Fundy, typically associated with releases from both anthropogenic activities and natural releases in the coastal zone.

Table 13. Contaminant levels (metals and hydrocarbons) in sediments on Georges Bank[a] compared with offshore areas of Eastern Canada. Number of samples in brackets.

Parameter	Unit	Georges Bank[a] (*n=42*)	Scotian Shelf and Grand Banks[b]	Scotian Slope[c] (*n=129*)
Metals				
Aluminum	mg/kg		300-22900	7100-69000
Antimony	mg/kg		<2-3	<2-4
Arsenic	mg/kg		<2-13	<2-7
Barium	mg/kg	< 110[d] (70-410)	0.5-690	110-610
Beryllium	mg/kg		<5-0.4	<5
Cadmium	mg/kg	0.042 (0.013-0.16)	<0.3-0.4	<0.3-5
Chromium	mg/kg	9 (1.9-20.7)	<2.0-39	4-70
Cobalt	mg/kg		<1.0-9.6	1-15
Copper	mg/kg	4.6 (0.08-15)	<2.0-47	<2-31
Iron	mg/kg	8000 (1000-28,000)	50-18000	2400-35000
Lead	mg/kg	4.4 (1-8)	<2.0-15.3	3.8-24
Lithium	mg/kg			8-56
Manganese	mg/kg		<2.0-630	62-2100
Mercury	mg/kg			<0.01-0.03
Molybdenum	mg/kg		<2.0-6.0	<2-2
Nickel	mg/kg	5.3[d] (<0.9-43)	<2.0-28	<2-44
Selenium	mg/kg		<2.0-34	<2-4
Strontium	mg/kg		3-160	<5-470
Thallium	mg/kg		0.1-0.3	0.1-0.7
Tin	me/kg		<2.0-4.0	<2-9
Uranium	mg/kg		<0.1-0.8	0.3-3.2
Vanadium	mg/kg		2.0-40	6-110
Zinc	mg/kg	11.8 (2-86)		8-84
Hydrocarbons				
Benzene	mg/kg			0.012-<0.025
Tolune	mg/kg			<0.025
Ethylbenzene	mg/kg			<0.025
Xylene	mg/kg			<0.050-<0.05
C6-CIO	mg/kg			<2.5
Cl0-C21	mg/kg			<0.250-5.32
C21-C32	mg/kg			<0.250-7.73
TPH (Total of C6-C32)	mg/kg		1-26	<3-13

Source: a. Bothner et al. (1987). b. Summary from JWEL 2002. c. JWEL 2002b. d. Median value

Major Harbours: Occasional locally-elevated PAH concentrations have been found in the Saint John Inner Harbour. An analysis of sediment data obtained from the harbour from 1996-1999 (Zitco 1999) determined that over 80 percent of sediment samples analyzed for total PAH (thirteen reported PAHs) had levels below 2.0 mg/kg, and over 50 percent of measurements were below detection (Zitco 1999). A recent analysis of levels of metals and organic contaminants (PAHs and PCBs) in sediments in the vicinity of wharves and berthing areas in inner Saint John Harbour (including the Saint John waterfront, Courtenay Bay and Rodney Terminal, Bay Ferries Wharf) in samples obtained by ECCC for disposal at sea permitting from 2007 to 2014 (ECCC Disposal at Sea Geodatabase 2017,[26] Envirosphere Consultants 2016 MS), also showed that levels of PAHs in sediments only rarely exceed the Canadian Environmental Protection Act Disposal at Sea guideline of 2.5 mg/kg, similar to the situation in the mid- to late 1990s (Lindsay and Zitco 1996, Zitco 1999). Saint John Outer Harbour has comparatively low levels of PAHs and typically non-detectable concentrations of PCBs (Environment Canada 2003, Van Geest et al. 2015). Total PCB concentrations in the inner harbour and outer harbour respectively ranged from <2.9-18 µg/kg dry weight to <2.9-9 µg/kg from 2011-2013 (Van Geest et al. 2015). The Black Point Ocean Disposal site is near the heavily industrialized Mispec Point, which is the location of a conventional crude oil berthing site (Canaport Monobuoy) and LNG tanker berths. Coastal sediments collected off Mispec Point at the mouth of Saint John Harbour in 2006 (Irving Oil 2009)[27] from the coast to 2-3 km from shore showed detectable levels of total PAHs, dioxins, furans and TPH (C_6-C_{34}), and non-detects at standard laboratory detection limits for other hydrocarbons including BTEX and VOCs (Irving Oil Limited 2009). PAH levels (average 0.28 (0.09-0.78) mg/kg) were below CCME Marine SQG and CEPA Ocean Disposal guideline levels. Levels of dioxins (TCDD) were 51.6 pg/g (2.17-138 pg/g), furans 11.8 pg/g (0.64-36.6 pg/g) and TPH 4.46 µg/g (1.70-12.0 µg/g) (Irving Oil Limited 2009).

Sediments off Mispec Point east and southeast of the Black Point Ocean Disposal site in a baseline study for the since-abandoned Eider Rock Marine Terminal Project (Irving Oil Ltd. 2009) exceeded the ocean disposal guideline level for PAHs (5.2 µg/kg and 16.9 µg/kg) and showed detectable arsenic in several samples. This site is in the vicinity of the Canaport Monobuoy, a floating buoy mooring facility for the Irving Oil Refinery and might be expected to have some contamination arising from tanker activity.

<u>Aquaculture</u>: Pesticides have been used to control sea lice in fish farms in New Brunswick and Nova Scotia since the first outbreak was experienced in 1994 (Burridge et al. 2010, Burridge and Van Geest 2014). The chemicals are released into the environment but no measurements have been made of levels in organisms or in sediments, although in some cases dispersal has been monitored and toxicity to invertebrates assessed (Ernst et al. 2001). Chemicals which have been applied include an organophosphate pesticide formulation called Nuvan® (active ingredient: chlorpyrifos); a pyrethrum formulation containing a mixture of natural pyrethrins including cypermethrin and deltamethrin; Salartect® formulation, an in-feed product with ivermectin as the active ingredient; Excis®; Salmosan®; Paramove® 50; AlphaMax®; SLICE with the active ingredient emamectin benzoate; and Calicide® with the active ingredient teflubenzuron (Burridge and Van Geest 2014). Emamectin benzoate can induce premature moulting in lobster (Waddy et al. 2002). Both deltamethrin and

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[26] A national database of sediment properties and contaminants maintained by ECCC Environmental Assessment and Marine Programs for sediments assessed for disposal at sea.

[27] Baseline information collected for the environmental assessment of the proposed construction and operation of a new petroleum refinery and marine terminal in the vicinity of the existing Irving Oil Ltd refinery on Mispec Point in Saint John Harbour. Both projects were subsequently abandoned.

cypermethrin could potentially bioaccumulate (Burridge and Van Geest 2014). Both chemicals can also bind to organic particles and therefore have the potential to accumulate in sediments (Harding 2013, Burridge and Van Geest 2014). Iodophor or iodine-based disinfectants such as *Wescodyne®* and associated carrier compounds are also widely used in the aquaculture industry and in large quantities, in particular to protect against transfer of fish diseases but their presence in sediments has not been tested (Denning 2008). Toxicity of deltamethrin formulations to marine and estuarine crustaceans has been assessed by Fairchild et al. (2010).

Other contaminants including PAHs from combustion sources, as well as PAHs, PCBs and DDE from feed and faeces from finfish aquaculture sites can occur at low levels in sediments around aquaculture sites. Five types of alkylated naphthalenes (PAHs), a particular PCB (IUPAC congener 153) and DDE, in addition to other chlorinated hydrocarbons, occurred in feed and commercial fish oil. They were also detected in sediments under finfish cages and up to 100 m distant from salmon aquaculture cages in the southwestern Bay of Fundy (Hellou et al. 2005a). Highest levels of alkylated naphthalenes, PCB Congener 153, and DDE were 45 ng/g, 3 ng/g and 7 ng/g dry weight respectively (Hellou et al. 2005a). Sediments around fish pens in this study also detected PAHs from other common sources, such as combustion processes (Hellou et al. 2005a). This study demonstrates that many organic compounds considered to be contaminants can be released into the marine environment by the aquaculture industry and may be present in low concentrations around fish farm sites. The overall significance of the finding remains to be determined.

Total PAHs were measureable at the sites, although at low levels; and canthaxanthin, a colour additive for salmon feed, also occurred in sediments at the sites. Other contaminants of interest which were not detected included PCBs (detection limit 0.05 µg/g dry weight); mono- through tetra-chlorophenols and pentachlorophenol (detection limit 0.05-0.1 µg/g dry weight); and cypermethrin, asamethiphos, and ivermectin, three chemicals used in sea lice treatments (Burridge et al. 1999).

Other areas: Sediments in an estuary below a sulfite pulp mill in L’Etang Inlet occasionally contained lignosulfonates (byproducts of sulfite pulp production) (Zitco 1999).

Chlorobenzenes were not detected in tidally influenced sediments or waters in the Annapolis River near Bridgetown (detection limits <0.01 µg/g wet weight and 0.02 pg/L respectively) (Rutherford et al. 1996).

PCB concentrations in sediments sampled in 2015 at Gulfwatch[28] monitoring locations in Nova Scotia and New Brunswick (ESIP 2017) were always above 100 pg/g dry

[28] Gulfwatch is based on the U.S. Mussel Watch program, which annually has assessed the health of some 180 coastal locations in the U.S. since 1986 (O’Connor 1992, 1998). It annually has sampled mussels in approximately two dozen coastal areas around the Gulf of Maine, including sites in New Brunswick and Nova Scotia, and measures a suite of trace metals, PAHs, PCBs and pesticides. The Gulfwatch program is operated by Gulf of Maine Council (GOMC) (http://www.gulfofmaine.org/), an organization set up by the U.S. states and Canadian provinces which border the Gulf of Maine, to

weight and about half the sites had levels of several hundred pg/g dry weight, up to 50 ng/g dry weight at one site (Tin Can Beach on the north side of Saint John Harbour near Courtenay Bay) (ESIP 2017). Levels of PAHs were roughly similar at all sites, typically between about 200 and 225 μg/kg dry weight, with the highest at more than 258 μg/kg at Grosses Coques, in St. Mary's Bay, Nova Scotia, and lowest at about 100 μg/kg dry weight at the Broad Cove, Nova Scotia site (ESIP 2017).[29] No pesticides from the suite monitored in Gulfwatch were detected in sediments at any of the sites.

The flame retardant chemicals PBDEs have been found in sediments collected throughout U.S. coasts during 2004-2007 in sampling associated with the U.S. Mussel Watch program but were not detected in one sample from coastal Maine (Shaw and Kannan 2009).

4.2.5. Organic Contaminants in Sediments – Bay of Fundy/Gulf of Maine Offshore

Organic contaminants in sediments in offshore areas of the Bay of Fundy have rarely been measured. In contrast to the industrial harbour at Saint John, subtidal gravelly sand sediments at 35-40 m below mean low water off Digby Neck in the Bay of Fundy have low (non detectable) levels of PAHs and PCBs (Brylinsky 2005 MS) (Table A1). Moderate levels of the organochlorine pesticide hexachlorobenzene were detected in sediments at the mouth of the Kennebec River, Maine (Hauge 1988 from Harding 2013).

4.2.6. Radionuclides in Sediments – Bay of Fundy/Gulf of Maine Coastal and Nearshore

Levels of radionuclides typically are only detected in urban areas in relation to releases from medical facilities in major harbours and as a general background, which can include elements from nuclear weapons tests and accidental releases such as the reactor accident at Chernobyl, U.S.S.R. (now Ukraine). The 705 MW CANDU nuclear reactor which has operated at Point Lepreau, New Brunswick by NB Power since 1982 has not contributed significant levels of radionuclides to the marine environment (sediments, water or biota) as shown by monitoring programs, both baseline and operational (Énergie NB Power 2015). The reactor uses seawater for cooling but in addition has low-level atmospheric releases—principally tritium—which are below health exposure levels. These releases reach the marine environment and intertidal areas, as well as the terrestrial and freshwater environment around the site (Figure 9).

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coordinate cooperation and initiate and manage activities to maintain and enhance the Gulf's marine ecosystem, its natural resources and environmental quality. The *Agreement on the Conservation of the Marine Environment of the Gulf of Maine* which set up the GOMC was signed in December 1989 by the premiers of Nova Scotia and New Brunswick and the governors of Maine, New Hampshire and Massachusetts (LeBlanc et al. 2011).

[29] The units for PAHs in ESIP (2017) appear to have been incorrectly stated as mg/kg instead of μg/kg, and have been correctly presented here.

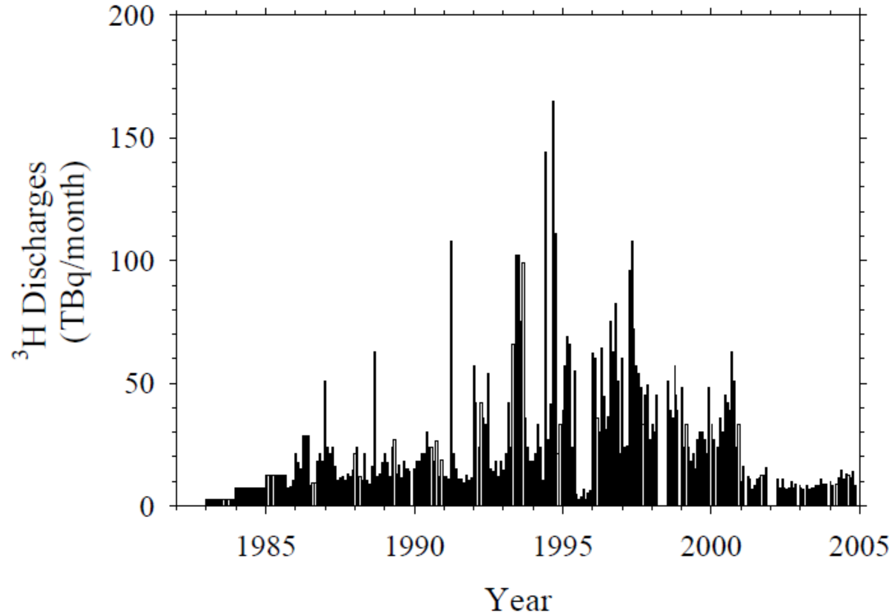

Figure 9. Monthly atmospheric discharges of tritium (^{3}H) from the Point Lepreau Nuclear Generating Station (NBEPC 2006).

Measurements of a range of radionuclides in the marine environment for five years (1977-1982) (baseline) and annual measurements subsequently until 2006 by DFO in the Point Lepreau Environmental Monitoring Program (PLEMP) (Nelson et al. 1998, 2001, 2007 MS) demonstrated that tritium was the only radionuclide released from the reactor which is routinely measurable above preoperational levels in the environment, but levels are significantly below those considered to be harmful to organisms or humans. Levels of tritium were not measured in sediments. As in other marine areas, fallout of the radioisotope ^{137}Cs from the Chernobyl reactor accident in the Ukraine in 1986 was experienced in the Bay of Fundy. Scavenging by particles and subsequent settling and dilution with deep Atlantic water and fresh water inputs containing lower ^{137}Cs acted to reduce the levels in water (Nelson et al. 1998).[30] Énergie NB Power monitors radiation levels in the environment at the site in its Radiation Environmental Monitoring Program (REMP) which includes annual measurements of tritium and other isotopes in seawater, seafood, seaweed (dulse) and local marine fish and invertebrates, as well as ambient gamma radiation in the intertidal zone (Énergie NB Power 2015). Tritium is the only radionuclide released and detected in seawater and no radionuclides which could be attributed to the reactor were found in biota in one year of the survey (2015) (Énergie NB Power 2015). Similarly, levels of tritium in seawater before and after start-up were similar (Nelson et. al 2001).

[30] The ^{137}Cs from the Chernobyl accident, as well as occurrences from nuclear weapons testing in the 1960s, are used throughout the world as markers in sediment cores to determine sedimentation rates and demonstrate changing patterns of contaminants released by human activity and natural sources.

5.0 CONTAMINANTS IN WATER

5.1. SCOTIAN SHELF AND ADJACENT OFFSHORE WATERS

5.1.1. Metals in Water – Coastal and Nearshore

Dissolved metals are important to the marine ecosystem both as essential constituents of biological organisms, as nutrients, and also as contaminants. The main sources in coastal and nearshore waters in the bioregion are freshwaters in rivers and precipitation (Bundy et al. 2014). Dissolved metals are not routinely measured to assess contaminant impacts in coastal areas, although they are often measured in studies of oceanographic processes offshore. Dissolved trace metals in inshore areas have been studied most extensively in Halifax Harbour and Sydney Harbour, with limited numbers of measurements in other harbours such as Medway Harbour, Ship Harbour, Bras d'Or Lakes and Pictou Harbour (Windom et al. 1991 and Strain and Yeats 2002, both from Bundy et al. 2014). Relatively pristine waters such as Medway Harbour, Ship Harbour and the Bras d'Or Lakes have lower concentrations of metals including cadmium, copper, nickel, lead and zinc (typically associated with heavy metal pollution) than waters in industrialized harbours (Halifax, Sydney and Pictou) (Bundy et al. 2014). Heavy metal concentrations in inshore waters have been generally decreasing with time but copper levels in Halifax Harbour had increased from 1988/89 to 2001/02 (Bundy et al. 2014)—a reflection of declining industrial inputs overall, but continued influences of sewage, which is the major source of copper in urban harbours.

Intertidal waters in areas of the Nova Scotia Atlantic coast influenced by former gold mining activities can show elevated total arsenic concentrations in seawater (total arsenic includes dissolved and particulate) and occasionally total mercury in response to local environmental contamination (Doe et al. 2017). Levels of arsenic in seawater above CCME Marine Aquatic Life Guidelines have been observed in Seal Harbour, Wine Harbour, and Harrigan Cove, and mercury levels exceed the guideline in Wine Harbour. Both arsenic and mercury levels are low (i.e., below detection for mercury (<0.05 µg/L) and arsenic (<20 µg/L)) in other areas of the coast with similar geology from New Harbour to Gold River (Doe et al. 2017).

Although sediments and biota of Sydney Harbour have shown high levels of major contaminants, the waters recently have been largely free of them (Lee 2002). Levels of dissolved cadmium, copper, lead, nickel and zinc in five harbour areas (Sydney River estuary, central South Arm, Outer South Arm, mouth of South Arm and outer harbour) were all below existing water quality guidelines in 1999-2000 (Figure 10) (Lee 2002) while concentrations of heavy metals in particulates were similar to those found in sediments in the harbour in the same study. Monitoring for the Sydney Tar Ponds Remediation Project carried out from 2009-2012 found low levels of major contaminants in water (below CCME guidelines) (Walker and MacAskill 2014).

The occasional sinking and disposal of ships and other vessels and marine structures in nearshore waters provides another possible source of dissolved and particulate metals. In outer Lunenburg Harbour, levels of particulate lead were low in the water column, averaging 0.007 mg/L (range, < 0.004 to 0.30 mg/L) (Envirosphere Consultants 1996) around a naval frigate, the HMCS *Saguenay*, sunk to create an artificial reef.

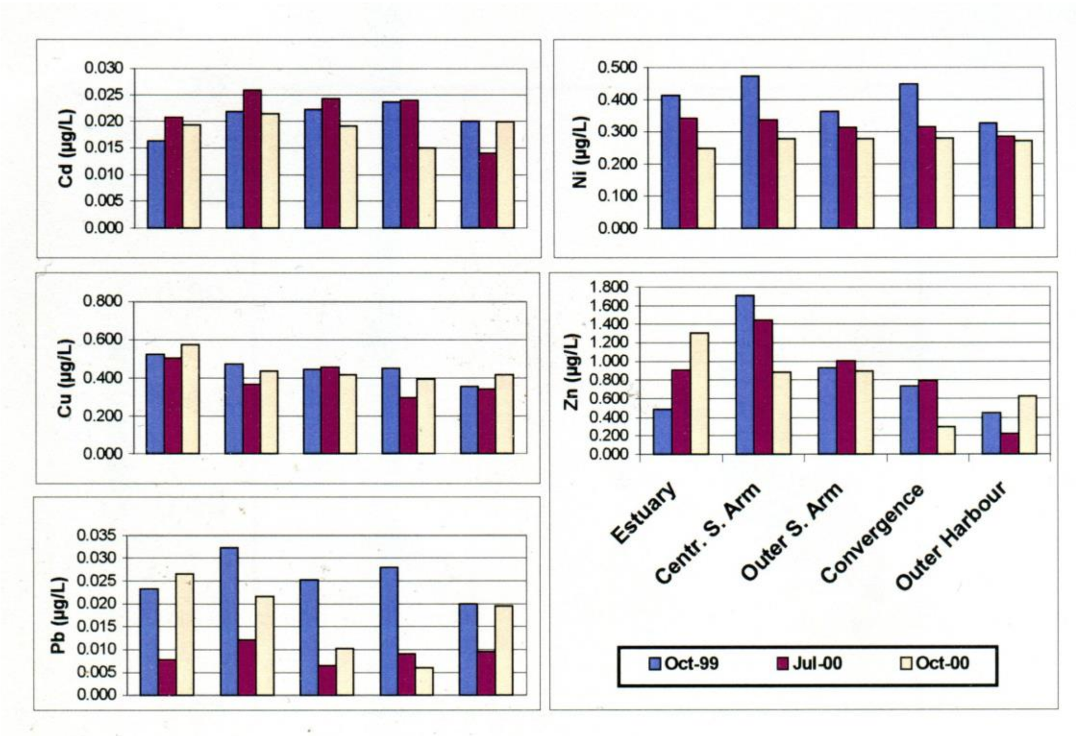

Figure 10. Dissolved metal concentrations in various harbour subdivisions, Sydney Harbour, 1999-2000 (Lee 2002).

5.1.2. Metals in Water – Scotian Shelf Offshore

Concentrations of dissolved metals in seawater in offshore areas of the Scotian Shelf Bioregion show subtle human influences. A decreasing northeast to southwest gradient in many dissolved metals has been observed for the Scotian Shelf (Yeats 1993, Breeze and Horsman 2005, Smith et al. 2014) (a cross-section is shown in Figure 11), reflecting the influence of waters leaving the Gulf of St. Lawrence which have elevated levels of dissolved metals, largely due to freshwater arising from the industrialized St. Lawrence River and Estuary. Atmospheric transport from nearby industrial areas in North America is a source of metals and other contaminants to the bioregion, demonstrated by similar lead isotope profiles in marine particulate matter in the Gulf of Maine and in coastal aerosols and precipitation in the region (Knowlton and Moran 2010). Profiles indicated both U.S. and Canadian sources.

Metal concentrations in seawater are in a constant state of flux as they participate in chemical reactions under changing conditions, and through interactions with sediments and biota. These interactions tend to trap metals—which arise from human activities and reach the ocean from coastal areas and through atmospheric deposition—on the continental shelf (Smith et al. 2014 and citations therein). Interactions with particulate matter (which scavenges metals) are particularly important (Weinstein and Moran 2004, Smith et al. 2014). The gradient of metal concentrations found in particulate matter, and the flux of metals in the Gulf of Maine and slope decreases offshore (Weinstein and Moran 2004, Smith et al. 2014). Human influences on metal loads in the Scotian Shelf Bioregion are evident, both in the gradients arising from the Gulf of St. Lawrence inputs, and in the particulate metal content in waters there, which is higher in the bioregion than on the Labrador Coast (Weinstein and Moran 2004). Dissolved metal concentrations in offshore waters are never high enough to significantly harm biological organisms, but can help to pinpoint human influences; slightly elevated concentrations of dissolved lead and copper at two locations on the inner Scotian Shelf have been attributed to industrial and urban inputs from the Halifax area (Smith et al. 2014).

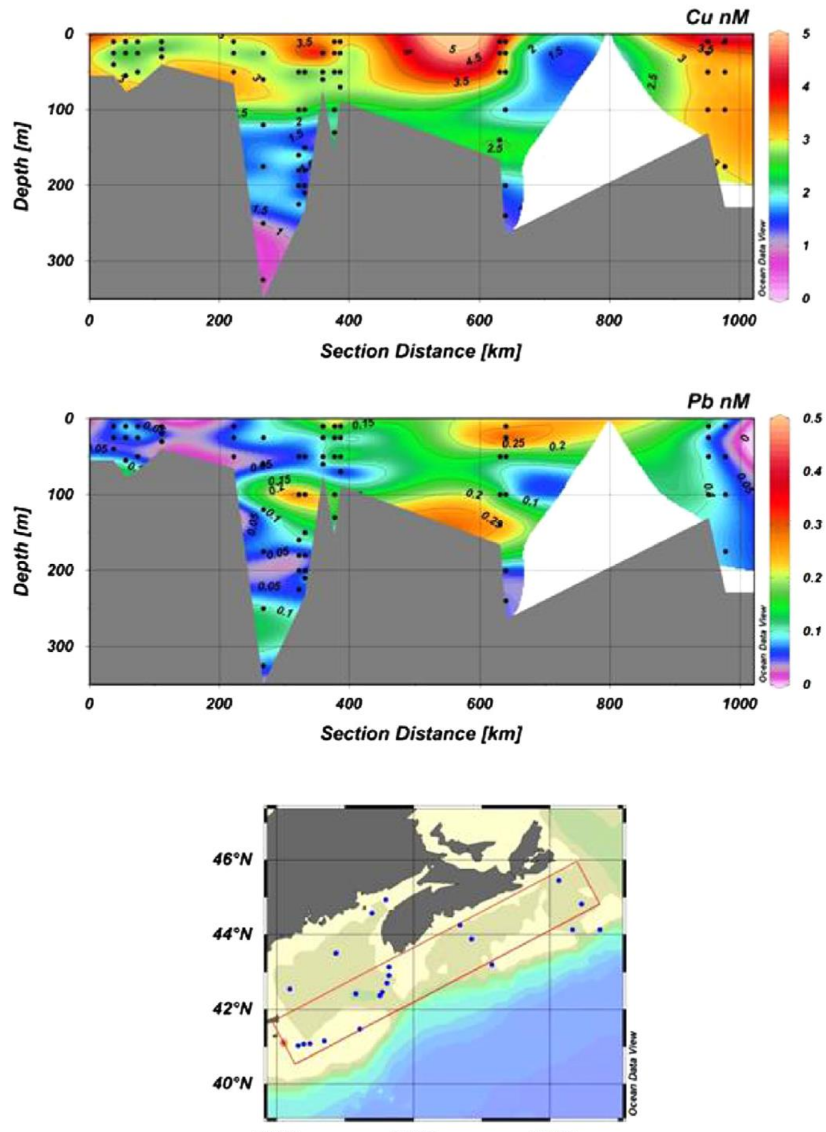

Figure 11. Distribution of dissolved Cu for a section through the Scotian Shelf and Gulf of Maine. Middle panel: Distribution of dissolved Pb for the same section (from Smith et al. 2014).

Apart from environmental monitoring conducted for offshore hydrocarbon production operations, and for chemical oceanography studies, little analysis has been done on trace metals in the waters over the Scotian Shelf. Dissolved metal concentrations of arsenic, cadmium, copper, lead and mercury on the Scotian Shelf, based on three cruises between 1985 and 1997, showed a northeast to southwest gradient but no temporal trends for copper, a metal which is toxic to some plankton species at concentrations only slightly greater than natural levels (DFO 2003). In contrast, levels of lead and zinc have shown a decreasing trend when measured over the same period (Yeats et al. 2008). Metal concentrations observed in the Gully as part of the same monitoring program were the same as in waters of the same origin on the Eastern Scotian Shelf (Yeats et al. 2008).

Trace metal levels in the water column above background and even above CCME guidelines for the protection of marine aquatic life have occasionally been found near offshore hydrocarbon production facilities. Mercury and cadmium are constituents of produced water and are released into the environment when the produced water is discharged. Levels of mercury above the guidelines were found in all water samples within 2 km of the Deep Panuke production facility in the direction of net flow (levels of 0.035 to 0.062 µg/L (2015) and 0.15 to 0.18 µg/L (2016); cadmium levels at several locations up to 2 km from the facility (levels of 0.19 to 0.3 µg/L) were also above the CCME guideline (Encana 2017) while other metals were within background ranges. Levels of selected metals were low around the Thebaud platform of the SOE Project east of Sable Island in 2009. Nickel, copper, iron and manganese were chosen as indicators of water originating in produced water, but were observed to be at background levels (Niu et al. 2010).

5.1.3. Organic Contaminants in Water – Coastal and Nearshore

Few studies were identified which focused on organic contaminants in water in coastal and nearshore areas of the Scotian Shelf. A wide range of pharmaceuticals can be found in sewage released into coastal waters (Metcalfe et al. 2003a, 2003b; Brun et al. 2006) and they are subsequently diluted and degraded in receiving waters. Of eight acidic and neutral drugs found in effluents from the Halifax Regional Municipality Mill Cove wastewater treatment facility,[31] which discharges into Bedford Basin, only Ibuprofen and Naproxen, two analgesic and non-steroidal anti-inflamatory drugs, were found in receiving waters near the outfall (Brun et al. 2006). Brun et al. (2006) focused on smaller wastewater treatment facilities in the bioregion thereby excluding larger WWTFs in major population centres; Mill Cove was the only one with marine receiving waters. Other compounds arising in sewage and which have been found in waters of Halifax Harbour include perfumes, which contain nitro and polycyclic musk compounds (Gatermann et al. 1999 from McCullough et al. 2005), including musk ketone, galaxolide, musk xylene, and tonalide. The impact of low levels of these compounds on the marine environment is not known. The Sydney Tar Ponds Remediation Project

[31] Drugs detected in Mill Cove WWTF effluent were Benzafibrate, Carbamazepine, Cyclophosphamide, Diclofenac, Gemfibrozil, Ibuprofen, Indomethacin and Naproxen (Brun et al. 2006).

carried out from 2009-2012 did not detect the organic contaminants PAHs and PCBs in seawater in Sydney Harbour and Northwest Arm (Walker and MacAskill 2014).

5.1.4. Organic Contaminants in Water – Scotian Shelf Offshore

Phenols and alkylphenols—endocrine disrupting chemicals which occur in produced water from oil and gas production facilities (Lee 2005)—were measured in a study of produced water constituents at platforms of one of two offshore projects operating near Sable Island (Niu et al. 2010). Ocean conditions there, and on Sable Island Bank in general, are dispersive, resulting in high dilutions of the produced water discharged from platforms (Niu et al. 2010). Phenols of various kinds were detected in produced water (Table 14) as well as in the ocean where phenol levels of up to 1.8 µg/L were observed in two samples near the Thebaud platform[32]. Nonylphenols were also found in produced water from the Thebaud platform (Table 14) and are occasionally detected in produced water from wells in the Encana Deep Panuke field, including 4n-octylphenol, 4-nonylphenol and 4-nonylphenol monoethoxylate at concentrations up to 226 ng/L (Encana 2017)—which is below the CCME 700 ng/L guideline level for the protection of marine life (Environment Canada 2002). Encana has been monitoring water for the presence of alkylphenols around the Deep Panuke project (annually since 2015) and only detected them in a survey in 2016, when they were present at all sampling stations at concentrations of from 10.6 to 64.1 ng/L, and thus below the CCME Marine Aquatic Life guideline of 700 ng/L (Encana 2017).

Table 14. Phenols in Venture and Thebaud produced water (Niu et al. 2010).

Compound	**Venture (9 July 2009)**	**Thebaud (10 July 2009)**	**Thebaud (13 Aug 2007)**
	µg/L	*µg/L*	*µg/L*
Phenol	7321	119723	102021
o-cresol	1795	71523	2022
m & p-cresol	965	30706	34069
2,6-dimethylphenol	19	2065	3632
2-ethylphenol	80	3230	6488
2,4 & 2,5-dimethylphenol	71	7138	14946
3 & 4-ethylphenol	189	7484	7004
2,3-dimethylphenol	15	686	1248
2-isoproplyphenol	9	716	1597
2-proplyphenol	10	414	923
3 & 4-isopropylphenol	28	1838	4301
2-sec-butylphenol	5	92	240
3 & 4-tert butylphenol	9	373	1000
4-sec-butylphenol	7	254	545
4-isopropyl-3-methylphenol	4	23	54
4-nonylphenol	7	Nd	nd
Total Phenols	**10,530**	**246,265**	**180,893**

32 There is no CCME guideline for phenols in seawater. The guideline for freshwater is 4 µg/L (CCME 1999).

TPHs, volatile organic compounds (BTEX) and PAHs—all of which occur in produced water—rarely have been detected or occur at low levels in the water column near offshore production facilities. Monitoring of water during drilling in the Sable Offshore Energy Project (JWEL 2000, 2003), at the Thebaud production facility (Niu et al. 2010), and in recent monitoring for the Encana Deep Panuke Project (Encana 2017) all have shown mostly non-detects for these substances. However levels of alkanes of 0.4 μg/L near background were measured commonly near the Thebaud platform, ranging from non-detect (below the detection limit of 0.1 μg/L) to 2.8 μg/L (Niu et al. 2010).

Presence of oil on seabirds and other wildlife is an indicator of the extent of solid and liquid phases of hydrocarbons in the oceans. Sampling of seabirds and other animals which die at sea and wash ashore in coastal areas, as well as recovery of oil from beaches, has been an important source of information on the occurrence and sources of various kinds of contaminants. Oiling rates in birds washed ashore on Sable Island—determined from shoreline monitoring studies—have declined since 1993 (Lucas et al. 2012, ExxonMobil 2017). The surveys have been conducted a number of times each year through all seasons to monitor trends in numbers of birds reaching the beach and rates of oiling, as well as to collect samples of hydrocarbons found to allow gas chromatographic identification of source types (Lucas and MacGregor 2006, ExxonMobil 2017). Typically birds have little oil residue on them, and sources of the hydrocarbons were identified as being mainly from crude oil (77.0 percent)[33] and fuel oil (14.9 percent), while 8.1 percent were bilge oil mixtures (Lucas and MacGregor 2006). The proportion resulting from crude oil in the 2006-2009 period was lower (56.9 percent) (Lucas et al. 2012). Tanker operations were the main source of hydrocarbon contamination in the study (tankers are the main source of crude oil discharges) while fuel and bilge oils may be discharged by all vessel and platform types (Lucas and MacGregor 2006).

Low levels of trifluoroacetate (TFA), a highly stable fluorocarbon byproduct of anthropogenic and industrial activities and possibly natural processes such as deep-sea vents, has been measured in the North Atlantic and Sargasso Sea off eastern North America (Scott et al. 2005). Levels were typically 150-175 ng/L in the upper 1000 m and lowest (20 ng/L) in the upper 50 m. Known sources of TFA include thermolysis of perfluorinated chemicals, and atmospheric oxidation of hydrochlorofluorocarbons and hydrofluorocarbons, and fluorotelomer alcohols (Scott et al. 2005).

5.2. BAY OF FUNDY/GULF OF MAINE

5.2.1. Metals in Water – Bay of Fundy/Gulf of Maine Coastal and Nearshore

Apart from measurements of mercury (see Section 6.2.1) no information on metals in water in the environment was identified in the background review. The Gulf of Maine Council on the Marine Environment, Ecosystem Indicators Partnership (ESIP) has been monitoring important embayments representative of major watersheds in the Gulf of

[33] The oiling rate is the percentage of bird corpses found on which some oil was found.

Maine: Passamaqoddy Bay, Musquash Estuary, Outer Saint John Harbour/Saint John River and Chignecto Bay in New Brunswick, and Minas Basin and Annapolis Basin in Nova Scotia (ESIP 2017). Total nitrogen and phosphorus were contaminants indicative of eutrophication in the parameters monitored. The baseline to date (2013-2016) is not sufficient to establish seasonal or regional trends (ESIP 2017).

5.2.2. Organic Contaminants in Water – Bay of Fundy/Gulf of Maine Coastal and Nearshore

No research studies on organic contaminants in seawater in the Bay of Fundy during the period covered by this review were identified, although levels of contaminants in water are occasionally measured and reported for monitoring and baseline studies for industrial projects. Polychlorinated dioxins and furans were detected in seawater at levels of 9.4 pg/L (3.1 to 15.8 pg/L) and 7.5 pg/L (5.1 to 11.6 pg/L, n = 14) respectively in seawater collected off Mispec Point at the mouth of Saint John Harbour in 2006 (Irving Oil 2009). Hydrocarbons including PAHs, BTEX and chlorinated organic compounds and pesticides were not detected in standard laboratory scans done at the time.

5.2.3. Radionuclides in Water – Bay of Fundy/Gulf of Maine Coastal and Nearshore

Levels in seawater of tritium—one of the main radionuclides released from the Point Lepreau Nuclear Generating station—are not elevated in nearshore waters adjacent to the site (Nelson et al. 2007, Énergie NB Power 2015). Levels have been generally at or below the detection limit (approximately 4.0 Bq/L) (Nelson et al. 2001). The main potential sources of tritium to the environment at the site are cooling water and deposition from atmospheric emissions (Nelson et al. 2007).

6.0 CONTAMINANTS IN BIOTA

6.1. SCOTIAN SHELF AND ADJACENT OFFSHORE WATERS

6.1.1. Metals in Biota – Coastal and Nearshore

Metals are natural and ubiquitous in the marine environment of coastal and offshore waters of the Scotian Shelf, reflecting principally the local geology and sediment composition, which in turn influence concentrations in water and are associated with particulate matter and sediments. Contaminant metals reach the ocean in freshwater runoff and atmospheric transport of particulate matter (e.g., dust) and are accumulated by organisms at various levels in the food chain. Although a variety of metals influence marine organisms and have been the subject of studies, mercury and its organic form methyl mercury has been a particular focus of research in the bioregion in response to concentrations which have been increasing in the environment of the region from various sources (Environment Canada 2016). In Nova Scotia, in particular, some coastal areas have elevated concentrations in the environment resulting from historic gold mining, to which marine and estuarine organisms are exposed. Studies of various kinds in the region have been carried out to assess mercury levels in the biota in the bioregion.

Birds: Birds are higher-trophic-level organisms which tend to accumulate contaminants. Measurements of contaminants in seabirds, waterfowl, and raptors have been useful for monitoring contaminant conditions in various habitats, different trophic levels, and as indicators of contaminant sources. Environment Canada has a long-standing program of monitoring metals and persistent organic contaminants in seabird eggs in the Atlantic Region, which includes the bioregion (Elliott et al. 1992, Gebbink et al. 2011, Chen et al. 2012). Aquatic birds and raptors acquire contaminants principally through their food, which they obtain while pursuing a complex lifestyle which exposes them to different types and trophic position of food species, varied feeding locations, and different seasonal feeding patterns, in different coastal and offshore environments, etc., all of which influence contaminant concentrations, regional variation, and composition. Mercury and methyl mercury concentrations in seabirds, because of the potential toxic effects and rising levels in the environment at least until the early 2000s, have been a focus of studies on seabirds in the bioregion, most of which have focused on birds in colonies in the Gulf of Maine and Bay of Fundy (Elliott et al. 1992, Fox et al. 2007, Goodale et al. 2008, Bond and Diamond 2009, Braune and Noble 2009,) but include coastal areas of Nova Scotia (Pollet et al. 2017, Hedd et al. 2018).

In coastal areas of the Scotian Shelf, Leach's Storm-petrel—a species which occurs and breeds in the bioregion—has elevated levels of mercury which are near levels which could result in physiological harm (Goodale et al. 2008, Pollet et al. 2017). The mercury levels are thought to be due to naturally-elevated levels in fish on which it feeds far offshore (Hedd et al. 2018).[34] Despite elevated mercury levels, however, petrels studied on Bon Portage Island off the southwest coast of Nova Scotia from 2011 to 2015 (Pollet et al. 2017) didn't show effects on important physiological indicators including date of egg-laying, egg volume, nestling growth rate, hatching success, fledging success, or the rate of successful returns to the colonies after long offshore foraging excursions (Pollet et al. 2017).

Common Loon (*Gavia immer)* breeds on lakes throughout Canada but outside breeding season its range includes marine and estuarine coastal areas throughout the bioregion. During breeding the species is exposed to various metals through a primarily fish diet—in particular mercury and methyl mercury which is frequently found at elevated

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[34] During breeding and egg incubation, Leach's Storm-petrels feed principally far from their colonies in Newfoundland, Nova Scotia and the Gulf of Maine, in areas along the continental shelf edge and slope, where the main prey is lanternfish (Myctophidae) (Goodale et al. 2008, Hedd et al. 2018). The Hedd et al. (2018) study used novel global location sensor (GLS) tag technology for the first time to demonstrate precisely the feeding movements of birds from colonies in Newfoundland, Nova Scotia and the Gulf of Maine to offshore areas. Myctophids have elevated mercury levels compared with other fish (Monteiro et al. 1996 from Hedd et al. 2018) to which elevated levels observed in colonies has been attributed (Goodale et al. 2008), but the connection between the diet and the levels observed in birds and eggs needs to be further investigated (Hedd et al. 2018).

concentrations in freshwater fish (Burgess et al. 1998, 2005; Environment Canada 2016). Mean blood mercury concentrations in Kejimkujik loons are the highest found in breeding Common Loons across North America (Burgess et al. 1998, 2005), attributed to high levels in food to which adults are exposed during breeding (Burgess et al. 2005).[35] The results came from surveys in 1995-1997 for mercury, selenium, lead and organic contaminant concentrations of loons from several Halifax area lakes and 24 lakes in Kejimkujik National Park in southwestern Nova Scotia, as well as in coastal areas of New Brunswick (24 lakes in the Lepreau area and one in Fundy National Park) (Burgess et al. 2005). Of adult loons at Kejimkujik, 92% had blood mercury levels >4 μg/g (wet weight), levels which could cause physiological impairment (Burgess et al. 2005). In contrast to mercury, lead and selenium levels in blood of common loons sampled in 1995 and 1996 were low compared to other areas of North America and not physiologically threatening (Burgess et al. 2005).

<u>Invertebrates</u>: Trace metal levels in invertebrates in coastal areas of the Scotian Shelf are low, generally near background levels, except in areas which have industrial development (e.g., harbours) and areas which have anthropogenic sources (e.g., former gold mining areas). Blue Mussels frequently are used to monitor metal levels in the environment, because of their common occurrence and relatively easy access for sampling.[36]

Levels of various metals in mussels from the nearshore commercial harvest are low (Table 15)[37] and comparable to levels found in mussels in isolated locations such as New Harbour on the Eastern Shore of Nova Scotia, used as a reference site in a study of mercury contamination (Doe et al. 2017) and in the Bay of Fundy/Gulf of Maine where remote sites are used in the Gulfwatch monitoring program (LeBlanc et al. 2011) (Section 6.2.1). The one Gulfwatch site along the Atlantic coast of Nova Scotia (Barrington Passage) has among the lowest levels in mussels of all metals monitored (Figure 12). Levels in mussels in industrialized areas of the Atlantic coast of Nova Scotia tend to be higher than in undeveloped and pristine areas. As they are for sediments, levels of tributyltin in blue mussels are elevated in Halifax Harbour compared to a reference site in Chezzetcook Inlet, Nova Scotia (six sites, mean (SD) = 2.9 (1.2), range = 1.4 to 4.8 1-3 ng/g tin wet weight) versus no detectable tributyltin (TBT) at the reference site (Carter et al. 2004). Chau et al. (1997) also found elevated levels of tributyltin in Halifax Harbour mussels but levels were an order of magnitude higher (143-1198 ng/g tin dry weight) than in the Carter et al. (2004) study. Levels of tributyltin in mussels in Saint John Harbour, New Brunswick were lower than Halifax Harbour, ranging from 20-76 ng/g tin dry weight in the same 1997 study (Chau et al. 1997). The presence of tin can also lead to imposex and modeling of expected water

[35] Most of the mercury in loon blood is typically in the methyl mercury form (Burgess et al. 2005, Environment Canada 2016).

[36] Another closely-related mussel, *M. trossulus,* which is quite similar in appearance, occurs in populations which are interspersed through the region, and may have been confused with *M. edulis* in some of the studies.

[37] Location of purchase of mussels may not indicate local origin.

concentrations of tin arising from sewage (Hellou et al. 2003) gave concentrations in seawater of about 0.8 ng/L along the Halifax waterfront, high enough to also be a potential imposex cause (Hellou et al. 2003). TBT also has other industrial uses and is released to the aquatic environment through municipal sewage particularly when sewage treatment is lacking (Fent 1996 from Coray and Bard 2007).

Table 15. Total metals in mussels collected from Thebaud platform and Halifax grocery for comparison in 2010 (ExxonMobil 2011).

Metals	**Units**	**RDL**	**Thebaud Platform**	**Halifax Grocery**[a]
Aluminum (Al)	mg/kg	2.5	<2.5	8.5
Antimony (Sb)	mg/kg	0.50	<0.50	<0.50
Arsenic (As)	mg/kg	0.50	0.64	1.24
Barium (Ba)	mg/kg	1.5	<1.5	<1.5
Beryllium (Be)	mg/kg	0.50	<0.50	<0.50
Boron (B)	mg/kg	1.5	4.9	4.5
Cadmium (Cd)	mg/kg	0.050	0.581	0.209
Chromium (Cr)	mg/kg	0.50	<0.50	<0.50
Cobalt (Co)	mg/kg	0.20	<0.20	<0.20
Copper (Cu)	mg/kg	0.50	0.64	1.03
Iron (Fe)	mg/kg	15	<15	35
Lead (Pb)	mg/kg	0.18	<0.18	<0.18
Lithium (Li)	mg/kg	0.50	<0.50	<0.50
Manganese (Mn)	mg/kg	0.50	0.76	1.85
Mercury (Hg)	mg/kg	0.01	<0.01	0.01
Molybdenum (Mo)	mg/kg	0.50	<0.50	<0.50
Nickel (Ni)	mg/kg	0.50	<0.50	<0.50
Selenium (Se)	mg/kg	0.50	<0.50	0.56
Silver (Ag)	mg/kg	0.12	<0.12	<0.12
Strontium (Sr)	mg/kg	1.5	9.7	6.0
Thallium (Tl)	mg/kg	0.020	<0.020	<0.020
Tin (Sn)	mg/kg	0.50	<0.50	<0.50
Uranium (U)	mg/kg	0.020	<0.020	<0.020
Vanadium (V)	mg/kg	0.50	<0.50	<0.50
Zinc (Zn)	mg/kg	1.5	9.3	13.2

a. Sobeys.

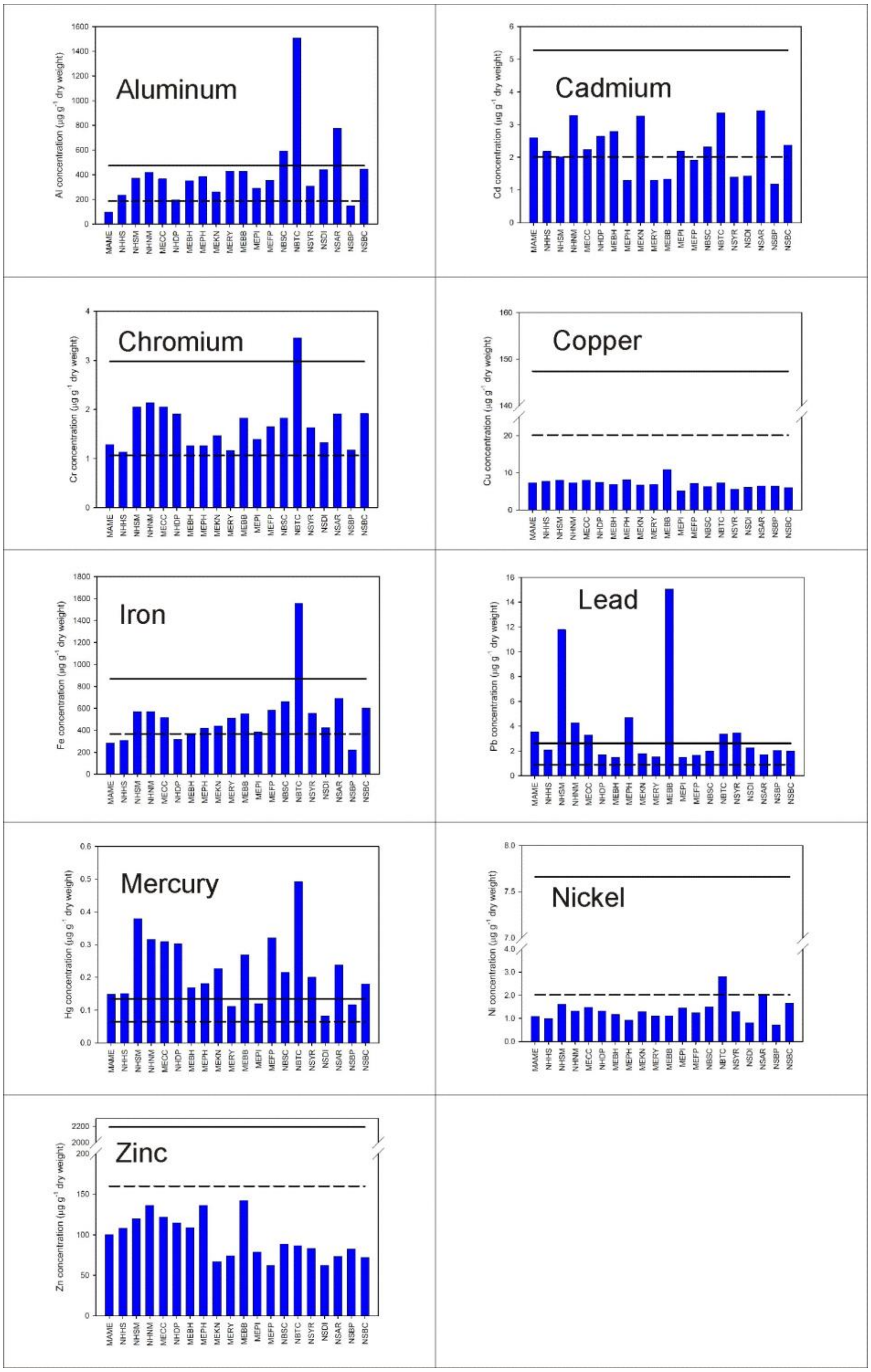

Figure 12. Distribution of metal contaminant concentrations in mussel tissues at Gulfwatch sites in 2009. Dashed line = Median level observed 2008 in U.S. National Status and Trends Program in 2008; Solid line = 85th percentile. New Brunswick and Nova Scotia sites are shown as the seven bars on the right: NBSC= St. Croix Estuary; NBTC=Tin Can Beach (Saint John Harbour); NSYR=Yarmouth; NSDI=Digby Island; NSAR=Apple River; NSBP= Barrington Passage; NSBC=Broad Cove.

Elevated tributyltin levels in several coastal areas of the bioregion are suspected to have been the cause of the occurrence of imposex—the condition of male sexual characteristics superimposed on female ones in Dogwhelks (*Nucella lapillus)* (Prouse 1996, Prouse and Ellis 1997). Prouse and Ellis (1997) found the condition in 100 percent of whelks sampled at Portuguese Cove in Halifax Harbour in 1995. Imposex is the best-known biological effect of tributyltin, and as well is suspected as a factor in the absence of male whelks from parts of the harbour (Prouse and Ellis 1997). Imposex continues to occur in Halifax Harbour: 41.2 percent and 16.6 percent of female Dogwhelks sampled at Tufts Cove and Point Pleasant at the mouth of the harbour in 2008 were affected (Titley-O'Neal et al. 2011b). Although tributyltin was not detected, dibutyltin concentration in whelk tissues at Tufts Cove was 3.84 ng/g tin dry weight. Levels of tributyltin and dibutyltin (DBT) in tissues of whelks were in the mid-range compared with Saint John and Sydney harbours (levels of 18 and 26 ng/g wet weight for TBT and DBT respectively) (Prouse and Ellis 1997, Titley-O’Neal et al. 2011b) and had intermediate incidences of the condition (92 percent of females). Coray and Bard (2007) also found imposex occurrences ranging from 19% at the mouth of Halifax Harbour to 100% in mid-harbour, while dogwhelks from reference sites outside the harbour yielded no cases of imposex. TBT also induces intersex, another reproductive condition, in periwinkles (*Littorina littorea*) which had a gradient of occurrences ranging from no cases outside Halifax Harbour to 100% occurrence at the harbour head (Coray and Bard 2007).

Several biomarkers which can be used to monitor impacts of environmental contaminant metals on Blue Mussels, including vitellin-like proteins,[38] metallothioneins, labile zinc and lipid peroxidation levels, as well as condition index, did not correlate with tissue metal concentrations or vary significantly between several Halifax Harbour areas sampled (four sites on the Dartmouth side of Halifax Inlet: Bedford Yacht Club, Dartmouth Cove, downtown Dartmouth, and the Bedford Institute of Oceanography) (Carter et al. 2004). Vitellin-like proteins are indicators of potential endocrine disruption and changes in condition index, while metallothioneins, labile zinc levels and lipid peroxidation levels can indicate exposure to contaminants (Carter et al. 2004). In the same study, concentrations of metals in mussels at six locations in Halifax Harbour (Bedford Yacht Club, Dartmouth waterfront, Dartmouth Cove, Bedford Institute of Oceanography and two sites at container piers) were mostly not elevated over those in reference mussels from Chezzetcook Inlet, but levels of zinc were higher and manganese levels were lower (Carter et al. 2004) (Table A3). These levels were comparable to those reported by Yeats et al. (2008) for Halifax Inlet.

Levels of contaminant metals in biota in Sydney Harbour, while elevated over baseline levels in the decades after closure of the Sydney Steel mill (Stewart and White 2001), have largely been decreasing. Between 2009 and 2012, Rock Crab and Blue Mussels in Sydney Harbour were shown to have low levels of contaminant metals (Walker et al. 2013c, 2013d; Walker and MacAskill 2014). Levels of metals in the hepatopancreas of Rock Crab (*Cancer irroratus*) in South Arm of Sydney Harbour in 2009-2012 were comparable to or below levels measured in that species in other areas (Walker et al. 2013c). Some contaminant metal concentrations (arsenic, cadmium and copper) were

[38] Vitellogenin is a protein used in egg formation.

highest at reference sites in Northwest Arm, at a location furthest from the most contaminated parts of the harbour (South Arm and the outlet of Muggah Creek) (Walker et al. 2013c) (Table A3). Overall, even the highest cadmium and copper levels were 2-8 times lower than those reported by Chou et al. (2002) in Rock Crabs analyzed from natural settings in the Bay of Fundy (Walker et al. 2013c). Some arsenic levels found in these crabs, while likely arising naturally and not through exposure to industrial contamination, exceeded the CFIA guideline for food consumption (0.5 µg/g) (Walker et al. 2013c). Comparing current contaminant burdens measured in Rock Crabs in Sydney Harbour with levels in other industrial harbours from the literature, Walker et al. (2013c) determined that Sydney Harbour levels in the 2009-2012 period were significantly lower.

Concentrations of major contaminants in natural populations of mussels—both Blue Mussels and Horse Mussels (*Modiolus modiolus*)—in Sydney Harbour were relatively high when last sampled in 1995 (Ernst et al. 1999) but have not been evaluated since. Caged Blue Mussels deployed during the Sydney Tar Ponds remediation project (Walker et al. 2013d, Walker and MacAskill 2014) have shown levels of metals and organic contaminants to be lower than those in other uncontaminated coastal areas (e.g., by the Gulfwatch Program) (Walker and MacAskill 2014) (Table A3).

Tributyltin concentrations in Dogwhelks (*Nucella lapillus*) sampled in Sydney Harbour in 1995 were from 74-75 ng/g wet weight (compared to dibutyltin levels of 58 ng/g wet weight)—the highest of the three major harbours in the bioregion (the others were Halifax and Saint John Harbours) and resulted in all female whelks showing the imposex condition (Prouse and Ellis 1997). No whelks were found in 2008 in a study to reassess the occurrence of imposex in the harbour (Titley-O'Neal et al. 2011b).

Mussels, softshell clams, periwinkles and seaweeds in intertidal areas in the vicinity of some former gold mining areas have elevated levels of arsenic and mercury compared to those from control areas and the commercial harvest (Koch et al. 2007, Doe et al. 2017). Clams in Seal Harbour, Nova Scotia, a small coastal inlet outside the mouth of Country Harbour and which was heavily contaminated with arsenic and mercury through previous gold mining activity, had high levels of arsenic in 2004 (160 [67.2-309] mg/kg wet weight [n=10]) and 2005 (50.0 [9.1-259]) mg/kg wet weight) (Doe et al. 2017) and 218 to 228 ppm wet weight (Koch et al. 2007). Arsenic was mostly present in the more toxic, inorganic form (Koch et al. 2007, Doe et al. 2017). Even the lowest arsenic levels observed in less contaminated areas of Seal Harbour were higher than at a reference location (New Harbour, 1.62 mg/kg wet weight) (Doe et al. 2017). Mercury levels in the same clams of 0.10 mg/kg (range 0.07-0.15 mg/kg wet weight) were less significantly elevated than for arsenic (Doe et al. 2017). Clams from Seal Harbour have been judged unsuitable for human or animal consumption in human health and ecological risk assessments based on arsenic and mercury levels, and a shellfish harvesting closure at the mouth of West Brook has been instituted for clams and mussels by DFO (Doe et al. 2017).

Blue Mussels showed a similar spatial pattern to softshell clams in metal concentrations in areas contaminated by former gold mining activities. Levels of arsenic and mercury in intertidal mussels from Seal Harbour were elevated in a study conducted by

Environment Canada (Doe et al. 2017). Arsenic levels in tissues were 6.3 (4.6-7.9) (n=8) mg/kg wet weight compared with 1.76 mg/kg at a reference site (New Harbour); and mercury levels were in the range of 0.07-0.10 mg/kg wet weight compared with reference evels of 0.07 mg/kg at the reference site (Doe et al. 2017). Arsenic levels of 34 to 109 µg/g dry weight (approximated as 5.1 to 16.3 µg/g wet weight)[39] have also been measured in blue mussels from Seal Harbour (Whaley-Martin et al. 2012).

Mussels and softshell clams from former gold mining areas other than Seal Harbour typically have arsenic and mercury levels which are lower than Seal Harbour but elevated above reference levels (Doe et al. 2017). Levels of arsenic in Softshell Clams in these areas ranged from 1.85 to 45.8 mg/kg wet weight and mercury ranged from <0.05 to 0.11 versus reference levels of 1.62 and 0.05 mg/kg wet weight respectively (Doe et al. 2017). Similarly, in Blue Mussels, arsenic concentrations ranged from 1.82 to 10.6 mg/kg wet weight and mercury from <0.05 to 0.14 mg/kg wet weight versus reference levels of 1.76 and 0.07 respectively.(Doe et al. 2017). The high arsenic level in Blue Mussels (10.6 mg/kg) found at Gold River southwest of Halifax, where environmental contamination with the metal was unexpected, highlights regional variation. Mussels at other former gold mining sites extending from Wine Harbour to Gold River would be acceptable for human consumption according to available food quality standards for arsenic and mercury, and tissue concentrations were mid-range of levels reported in the literature (Doe et al. 2017). Arsenic and mercury levels from mussels in Isaacs and Country Harbours (1.3 to 2 µg/g wet weight and 0.02 to 0.05 µg/g respectively) (Walker and Grant 2015), however, are comparable to reference levels reported in Doe et al. (2017).

Periwinkles (*Littorina littorea)* in Seal Harbour had high levels of arsenic (13 to 190 mg/kg wet weight) (higher than any previously reported in the literature and also consisting of a high proportion of inorganic arsenic) (Whaley-Martin et al. 2013) and would pose a risk for wildlife consumers. Similarly, intertidal seaweed (*Fucus* sp.) in Seal Harbour contained high levels of arsenic (27 to 43 mg/kg wet weight) and a high fraction of the inorganic form of arsenic (Koch et al. 2007). Remediation of the source areas of the contamination (e.g., tailings deposits from gold mines located upstream) have occasionally been undertaken; however large-scale remediation activities would only likely occur in a coastal area if there were an imminent threat to wildlife species at risk or if the area had conservation significance (e.g., a wildlife management area).

6.1.2. Metals in Biota – Scotian Shelf Offshore

Information on levels of metals in organisms in offshore areas of the Scotian Shelf has been obtained through oceanographic research in support of fisheries, to support management needs of specific areas (such as the Gully Marine Protected Area on the Scotian Shelf), to monitor food quality of fishery species, and to test predictions of

[39] Assuming a wet weight to dry weight conversion factor of 6.7 (McCullough et al. 2005). Other wet weight to dry weight concentration ratios from Nova Scotia studies: Softshell clams 7.3-7.5 (Doe et al. 2017), Blue Mussels 5 (Yeats et al. 2008) and 6 (Hellou et al. 2000). Other wet to dry weight conversions are presented in Mo and Neilson (1992, 1994) and Ricciardi and Bourget (1998).

impacts of offshore activities, principally offshore hydrocarbon exploration and development.

Birds: Little information is available on metal concentrations in seabirds in offshore areas of the bioregion, although concentrations measured in various species in coastal and inshore areas where they must come ashore to breed (see Section 6.2.1) reflect their exposure to contaminants which they encounter over their overall, sometimes broad, annual and seasonal ranges. Leach's Storm-petrel, a species which nests on islands throughout the bioregion, feeds in deep water past the edge of the continental shelf where its primary food source, myctophid fish, have naturally elevated mercury levels and are suspected of causing elevated levels found in the petrels sampled at coastal colonies (Pollet et al. 2017, Hedd et al. 2018). Levels of mercury and methyl mercury in eggs and blood of juveniles and adults sampled on Bon Portage Island are similar to those observed in the species at sites in the Gulf of Maine and outer Bay of Fundy (Goodale et al. 2008, Bond and Diamond 2009) and are elevated compared with a range of other common seabirds which occur in those areas (Goodale et al. 2008, Pollet et al. 2017), as well as to levels observed globally (Pollet et al. 2017).

Fish and Invertebrates: Overall, little recent information is available on metal levels in fish and invertebrate species on the Scotian Shelf. Scientific interest in metal concentrations, in part in response to food contamination concerns associated with mercury in certain commercial fisheries species, led to studies in the 1970s and 1980s which established levels for some species (reviewed in Stewart and White 2001). In general, metal levels in most fish at the time were low, except for levels of mercury in large fish having long life spans such as swordfish, tuna, sharks, dogfish, large halibut and larger offshore lobsters (Zitco 1981 from Stewart and White 2001). Subsequently, levels of metals and other contaminants have been monitored in the commercial catch and at the market by Health Canada and the CFIA, and by industry in obtaining approvals for international shipments. Information obtained by industry is proprietary and Health Canada and CFIA do not routinely report levels, or do so in such a way that localized information (e.g., the Scotian Shelf) is not available. For mercury, a contaminant of particular concern for human consumption, levels in a variety of fish species in commercial markets (including local species such as flounder, Haddock, White Hake, Atlantic Herring, Atlantic Mackerel, Monkfish and American Lobster) typically had total mercury levels below 0.2 ppm wet weight. Other locally fished species had levels between 0.2 ppm and the guideline level of 0.5 ppm (Health Canada 2007).

Blue Mussels growing in the offshore have been used to monitor impacts of hydrocarbon production operations. Mussels growing on the Thebaud platform had similar trace metal levels to mussels from the nearshore commercial harvest (ExxonMobil 2017) (Table 15).

Low levels of trace metals were found in krill (*Meganyctiphanes norvegica*) sampled in the Gully and Emerald Basin between 2004 and 2006 (Yeats et al. 2008). Detectable levels of the heavy metals chromium, copper, lead and zinc, as well as iron and tin were comparable to those found in the Barents and Greenland seas (Yeats et al. 2008) (Table A3). Low levels of metals, such as are found in oceanic zooplankton, are not likely to pose a high risk to higher levels in the food chain (e.g., whales and seabirds); however, limited information is available to properly carry out risk assessments in this part of the bioregion.

6.1.3. Organic Contaminants in Biota – Coastal and Nearshore

Birds, marine mammals, invertebrates and fish in coastal areas of the Scotian Shelf are exposed to organic contaminants throughout their lives at varying levels depending on their ranges and foraging patterns. Assessments of organic contaminant levels in the biota in coastal and nearshore areas have focused largely on invertebrates and fish in the commercial catch, and little information is available locally on levels in other organism groups which occur in nearshore areas.

<u>Birds:</u> Persistent organic compounds including PCBs and pesticides have been detected in Common Loons breeding on Nova Scotia lakes (Burgess et al. 2005). The species spends part of its life cycle in coastal areas of the Scotian Shelf and off northeastern North America where it accumulates pollutants from its fish diet. Loons from lakes in coastal areas of Nova Scotia sampled in 1995 (24 lakes in Kejimkujik National Park and several lakes in the Halifax area) had measureable blood levels of PCBs, DDT breakdown products (DDE and DDD), oxychlordane, trans-nonachlor, mirex and hexachlorobenzene (Burgess et al. 2005). Kejimkujik loons had the highest levels of PCBs, DDE, oxychlordane, trans-nonachlor, mirex and hexachlorobenzene compared with loons breeding in lakes near Halifax or in the Lepreau area of New Brunswick, with PCBs and DDE predominating. Levels were on the low end of the range reported for other large birds (e.g., Bald Eagle) for which similar contaminant information was available (Burgess et al. 2005).

Tree Swallow nestlings sampled near Sydney Harbour, Cape Breton in the bioregion had detectable levels of PCBs, organochlorine pesticides, dioxins, furans and metals, but which were below levels in birds from the Great Lakes and St. Lawrence and Hudson Rivers or would cause reproductive impairment (Burgess et al. 2000).

<u>Invertebrates</u>: Readily accessible intertidal or shallow water invertebrates such as mussels, crabs, whelks, and lobster have been used to assess accumulation and effects of contaminants in coastal areas. Physiological measures in mussels and other organisms in Halifax Harbour and other industrialized harbours in the bioregion have shown that contaminant levels from various sources and in different combinations, sometimes at extremely low levels, subtly influence biological processes, but the relationship is sometimes complex. An example is the influence of tributyltin, an organometallic compound and a well-known endocrine disruptor worldwide which occurs in sediments and biota in Halifax Harbour (see Section 6.1.1). A similar effect is feminization and a study of lobster from Halifax Harbour showed egg precursors in male reproductive organs (Sangalang and Jones 1997), suggesting the presence of organic contaminants—in particular hormones—capable of endocrine disruption in invertebrates (Robinson et al. 2009). Physiological effects however, such as abnormal patterns of biological compounds involved in reproduction of mussels which would have suggested an endocrine disrupting effect of sewage and tributyltin (e.g., vitellogenin in egg

production), have not been found in the harbour (Hellou et al. 2003, Carter et al. 2004). Various human hormones are found in sewage and have the potential to be spread widely with water movements. The presence of sewage markers—silver and the human cholesterol breakdown product coprastanol— have been detected widely in the harbour after arising from the main source area on the Halifax waterfront (Hellou et al. 2002). Presence of coprastanol and silver in mussels from the outer harbour and Northwest Arm confirms exposure to sewage effluent (Hellou et al. 2002).

Nitro- and polycyclic musk compounds found in perfume (Gatermann et al. 1999, from McCullough et al. 2005), including musk ketone, galaxolide, musk xylene, and tonalide, have been found in marine biota from Halifax Harbour. Nitro- and polycyclic musks predominated in softshell clams and mussels from the harbour, which also had relatively high concentrations of musk ketone, and galaxolide (Gatermann et al. 1999, from McCullough et al. 2005), with elevated musk ketone levels likely due to exposure to levels of the same compound in water. Musk xylene and musk ketone also have been detected in fish oil from a pollock caught in the Halifax area but not in several other species tested (Gatermann et al. 1999, from McCullough et al. 2005). This study also detected many of these compounds in sewage and waters of Halifax Harbour, showing there could be transfer to fish, a high level of the food chain. The overall effect of the compounds on fish has not been investigated.

Blue mussels growing on the Halifax waterfront in the early 2000s, where there were influences of combined raw sewage outfalls and a naval dockyard, differ from those some distance away in having a high female-to-male sex ratio (~2:1), a higher lipid content in males, and delayed production of vitellins in females (Hellou et al. 2003). Higher levels of PACs, coprastanol, and the metals silver and tin in these mussels compared to other areas of the harbour indicated exposure to sewage and/or water contaminated by naval and other port-related activities (Hellou et al. 2003).[40] Mussels in other areas of the harbour, however, didn't show a response in terms of concentration of vitellin-like proteins which could be related to tissue burden of tributyltin (Carter et al. 2004). Two human hormones and the organic endrocrine-disrupting compound Bisphenol A (BPA), also associated with municipal sewage, have also been found in water and sediment throughout Halifax Harbour and Bedford Basin and in municipal sewage (Robinson et al. 2009).[41] The natural human hormone 17-beta-estradiol excreted by humans of both sexes, as well as the synthetic 17-alpha-ethinylestradiol (a pharmaceutical and the active ingredient in oral contraceptives) and Bisphenol A, which all have feminizing effects on organisms, all occurred at concentrations which potentially could affect organisms (Robinson et al. 2009, Robinson and Hellou 2009). Levels of the three compounds consistently ranked as BPA > estradiol > ethinylestradiol. BPA reached 2.6 ng/L in seawater and 9.5 ng/g in sediments, the natural estradiol was at

[40] Improvements to sewage treatment in Halifax Harbour after these studies were conducted have changed the distribution and level of treatment of sewage releases and dilutions experienced in the marine environment, and recent patterns of these compounds have not been determined.

[41] This study was carried out after a new wastewater treatment facility was installed on the Halifax waterfront in 2007.

levels up to 0.57 ng/L and 0.86 ng/g, and the synthetic ethinylestradiol was at low levels, usually below the method detection limit (0.14 ng/L and 0.28 ng/g) respectively. The three compounds were also present, but at higher levels in municipal sewage, both pre- and post-treatment (Robinson and Hellou 2009). All three degrade in the environment and are reduced in concentration by sewage treatment (Robinson and Hellou 2009).

Coray et al. (2007) used measurements of the immune response of mussels (*M. edulis* and *M. trossulus*) from Halifax Harbour as indicators of the influence of contaminants found in municipal effluents in the harbour. Measurements showed that contaminant conditions in waters at the sites tested were seriously impaired compared to a reference site which was not influenced by municipal effluents. Of measures tested, including phagocytic activity, cellular production of hydrogen peroxide, number of circulating haemocytes, and cellular viability, two—a reduced phagocytic activity and reduced production of hydrogen peroxide—indicated an influence of contamination in the harbour (Coray et al. 2007). Survival time in air of mussels (*M. edulis* and *M. trossulus*) from Halifax Harbour was lower in mussels with higher tissue burdens of PAHs, indicating a response to stress from contaminants (Hellou and Law 2003).

Intertidal Blue Mussels in Halifax Harbour pick up and accumulate contaminants such as PCBs from water and particles they ingest. A wide range of PCBs have been manufactured and occur in the environment, even though they are no longer produced in Canada. Mussels growing in Halifax Harbour tested throughout the year had measurable tissue levels of 10-16 PCB congeners (Hellou et al. 2002a). Levels of the more abundant and most bioaccumulative PCB compounds, IUPAC #138 and #153, reached 20 and 25.5 ng/g dry weight, respectively—in the lower range of levels reported in a study of Atlantic and Pacific coasts of the United States (Hellou et al. 2002a) but near the median of the U.S. National Standards and Trends Program Mussel Watch of 29.2 ng/g for total PCBs in 2009 (LeBlanc et al. 2011). Highest levels of these two groups of compounds are above levels of total PCBs observed in several of the Gulfwatch mussel monitoring sites in New Brunswick and Nova Scotia in the bioregion (LeBlanc et al. 2011) (Figure 13).

Levels of PAHs in mussels in Halifax Inlet in the late 1990s reached particularly high levels at some sites and times in the central part of the harbour and also were highly variable (Hellou et al. 2000). Total PAH (31 PAH compounds) measured at 18 sites in Halifax Harbour, harbour mouth and Northwest Arm were moderately high, typically ranging from non-detectable to below about 200 ng/g wet weight, with occasional extreme values in the range of 500 to 1300 ng/g wet weight (Hellou et al. 2000). Average concentrations for total PAH were 155 ng/g wet weight (range 40-530, November 1997), 229 µg/g wet weight (April 1999) and ranged from 259-314 ng/g wet weight in July 1999), some of which exceeded recent 85th percentile levels for the U.S. National Status and Trends Program indicating levels of concern (Hellou et al. 2000, LeBlanc et al. 2011). Fluoranthene was the predominant PAH followed by pyrene and phenanthrene, and the mix of PAHs indicated that PAHs derived from combustion sources predominated throughout the harbour but petroleum sources were inferred from one site (near Tufts Cove) because low molecular weight alkylated PAHs were detected there (Hellou et al. 2000).

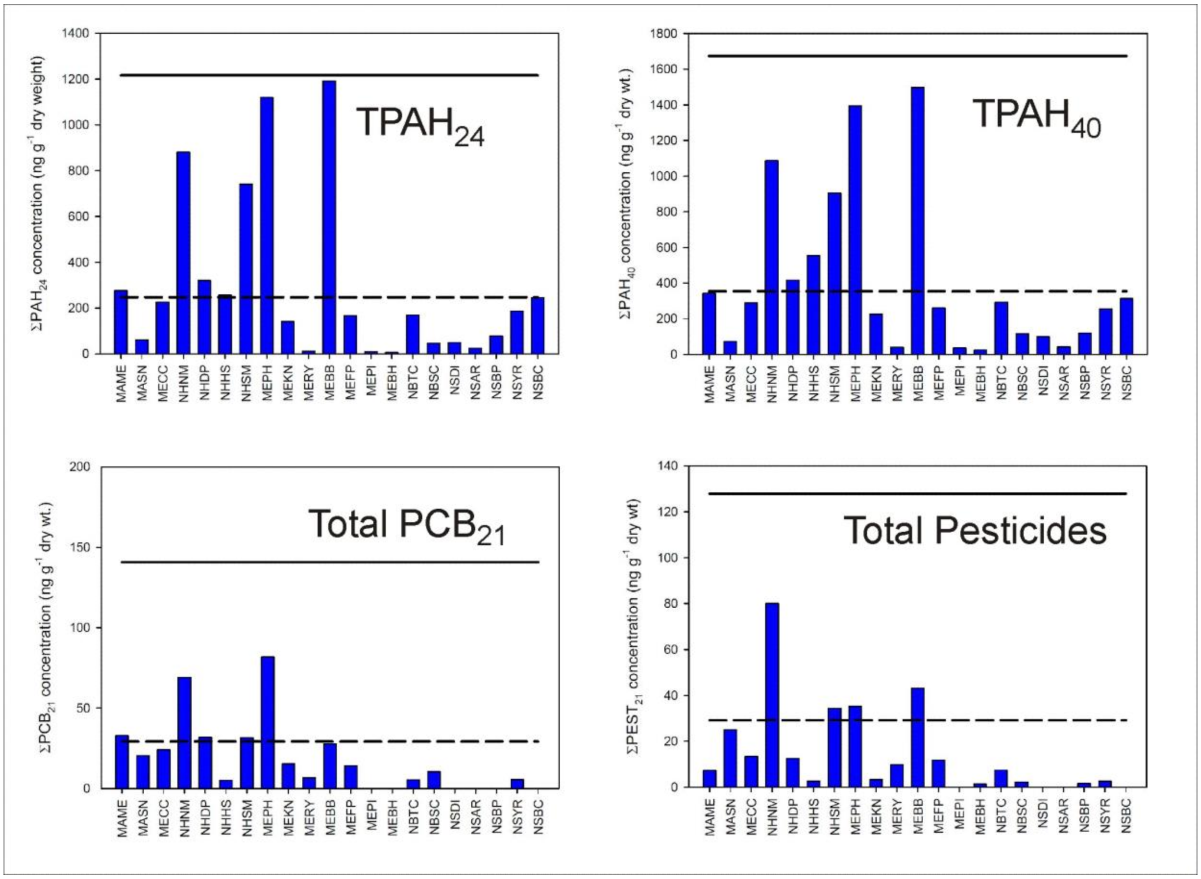

Figure 13. Distribution of organic contaminant concentrations in mussel tissues at Gulfwatch sites in 2009. Dashed line = Median level observed 2008 in U.S. National Status and Trends Program in 2008; Solid line = 85th percentile. New Brunswick and Nova Scotia sites are shown as the seven bars on the right: NBSC= St. Croix Estuary; NBTC=Tin Can Beach (Saint John Harbour); NSYR=Yarmouth; NSDI=Digby Island; NSAR=Apple River; NSBP= Barrington Passage; NSBC=Broad Cove.

High levels of PAHs in lobster in Sydney Harbour in the early 1980s triggered investigations which later led to a clean-up of sources including the Sydney Tar Ponds (Stewart and White 2001, Griffiths et al. 2006). Levels of contaminants in biota in Sydney Harbour, while showing contamination in the decades after closure of the Sydney Steel mill (Stewart and White 2001), have largely been decreasing. Organic contaminants measurements made between 2009 and 2012 in Rock Crab and Blue Mussels in Sydney Harbour in a baseline and operational monitoring program for the Sydney Tar Ponds Clean-up, showed low levels of organic contaminants (PAHs and PCBs) (Walker et al. 2013c, 2013d; Walker and MacAskill 2014). Low levels of PCBs and metals were measured, although PAHs were mostly undetected in the hepatopancreas of Rock Crab in the South Arm of Sydney Harbour in 2009-2012 (Walker et al. 2013c). PCB levels, while low, peaked in contaminated areas of the harbour (Walker et al. 2013c) (Table A3). PAH concentrations in crab hepatopancreas were below detection (<0.05 µg/g) over the four years, except for one sample in which naphthalene was detected (0.14 µg/g) (Walker et al. 2013c). In Blue Mussels, individual PAH compounds were mostly undetectable (detection limit <0.05 µg/g), except for fluoranthene and pyrene and occasional detections of six other compounds. PCBs were generally not detected in mussels but measured levels of 0.05-0.07 µg/g were well below CFIA guidelines of 2 µg/g for chemical contaminants and toxins in fish and fish products (Walker and MacAskill 2014).

Hydrocarbon levels were low in mussels from the nearshore commercial harvest (Table 16) (ExxonMobil 2011), which were sampled to provide information on background levels in a monitoring program using mussels as a biomonitor for offshore hydrocabon production activities. PAHs as well as nonylphenols and their ethoxylates have also been monitored in mussels from the commercial market and have been found to occur at low levels (Encana 2017) (Table 17).

No dioxins or furans were detected in Rock Crab tissues in the vicinity of the Stora Pulp and Paper Mill in the Strait of Canso in 1994-1995 in environmental effects monitoring carried out under the Canadian Pulp and Paper Regulations (Parker and Smith 1999).

Table 16. Total petroleum hydrocarbon concentrations (mg/kg dry weight, C_{10}-C_{24}) in pools of mussels from moorings on Sable Island Bank and purchased in the Halifax commercial market, 1998-2010 (JWEL 2002, 2003; ExxonMobil 2011). Range and number of pools are in parentheses.

Time Period	Venture Platform and Vicinity	Thebaud Platform and Vicinity	Halifax Supermarket
Aug.- Oct. 1998	13.83 (8.5-20.5) (6)		
Oct 98-Apr 99	19.70 (8.55-37.7) (11)		
Nov 99-Feb 2000	13.42 (9.51-18.63) (8)	12.70 (6.63-17.62) (4)	
Feb-May 2000	23.22 (14.62-33.57) (13)	22.93 (14.87-34.22)	
Aug-Nov 2000	24.58 (21.26-28.64) (3)	32.39 (2)	
July 2001		25.87(2)	
July 2002		44.54[a]	11.4
July 2003	10.64 (n=2)		
Oct 2005		20.04[a]	6.61
Sept 2007		14.28[a]	3.36
July 2009		14.73[a]	32.27
July 2010		24.27[a]	17.65

a. Mussels growing on legs of Thebaud platform.

Table 17. PAH and nonylphenols in mussels collected from Deep Panuke platform and Halifax grocery for comparison in 2015 and 2016 (Encana 2017).

Chemical	Units[b]	Year	Production Facilities	Halifax Grocery[a]
PAHs (Individual Priority PAHs and Total)	mg/kg	2015	ND	ND
	mg/kg	2016	ND	ND
4-Nonylphenol	ng/kg	2015	17.5	16.3
	ng/kg	2016	17.0	16.1
4n-Octylphenol	ng/kg	2015	0.59	1.1
	ng/kg	2016	ND	1.25
4-Nonylphenol monoethoxylate	ng/kg	2015	1.28	ND
	ng/kg	2016	ND	ND
4-Nonylphenol diethoxylate	ng/kg	2015	ND	ND
	ng/kg	2016	1.41	1.55

ND = not detected. a. Sobeys. b. Dry weight.

6.1.4. Organic Contaminants in Biota – Scotian Shelf Offshore

Organic compounds continue to occur in the global environment, and are concentrated as they pass through the marine food chain. Of particular concern are those which can bioaccumulate and impact higher vertebrates, such as DDT and its degradation products causing eggshell-thinning in birds, and dioxins which can cause cancer in humans through direct exposure and in food. Many newer chemicals, such as flame retardants (e.g., polybrominated diphenyl ethers, PBDEs) have been released through widespread industrial use and have been shown to follow similar pattens of accumulation. Concern over the presence of the componds is both with ecosystem-trophic effects such as bioaccumulation, as well as the occurrence of levels harmful to humans and wildlife when consumed in food.

Fish: Health Canada, through the CFIA and the fishing industry, regularly test fish and fish products for mercury; organic contaminants 2,3,7,8 TCDD (dioxin), DDT and metabolites; and PCBs. Levels obtained by industry are proprietary and the CFIA does not routinely summarize the information. Occasionally reports are prepared in response to public concern over particular issues. These surveillance reports provide current estimates of the exposure of Canadians to these contaminants and are a valuable tool to improve risk assessments and to develop the appropriate strategies to manage associated risks. In one such special survey of fish and seafood, PCB levels in sampled fish and seafood ranged from 0.3 to to 17.5 ppb (Table 18) and PBDE levels in the sampled fish and seafood products did not exceed 5.5 ppb (Table 19) (CFIA 2002). Farmed salmon contained an average level of 2.2 ppb followed by farmed char (1.0 ppb) (CFIA 2002) (Table 19).

Table 18. Contaminants in retail fish and seafood products: summary statistics for total PCB levels (ppb). Source: CFIA (2002).[a]

Species	Source	N	Mean	Standard Error (%)	Standard Deviation	Minimum	Maximum
Char	Farmed	6	6.5	1.5	3.7	3.5	13.5
	Wild	5	5.4	1.1	2.5	3.1	9.7
Oysters	Farmed	12	1.6	0.6	1.9	0.2	6.7
	Wild	4	0.4	0.03	0.06	0.4	0.5
Salmon	Farmed	19	17.5	2.4	10.6	4.4	45.1
	Wild	3	6.6	3.4	5.9	2.8	13.5
Shrimp	Farmed	13	0.3	0.1	0.5	0.04	2.0
	Wild	4	0.4	0.2	0.5	0.1	1.1

a. This industry survey would include some samples from Scotian Shelf Bioregion.

Table 19. Contaminants in retail fish and seafood products: summary statistics for total PBDE levels (ppb). Source: CFIA (2002).[a]

Species	Source	N	Mean	Standard Error (%)	Standard Deviation	Minimum	Maximum
Char	Farmed	5	1.0	0.4	1.0	0.4	2.7
	Wild	5	0.6	0.1	0.3	0.3	1.1
Oysters	Farmed	11	0.7	0.1	0.5	0.006	1.4
	Wild	4	0.4	0.08	0.2	0.3	0.6
Salmon	Farmed	19	2.2	0.3	1.4	0.4	5.5
	Wild	3	0.6	0.2	0.3	0.1	1.3
Shrimp	Farmed	13	0.2	0.06	0.2	<0.001	0.7
	Wild	4	0.1	0.05	0.09	0.009	0.2

a. This industry survey would include some samples from Scotian Shelf Bioregion.

Birds: Contaminant profiles of birds and marine mammals are useful as bioindicators for monitoring contaminant conditions of habitats, trophic levels, and as indicators of contaminant sources. While levels in tissues are of most interest, in particular due to the importance of bioaccumulation through the food chain, physical contamination of birds has been important in some instances, in particular in assessing the degree of marine contamination by crude oil, which continues to be an important contaminant in offshore areas.

Composition of hydrocarbons found on oiled seabirds and stranded tar collected on Sable Island from 1996 to 2005 (2343 oiled seabirds) showed them to be contaminated by three main source types: crude oil, fuel oil, and bilge oil mixtures (Lucas and MacGregor 2006). The main hydrocarbon identified was crude oil (77%) followed by fuel oils (14.9%) and 8.1% were bilge oil mixtures (Lucas and MacGregor 2006). Crude oil arises principally from poorly managed and illegal day-to-day operations in marine tanker traffic (Lucas and MacGregor 2006, see also Section 5.1.4).

Perfluorinated chemicals (PFCs), an important class of persistent and bioaccumulative industrial chemicals, have been found at relatively high concentrations in Herring Gull eggs from Sable Island sampled in 2008 (Gebbink et al. 2011). Of the two main groups of PFCs—perfluorinated sulfonic acids (PFSAs) and perfluorinated carboxylic acids (PFCAs)—levels from Sable Island were fifth highest in Canada for total PFSAs (the sum of the individual chemicals in the group and their prercursors) and in the top three for total PFCAs of fifteen colonies in Canada, which included industrialized sites (e.g., Toronto Harbour and the Montreal area where the highest levels were recorded) (Gebbink et al. 2011). The source of the elevated concentrations could not be identified in the study and the authors concluded that there must be a local, unknown, marine food source of PFCAs on Sable Island (Gebbink et al. 2011).[42] Levels of both groups of compounds on Sable Island were elevated over levels on Kent and Manawagonish Islands in the southwestern Bay of Fundy, which showed among the lowest levels of both ΣPFSAs and ΣPFCAs from across Canada (Gebbink et al. 2011). One site on the East Coast—Gull Island, NL—also had low levels of both groups of chemicals, comparable to the Bay of Fundy sites. The dominant PFC in gull eggs was perfluorooctanesulfonate (PFOS), which made up 89% of the total PFSA concentration. The manufacture of PFOS, as well as its precursors, was phased out by the main manufacturer between 2000 and 2002 but some is still produced globally (Gebbink et al. 2011).

Marine Mammals: Contaminant loadings in marine mammals can vary appreciably between species and the chemical compounds involved. Within individual species, levels of contaminants can be higher for males than females, and increasing concentrations are associated with increasing age (Arias et al. 2016). Concentrations can change seasonally; for example there is a decreasing contaminant load in reproductively active females, as a result of organochlorines passing from mother to young during gestation and lactation. In the western North Atlantic, which includes the bioregion, contaminant dynamics in marine mammals are similar to those observed in other parts of the world (Westgate et al. 1997, Shaw et al. 2005, Arias et al. 2016), where they are influenced by diet and range, and the levels and contaminant profile can vary based on regional differences and prey availability, as well as environmental and oceanographic factors that act to concentrate or dilute pollution inputs (Aguilar 1987).

Contaminant levels and composition in marine mammals in offshore areas in general show the effects of biomagnification, as they necessarily feed at high levels of the food chain; and also store contaminants, often in high concentrations, in fat reserves or blubber, which are important in feeding young. Organic contaminants are mainly lipophilic and dissolve in fat; marine mammals also have a limited ability to metabolize and eliminate such compounds from tissues, leading to a build-up of higher concentrations. Aguilar et al. (2002) provides a global overview of levels and trends of organic contaminants in marine mammals, which includes summaries of studies in the Scotian Shelf Bioregion. Comparatively little information is available from Canadian

[42] Gebbink et al (2011) used carbon and nitrogen isotope analysis to infer dominant food sources of gulls in fifteen colonies across Canada, including three Herring Gull colonies in the Scotian Shelf Bioregion—Kent and Manawagonish Islands, New Brunswick, and Sable Island, Nova Scotia. For the sites, the δ13C values in eggs indicated food sources which were mainly marine, versus freshwater/terrestrial for inland colonies.

waters and few studies have been conducted on contaminants in marine mammals, including cetaceans (whales, porpoises and dolphins) and pinnipeds (seals and walrus) in the bioregion. Marine mammals from the temperate fringe of the northern hemisphere, particularly fish-eating species which inhabit the mid-latitudes of European and western North American waters, show the greatest organochlorine loads, consistent with extensive production and use of organochlorines in industrialized countries in these parts of the world (Aguilar et al. 2002). Other studies that consider geographical trends of contaminant concentrations in marine mammals show that generally, contaminant levels in the body tissues of mammals are higher where mammals inhabit industrialized coastal areas (Westgate and Tolley 1999, Elfes et al. 2010). Some studies that include the bioregion are listed in Table 20.

Table 20. Organic contaminants in cetaceans in the Scotian Shelf Bioregion and Northwest Atlantic.

Reference	Species	Region	Local Area	Source	Years	Contaminant Types
Westgate et al. 1997	Harbour Porpoise (*Phocoena phocoena*)	Bay of Fundy/Gulf of Maine	Grand Manan/ Jeffreys Ledge	Blubber	1989-1991	CBZ, HCH, CHLOR, DDT, PCB, CHB
Hooker et al. 2008	Northern Bottlenose Whales (*Hyperoodon ampullatus*)	Scotian Shelf Edge	The Gully MPA	Skin and blubber	1996-1997 2002-2003	PCB, TOT OC; CHL; DDT; ENDO
Weisbrod et al. 2000	Right Whale (*Eubalaena glacialis*)	Outer Bay of Fundy/Gulf of Maine	Bay of Fundy	Free-ranging Right Whale-skin and feces	1994-1996	PCB; BHC; CHLOR; DDT; TOT OTH
Weisbrod et al. 2001	Atlantic White-sided Dolphin (*Lageno-rhynchus acutus)*	Outer Bay of Fundy/Gulf of Maine	Bay of Fundy/ Gulf of Maine	Blubber, liver, skin.	1994-1996	DDE, PC
	Long-finned Pilot Whale *(Globicephala melas)*	Outer Bay of Fundy/Gulf of Maine	Bay of Fundy/ Gulf of Maine	Blubber, liver, skin.	1990-1996	PCB
Peck et al. 2008	Atlantic White-sided Dolphin (*Lagenorhyn-chus acutus)*	U.S. East Coast	U.S. East Coast	Blubber, liver	1993-2004	HBCD
Elfes et al. 2010	Humpback Whale (*Megaptera novaeangliae)*	Outer Bay of Fundy/Gulf of Maine	Stellwagen Bank, Great South Channel, German Bank, Bay of Fundy	Blubber	2006	DDT, PCB, HCH, PBDE, CHLOR

Abbreviations for compounds other than DDT, DDE and PCBs: CBZ=Chlorobenzenes; ENDO=Endosulfan; HCH=Hexachlorocyclohexanes; CHLOR=Chlordane and chlordane-related compounds; PCB=Polychlorinated Biphenyls; CHB=Chlorinated boranes; CHL=Chlordane; BHC=Benzene hexachloride; HBCD=Hexabromocyclododecane; TOT OC=Total organochlorines; TOT OTH=Hexachlorobenzene, Aldrin, Endrin and Dieldrin.

Concentrations of PCB congeners and organochlorine compounds detected in skin and blubber samples of a population of Northern Bottlenose Whales (*Hyperoodon ampullatus*) centred on the continental shelf edge in the vicinity of the Gully were higher than in populations from the Davis Strait, and showed the presence of enzymes indicating exposure to hydrocarbons (Hooker at al. 2008). Tests also showed elevated levels of a protein (CYP1A1), which assists in the metabolism of hydrocarbons, in one year of a study in the early 2000s, suggesting the whales had been exposed to hydrocarbon contamination (Hooker et al. 2008 from DFO 2009a). In fish larvae, the induction of cytochrome P4501A (CYP1A) enzymes correlates with concentrations of alkyl-substituted polynuclear aromatic hydrocarbons (alkyl-PAH) in oil, but the range of compounds causing toxicity is unknown (Hodson et al. 2008). Northern Bottlenose Whales were suggested as a potential indicator species for monitoring of contaminants and resulting biological effects, along with flounder, Snow Crab, squid, krill/shrimp, and corals (DFO 2009a).

Environmental contaminants generated in developed areas of the Great Lakes and the St. Lawrence Estuary in Quebec also contaminate nearby waters, in particular the Gulf of St Lawrence, which is one of the main sources of water masses on the Scotian Shelf. The influence of the St. Lawrence and Gulf water masses, coupled with industrialized areas as sources, may explain the higher concentrations of various organochlorine compounds (PCBs, DDTs and several other organochlorine compounds) in Northern Bottlenose Whale from Scotian Shelf waters, compared to those in a population which occurs off Labrador, where the sources are primarily long-range transport (Hooker et al. 2008). The pesticides 4,4'-DDE and trans-nonachlor were found in tissue from Northern Bottlenose Whales in 1996-1997 and 2001-2003 (Hooker et al. 2008 from DFO 2009a) at concentrations generally consistent with those reported for blubber of other large whales in the North Atlantic (Hooker et al. 2008 from DFO 2009a) and were higher in the most recent samples.

Humpback Whales in the northeastern Gulf of Maine, including German Bank and the Bay of Fundy, have measurable concentrations of total PCBs, total DDTs, total chlordanes, and total PBDEs in skin and blubber, at levels higher than in humpbacks sampled concurrently in the North Pacific. The difference has been suggested to be a response to elevated levels of contaminants reaching the marine environment from the large urban population and industrialization along the eastern U.S. coast (Elfes et al. 2010). North Pacific (western Gulf of Alaska) humpbacks sampled in the study showed, in contrast, higher total HCH values, the likely result of exposure to environmental contaminants from tanker traffic and other shipping. A pregnant female Humpback Whale sampled after its death in a Nova Scotia fishery had levels of 23,100 ppb and 5,400 ppb (wet weight) for DDTs and PCBs, respectively (Elfes et al. 2010). Several of the chlorinated and brominated compounds measured in Humpback Whale blubber by Elfes et al. (2010) in the Gulf of Maine in 2005-2006 showed regional trends towards higher levels in the northeastern Gulf of Maine (i.e., increasing towards the Scotian Shelf Bioregion). Significantly higher levels of ∑PCBs, ∑DDTs, and ∑chlordanes, were found in the northeastern Gulf of Maine compared with southwestern areas, with mean values in the northeast approximately double those in the southwest (Elfes et al. 2010).

Concentrations of ∑PBDEs and ∑HCHs were similar in the two regions (Elfes et al. 2010).

Organochlorine compounds (DDT and Arochlor, a PCB congener) have been detected in seals from Sable Island from the mid-1970s to mid-1990s (Addison et al. 1998) and concentrations have been decreasing (Addison et al. 1998). Concentrations of PBDEs in maternal Grey Seals from Sable Island averaged 112 ± 55.2 ng/g lipid—over twice the concentration measured in their pups (Ikonomou and Addison 2008). The main exposure route is through food, while young animals are exposed to PBDEs through the placenta and milk, which selects compounds based on differences in lipophilicity and molecular weight (Ikonomou and Addison 2008, Shaw and Kannan 2009). Dioxins, furans, and PCBs also were detected in Grey Seals on Sable Island in sampling conducted in the mid-1990s (Addison et al. 1999, Addison and Stobo 2001); and organochlorine residues have also been found in Grey Seal pups (Addison and Stobo 2009). A time series of chlorinated organic contaminants in Grey Seals from Sable Island (Addison and Stobo 2001) continues to show decreasing concentrations of DDT and DDE in adult seal blubber. PCBs were lowest at the beginning of the time series in 1974; peaked in 1985 and decreased thereafter. Early observations in the study (e.g., Addison et al. 1984, Addison and Stobo 1993) are summarized in Stewart and White (2001). Various other organochlorine compounds including oxychlordane, alpha-hexachlorocyclohexane and trans-nonachlor also decreased, but hexachlorocyclobenzene remained at earlier levels (Addison and Stobo 2001).

Invertebrates: Petroleum hydrocarbons have occasionally been detected at low levels in tissues of marine invertebrate organisms in the Nova Scotia offshore (Table 21), reflecting the ubiquitous occurrence of these compounds in the marine environment. Low levels of hydrocarbons were found in Krill (*Meganyctiphanes norvegica*) sampled in the Gully between 2004 and 2006 (Yeats et al. 2008). The animals contained the alkane pristane but no other alkanes, and low concentrations of alkylated and parental PAHs (Yeats et al. 2008). Zhou et al. (1996) detected aliphatic hydrocarbons in Blue Mussels from moorings used for monitoring environmental effects of the Cohasset Panuke natural gas project west of Sable Island, which operated from 1992 to 2005, but determined that they originated naturally from phytoplankton.

Blue Mussels and invertebrates have been used as biomonitors of contaminant levels in offshore areas of the Scotian Shelf Bioregion, and have demonstrated that offshore exploratory drilling and hydrocarbon production on the Scotian Shelf have had little impact in terms of levels of contaminants in biota. Most of the industry activity and monitoring has been concentrated on Sable Island Bank in the vicinity of Sable Island. Some hydrocarbons are released from produced water and vessels operating around operational offshore platforms, and so measurements of contaminants in mussels are aimed at monitoring such releases. As in the earliest offshore hydrocarbon projects—the Cohasset Panuke development—mussels moored as sentinels or which grew on platforms showed that the indicator contaminant—TPHs—were not accumulated in tissues compared to control sites (ExxonMobil 2011). During drilling of offshore wells, muds containing hydrocarbons used in lubricating the drill stem and maintaining pressure balance in the well can also be released into the environment. However, as shown by monitoring studies, the dispersive environment around the production sites effectively dilutes any releases of contaminants which might occur. From 1999 to 2010, the SOE Project measured hydrocarbon levels (in particular the presence of carbon chains of C_{10}-C_{24} in length) in mussels and occasionally in other local invertebrates to determine if uptake occurred. Levels measured close to the facilities were comparable to those at distant sites not expected to be exposed to operational releases, including mussels from the nearshore commercial harvest sold in stores in Halifax (ExxonMobil 2011) (Table 16). Levels of the same hydrocarbons were low in Sea Scallops, Snow Crab, and Jonah Crab (JWEL 2004) (Table 21). Neither PAHs nor PCBs were detected (detection limit 0.05 mg/kg and 0.05 µg/kg respectively). Analyses carried out by the Canadian Institute of Fisheries Technology to support these studies further indicated that the hydrocarbons of C_{10}-C_{24} length were most likely of biogenic origin, likely produced by phytoplankton—a similar result to an earlier analysis (Zhou and Ackman 1996) of hydrocarbons in mussels moored near the Cohasset-Panuke platforms in the early 1990s.

PAHs as well as nonylphenols and their ethoxylates, found in produced water from offshore hydrocarbon production facilities, have been monitored in marine biota around the offshore Encana Deep Panuke project main production facilities centre and in commercial catch (Encana 2017). Individual priority PAHs were not detected in mussel and fish tissue, and nonylphenol compounds were found in many but not all of the samples as well as those taken from the commercial fishery (Tables 17 and 22).

Table 21. Total Petroleum Hydrocarbon (TPH) concentrations (mg/kg dry weight, C_{10}-C_{24}) in pools of miscellaneous invertebrates from Sable Island Bank obtained in 2003 in the vicinity of wells of the Sable Offshore Energy Project (Thebaud, Venture and North Triumph) and reference samples purchased commercially (JWEL 2004). Number of pools is in parentheses.

Species and Location	**Tissue and Concentration (mg/kg dry weight)**	
	Sable Island Bank	**Market**
Jonah Crab Thebaud (2003)	Leg-36.58. Hepatopancreas-15.38.	
Sea Scallop North Triumph (2003)	Adductor 14.8 (n=2) Other tissues 38.01	Adductor 18.15
Snow Crab North Triumph (2003)	Tissue 10.80 Hepatopancreas 43.95	Tissue 15.43
Rock Crab Venture (2003)	Tissue 10.30 (n=2); Hepatopancreas 432.72.	
Rock Crab Thebaud (2003)	Tissue 9.87; Hepatopancreas 85.38	
Sea Scallops (2005)[a]	Western Bank near Thebaud: Adductor 12.28 West Western Bank (control): Adductor 6.72 (n=2)	Adductor Trace

a. ExxonMobil (2006).

Table 22. PAH and nonylphenols in Atlantic Cod collected in the vicinity of the Deep Panuke platform and in commercial catch for comparison in 2016 (Encana 2017).

Compound	Units	Year	Production Facilities	Halifax Grocery[a]
PAHs (Individual Priority PAHs and Total)	mg/kg	2016	ND	ND
4-Nonylphenol	ng/kg	2016	11.6	92
4n-Octylphenol	ng/kg	2016	ND	ND
4-Nonylphenol monoethoxylate	ng/kg	2016	3.12	67.8
4-Nonylphenol diethoxylate	ng/kg	2016	2.44	387

ND = Not detected. a. Sobeys.

6.2. GULF OF MAINE/BAY OF FUNDY

6.2.1. Metals in Biota

The Bay of Fundy has been an important source of information on accumulation of contaminants in biota, in part because of the accessibility of seabird colonies, existence of coastal monitoring programs such as Gulfwatch in the Gulf of Maine, and presence of coastal marine mammals and fish which can be sampled for comparative studies. Apart from broad studies of metal contamination, mercury and its organic form, methyl mercury, have been a prominent focus of research in the Bay of Fundy.

Mercury is an important contaminant in both terrestrial and aquatic ecosystems because it can exist in organic (methyl mercury) form and can bioaccumlate in higher organisms (ECCC 2016). Mercer and Kidd (2015) reviewed studies that examined mercury levels reported in tissues of marine animals in the Bay of Fundy. In many cases, the results showed high risk factors for harm based on tissue levels known to cause effects (Mercer and Kidd 2015). The study, which surveyed available data extending into the 2000s, found that mercury[43] poses a risk to all but one species of seabird surveyed and about half of the fish species. It was not possible to evaluate risk of mercury for marine mammals and invertebrates due to paucity of data available. The study determined that for animals that eat fish or invertebrates, mercury levels in tissues pose a risk based on Environment Canada guidelines for acceptable concentrations in food for wildlife (Mercer and Kidd 2015). Mercury levels in half of the fish species, as well as lobster and clams may affect the health of their predators because of elevated mercury concentrations, but lower levels found in mussels, which are also consumed, will not (Mercer and Kidd 2015). While Burgess et al. (2013) from Mercer and Kidd (2015) show that total mercury concentrations in Herring Gull eggs decreased at Manawagonish Island, New Brunswick over 36 years (1972-2008), that trend did not reflect an overall

[43] Total mercury as well as the component inorganic and methyl mercury were assessed.

decline of mercury in the environment, but instead represented a shift in food habits to foods with lower levels of mercury.

Levels of mercury in different trophic levels in the marine ecosystem of the Gulf of Maine are consistent with estimates of levels in other ecosystems globally (Chen et al. 2008) (Table 23).

Table 23. Latitudinal variation of mercury concentrations (total Hg, µg/g wet weight) in various trophic levels of well-studied ecosystems. From Chen et al. (2008).

Location	**Lancaster Sound**[a]	**N. Baffin Bay**[b]	**Gulf of Maine**[c]	**Gulf of Farallones**[d]	**Ross Sea, Antarctica**[e]
Latitude	~74°N	~76°N	~44°N	~38°N	~74°S
Sampling date	1988-1990	1998	2001-2003	1993-1994	1989-1991
Microplankton	<0.004	0.003	0.002 ± 0.001	–	0.007 ± 0.001
Mesoplankton	0.012 ± 0.002 [f]	0.025 ± 0.017	0.003 ± 0.001	–	0.013-0.007 [h]
Macrozooplankton	0.012-0.02 [h]	0.020 ± 0.009	0.006 ± 0.001	0.006 (0.006-0.008)[g]	0.015 ± 0.005
Pelagic fish (muscle)	0.038 ± 0.006	0.04	0.047 ± 0.028	0.02 (0.018-0.022)	0.068 ± 0.066
Seal or porpoise (muscle)	0.214 ± 0.006	0.68 ± 0.29	0.501 ± 0.297	3.8 (0.96-1.46)	0.37

[a]Atwell et al. 1998. [b]Campbell et al. 2005. [c]Harding et al. [unpublished]. [d]Jarman et al. 1996. [e]Bargagli et al. 1998. [f]Mean ± SD. [g]Geometric mean (±1 SD). [h]Range.

Overall, levels of mercury and methyl mercury in tissues of marine organisms in the Bay of Fundy are relatively low, and trends do not show declining levels despite reductions of releases into the environment, reflecting the relatively large pool of the element already present in the marine environment (Sunderland et al. 2012). Levels of mercury in fish commonly caught and eaten in coastal communities in the outer Bay of Fundy are low, with levels in haddock, canned tuna, lobster, and pollock all below 0.5 mg/kg wet weight—a safe level for consumption by food quality guidelines (LeGrand et al. 2005). As in the Scotian Shelf offshore, larger fish found in the Bay of Fundy and Gulf of Maine, including tuna, shark, and swordfish, have higher tissue concentrations of mercury, reflecting a higher trophic position. Consequently, these species are recommended to be be less-frequently consumed by the public[44] (Health Canada 2007). Although levels in sediment-dwelling benthic invertebrates are low, mercury can be potentially transferred through them from sediments to higher trophic levels. Methyl

[44] There can be a wide range in concentrations of metals and in particular mercury in fish tissues. In response to a “mercury scare” in the 1970s, levels of mercury in a wide range of fish occurring in Atlantic coastal waters were measured. Levels of mercury in most fish were low, but levels were elevated in large fish having long life spans such as swordfish, tuna, sharks, dogfish, large halibut and larger offshore lobsters (Zitco 1981 from Stewart and White 2001). Currently, Health Canada recognizes different levels in fish, setting a higher guideline level for species including fresh and frozen tuna, shark and swordfish (Health Canada 2007).

mercury has been found in tissues of polychaetes in mudflats in the Southern Bight of Minas Basin, showing the potential for transfer to higher trophic levels (Sizmur et al. 2013). Tissue concentrations of methyl mercury reflect sediment levels, and organisms such as marine worms feeding on deeper sediments where methyl mercury is generated have correspondingly elevated methyl mercury concentrations in tissues (up to 69.6 µg/kg) (Sizmur et al. 2013). Otherwise, levels of mercury in invertebrates in the Bay of Fundy are frequently measureable but low (0.01-0.06 mg/kg dry weight) in the Southern Bight of Minas Basin and Yarmouth (English et al. 2015b). Mussels sampled regularly through Gulfwatch show generally low levels of mercury in the Bay of Fundy except at one location in central Saint John Harbour (Tin Can Beach) which repeatedly (at least since the early 2000s) showed elevated levels of mercury as well as several other metals in Blue Mussels harvested there (LeBlanc et al. 2011) (Figure 14).

Birds: Aquatic and coastal birds, including seabirds, water-associated birds such as cormorants and loons, waterfowl (e.g., ducks and geese), and shorebirds, as well as raptors are exposed to environmental contaminants, including metals, through their diet. Most species have wide geographic ranges, including some that move annually between hemispheres, so that the loading of contaminants reflects levels in a wide range of environments, not necessarily the bioregion alone. Apart from exposures in local “hotspots” of elevated environmental mercury, such as areas having legacy contamination from pulp and paper mills and gold-mining, atmospheric transport from combustion emissions and subsequent entry into the food chain is the main source of mercury to which birds are exposed (ECCC 2016).

Goodale et al. (2008) summarized information from existing databases on mercury levels in eggs and blood of 17 species of marine seabirds from islands along the Maine and southwestern New Brunswick coasts in the Gulf of Maine. Mean mercury levels in most species did not exceed adverse effects thresholds, but levels in eggs occasionally were above those which could have a physiological effect. Levels of mercury were highest in fish-eating birds—Leach’s Storm-petrel, Razorbill, and Black Guillemot—compared with species which feed on both fish and invertebrates (Goodale et al. 2008). Common Eider, a shallow-diving coastal species of sea duck which feeds on invertebrates, has among the lowest concentration levels of mercury in body and egg samples, and Leach’s Storm-petrel, a species which nests in coastal areas but feeds on fish far offshore, was noted as having among the highest (Goodale et al. 2008). Overall, mean mercury concentrations measured in eggs in studies of Gulf of Maine seabirds ranged from 0.04 to 0.62 µg/g wet weight (Goodale et al. 2008).

Mercury levels measured in the eggs of Herring Gulls collected from Manawagonish Island and Kent Island, located in southwestern New Brunswick, as well as Sable Island, Nova Scotia since 1972 have shown that environmental mercury in coastal ecosystems has remained relatively constant in Atlantic Canada throughout the past three decades or more (Burgess et al. 2013). Mercury in a primary food source has been suggested as the origin of the elevated concentrations of mercury in Leach’s Storm-petrel in Atlantic Canada (Hedd et al. 2018). Leach’s Storm-petrels from breeding colonies on Kent Island, New Brunswick, where particularly high levels of mercury have been observed in tissues, feed mainly in shallower waters in the Gulf of Maine and

Georges Bank, a fact determined conclusively recently by the use of global location sensor tags attached to birds from the area during their foraging excursions (Hedd et al. 2018). Mercury levels observed in eggs and blood of Leach's Storm-petrels from colonies in the outer Bay of Fundy (Bond and Diamond 2009) and along the New Brunswick-Maine coast in the Gulf of Maine (Goodale et al. 2008) are elevated in comparison to levels observed globally (Pollet et al. 2017).

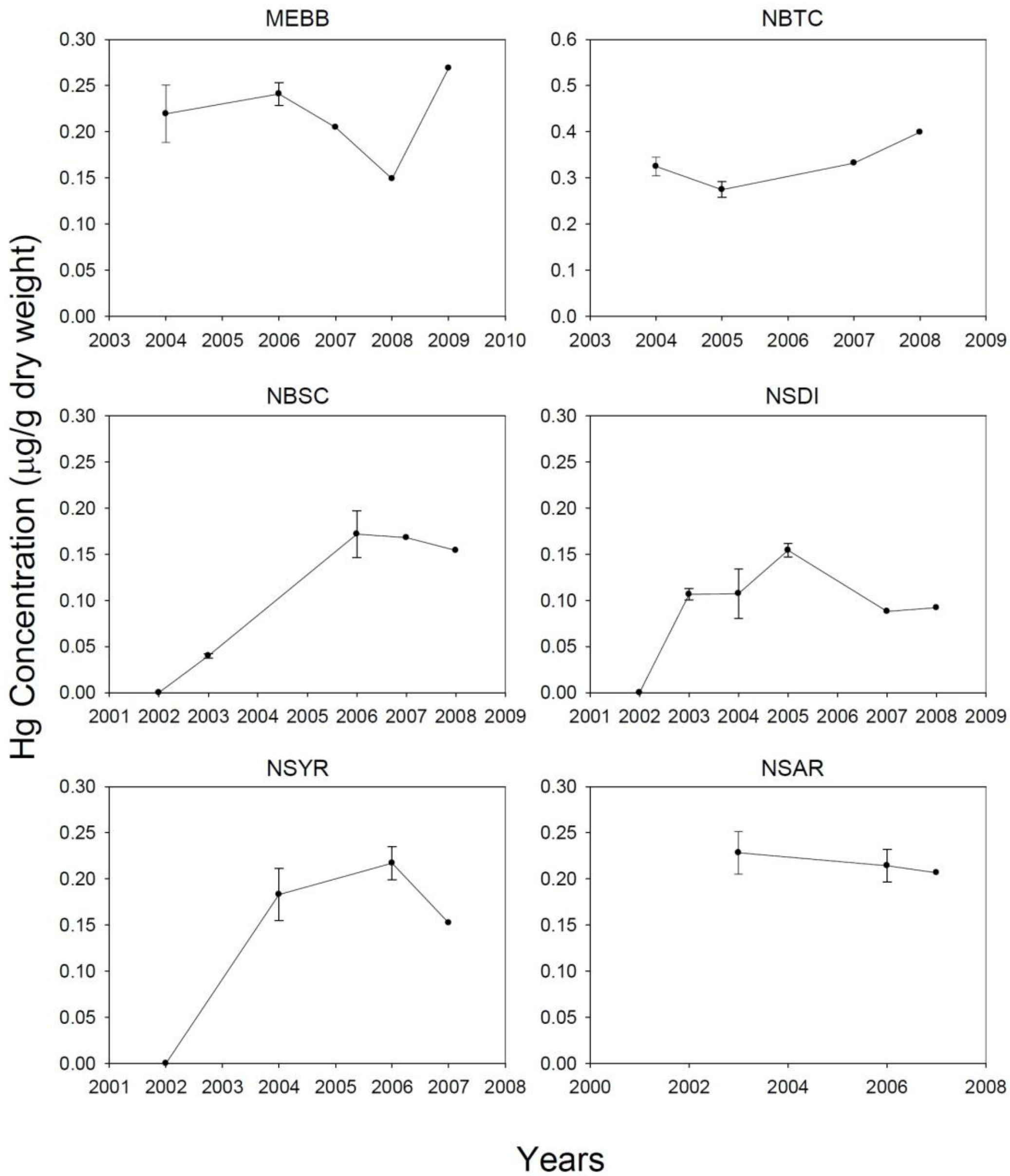

Figure 14. Trend of tissue concentrations of mercury in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

High levels of mercury in Common Loons in Nova Scotia, and New Brunswick are attributed to elevated levels in fish in freshwater lakes where they breed (Burgess et al. 2005). Common Loons on inland lakes in coastal areas of New Brunswick (24 lakes in the Lepreau area of eastern Charlotte County, New Brunswick, and Fundy National Park in the inner Bay of Fundy) had among the lowest levels of mercury in blood found in a study of loons sampled on lakes in Nova Scotia and New Brunswick in 1995-1996 (Burgess et al. 2005). Lead and selenium levels were low compared to other areas of North America and not physiologically threatening (Evers et al. 1998, 2003; Burgess et al. 1998, 2005).

Molluscs: Molluscs (clams and snails including zooplanktonic forms such as pteropods) are exposed to environmental contaminants where they live, often on or in sediments, and through feeding, which can include filtering suspended matter from the water, processing of sediments through deposit feeding, or preying on other organisms. The intertidal dogwhelk, *Nucella lapillus,* which feeds on other snails and clams, has shown endocrine-disrupting effects of the antifoulant chemical tributyltin from environmental exposures in some harbours, even though use of the chemical on most vessels has been banned for several decades (Maguire 2000). In Saint John Harbour, tributyltin is expected to be still occurring in sediments through ongoing ship traffic and maintenance activities, as it is in other major ports and smaller marinas in the bioregion (Carter et al. 2004, Titley-O'Neal et al. 2011). Presence of the compound was demonstrated in 1995 by the occurrence of the imposex condition in 66 percent of whelks sampled there (Prouse and Ellis 1997)—tributyltin is the main contaminant causing this condition. Prouse and Ellis found levels of dibutyltin and tributyltin in the whelks at concentrations of 39 and 9 ng/g wet weight respectively, lower than levels found in whelks in Halifax Harbour and Sydney, Nova Scotia, and whelks had a correspondingly low incidence of the imposex condition (Prouse and Ellis 1997). The highest concentration of tributyltin in whelk tissue observed in imposex-affected females in Saint John Harbour in a later study—63.75 ng tin/g, tissue dry weight in a sample from Red Head, Saint John Harbour in 2007—was higher than in 1995 (Titley-O'Neal et al. 2011b). The latter study showed a comparatively high incidence of imposex (20-38.5 percent of females) as well as highest levels of tributyltin (from 4.75 to 63.75 ng tin/g, tissue dry weight) at three locations on the east side of the harbour (Titley-O'Neal et al. 2011b). In contrast, imposex was not detected at reference sites along the west shore of the harbour (Titley-O'Neal et al. 2011b).

Measurements of vitellogenin—a biomarker of endocrine disruption in bivalves and thought to be potentially influenced by tributyltin—in Blue Mussels from Saint John Harbour showed vitellogenin levels with greater variability than in Halifax Harbour and were thus inconclusive in indicating endocrine-disrupting effects of tributyltin there (Gagné 2003 from Carter et al. 2004).

Levels of a suite of contaminants including trace metals in tissues of Blue Mussel (*M. edulus)* in several coastal areas of the outer Bay of Fundy in Nova Scotia[45] and New

[45] The furthest east site in Nova Scotia is Barrington Passage.

Brunswick through the Gulfwatch monitoring program have shown, with some exceptions, comparatively uniform and relatively unpolluted coastal conditions with occasional hotspots for both metals and organic contaminants (LeBlanc et al. 2011) and some trends which suggest improvements in conditions since the program began in 1991 (Figures 14-24). The Gulfwatch Program recently reported that in general, little or no change in trace metal concentrations in shellfish and sediments has been observed over the 1993-2008 period in the Gulf of Maine, similar to U.S. national trends (Jones et al. 2009). The data also shows, however, that the more heavily populated/industrialized coastal areas of the Gulf of Maine have higher contaminant levels in mussels compared to locations with smaller communities and less industrial activity (LeBlanc et al. 2011). New Brunswick and Nova Scotia sites sampled in the most recently reported round of sampling (2009) include both those in heavily industrial settings (e.g., the mouth of Saint John Harbour represented by Tin Can Beach; Portland Harbour, Maine) and relatively pristine sites (e.g., Apple River, Nova Scotia, on Chignecto Bay).

In general, the Canadian Gulfwatch sites have the lowest levels of most contaminants and show levels which have been relatively stable since the early 2000s (Figures 12 and 13). However, mussels from Saint John Harbour (Tin Can Beach on the north side of Saint John Harbour) typically had high levels of most contaminants, and in particular the highest levels of chromium, nickel, aluminum, and mercury for the Gulf of Maine as a whole, and also had elevated levels of iron and lead (LeBlanc et al. 2011). Locally elevated concentrations of lead were reported for Yarmouth, Nova Scotia, but also for Apple River, Nova Scotia, a comparatively remote and uninhabited site. Mussels from Yarmouth also had the highest silver levels (0.34 μg/g dry weight) which were well above those from other sampling locations (Figure 15). Silver is used as a tracer of municipal wastewaters, but the local levels likely reflect natural sources (LeBlanc et al. 2011). The only other metals for which Canadian Gulfwatch sites were notably high were Apple River, Nova Scotia, for iron, aluminum, and cadmium, and the St Croix River estuary site, New Brunswick, which had extremely high aluminum concentrations. Aluminum and iron levels[46] are thought, however, to be due to the influence of local geology in these areas, rather than human influence (LeBlanc et al. 2011).

Some of the non-industrialized Canadian sites had the lowest levels for the Gulf of Maine measured in 2009, including the lowest levels of iron measured in mussels at Barrington Passage (219 μg/g dry weight); lowest mercury level at Digby Island, Nova Scotia (0.083 μg/g); and the lowest silver level (Broad Cove, Nova Scotia, 0.010 μg/g) (LeBlanc et al. 2011).

[46] Trend diagrams for aluminum and iron were not shown.

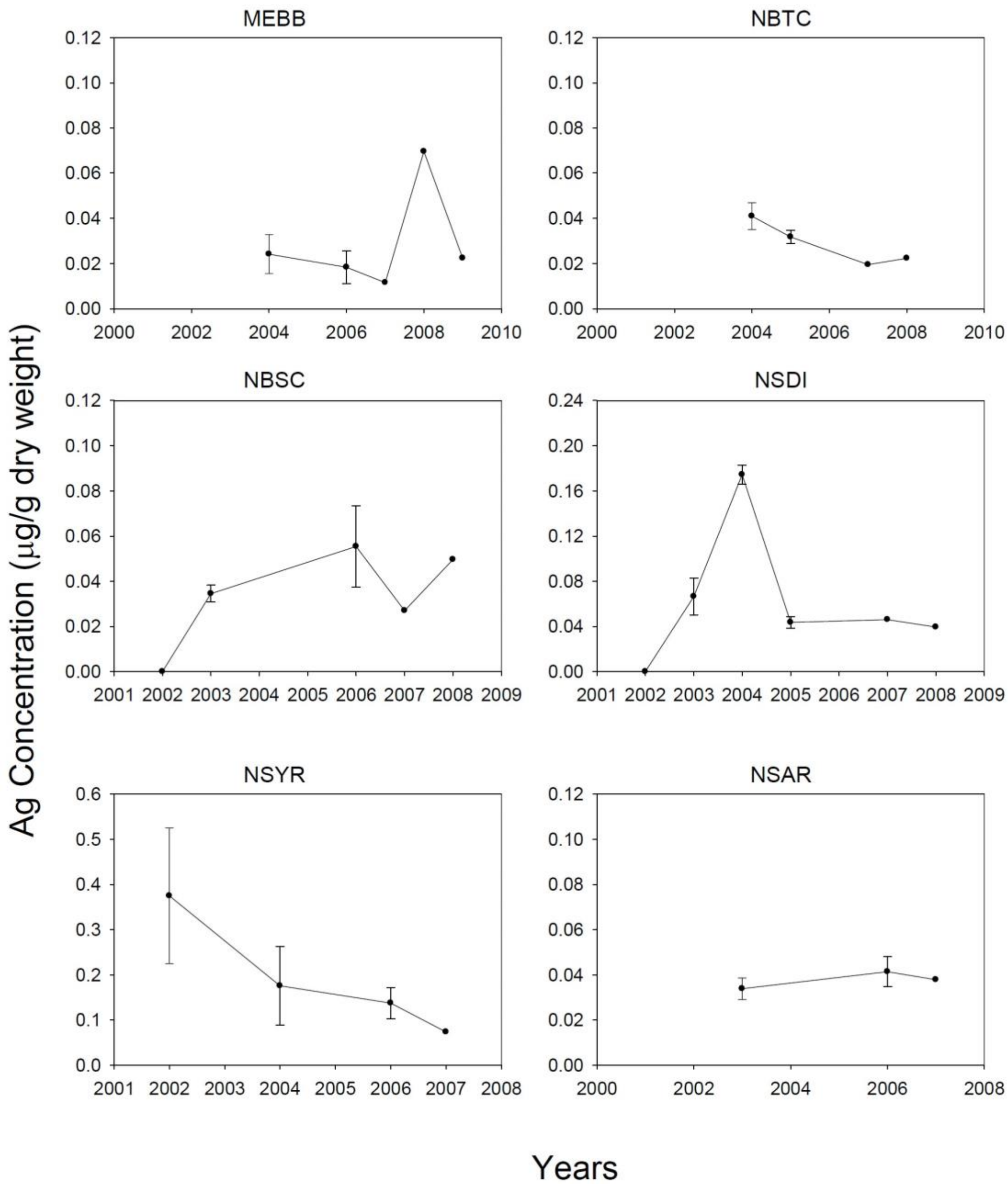

Figure 15. Trend of tissue concentrations of silver in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour, MEBB) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

Except for the high levels of some metals at the Saint John Harbour (Tin Can Beach) site, and occasional elevated concentrations at other locations, noted above, Canadian sites had comparable levels and ranges to other Gulfwatch sites for the metals silver, cadmium, chromium, copper, iron, aluminum, lead, nickel, zinc and mercury (LeBlanc et al. 2011) (Figures 12, 14-21) (LeBlanc et al. 2011).

Engel et al. (2006) measured low levels of metals in mussels sampled from the Annapolis Basin-Digby area of Nova Scotia and the Quoddy Region of New Brunswick in 2002 in areas unimpacted by human activity as well as some in the vicinity of aquaculture sites, sewage treatment facilities, a ferry terminal, and a pulpmill. Ranges observed were: arsenic, 5.0-14.3 µg/g dry weight; cadmium, 0.6-1.9 µg/g dry weight; copper, 3.4-8.7 µg/g dry weight; manganese, 6.0-44.6 µg/g dry weight; nickel, 0.6-1.9 µg/g dry weight; lead, 0.5-2.8 µg/g dry weight; zinc, 37.4-71.4 µg/g dry weight; selenium, 2.0-4.6 µg/g dry weight; and cobalt, 0.3-0.8 µg/g dry weight (Engel et al. 2006).

In a study of the Passamaquoddy Bay area, levels of trace metals in Atlantic Cod, Sea Scallops, and Softshell Clams in 1996 were comparable to those observed in other Maine coastal areas while lobster showed elevated levels of most metals. No Sea Scallops showed elevated levels of heavy metals; only silver and nickel were elevated in Softshell Clams; and only chromium was elevated in Atlantic Cod compared to other levels obtained through State of Maine and U.S. national monitoring programs (Passamaquoddy Tribe and CBRC 2001). Lobster meat and tomalley were higher in arsenic, cadmium, chromium, copper, selenium, silver and zinc compared to other Maine coastal areas (Passamaquoddy Tribe and CBRC 2001).

English et al. (2015b) studied metals in thirteen sediment-dwelling benthic invertebrates in the Bay of Fundy and found mostly low tissue levels of a suite of contaminant metals. Levels of arsenic in Softshell Clams were low, ranging from 1.7 to 3.0 ppm dry weight but lead levels which ranged from 0.59 to 0.98 ppm dry weight exceeded the CFIA guideline of 0.5 ppm for human consumption (English et al. 2015b). Levels of mercury in soft-shell clams were low (0.06 µg/g). The study included species from Yarmouth and the Wolfville-Kingsport area of Minas Basin in the Bay of Fundy (English et al. 2015b).

Concentrations of contaminant metals in mussels in coastal areas of the bioregion, including Gulfwatch values (reported as dry weight) with allowance for the wet/dry weight comparison, are typically highest in major harbours and urbanized areas; or in localized areas associated with specific industries, such as gold mining, where elevated concentrations of arsenic and mercury may occur (Walker and Grant 2015, Doe et al. 2017).

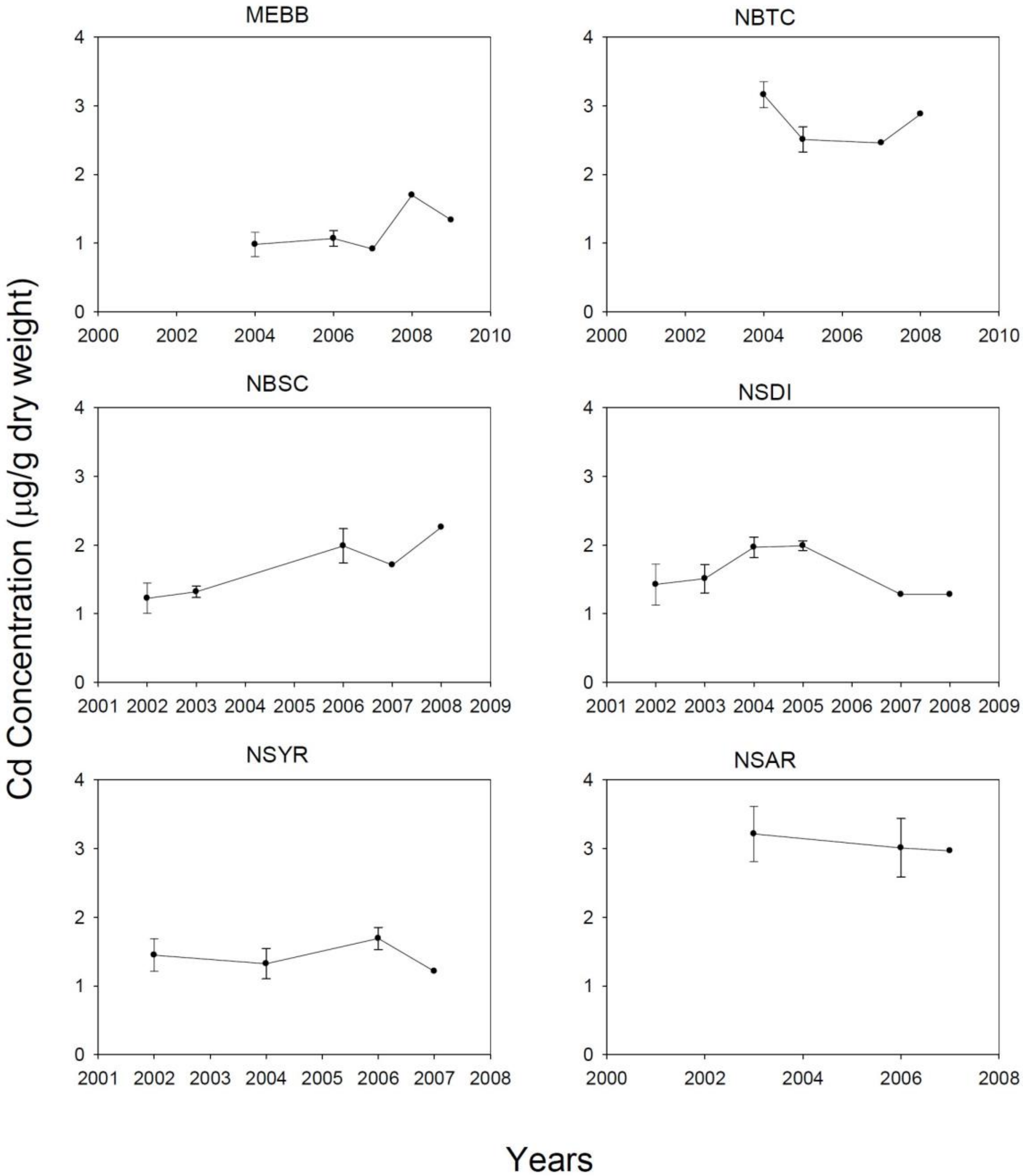

Figure 16. Trend of tissue concentrations of cadmium in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

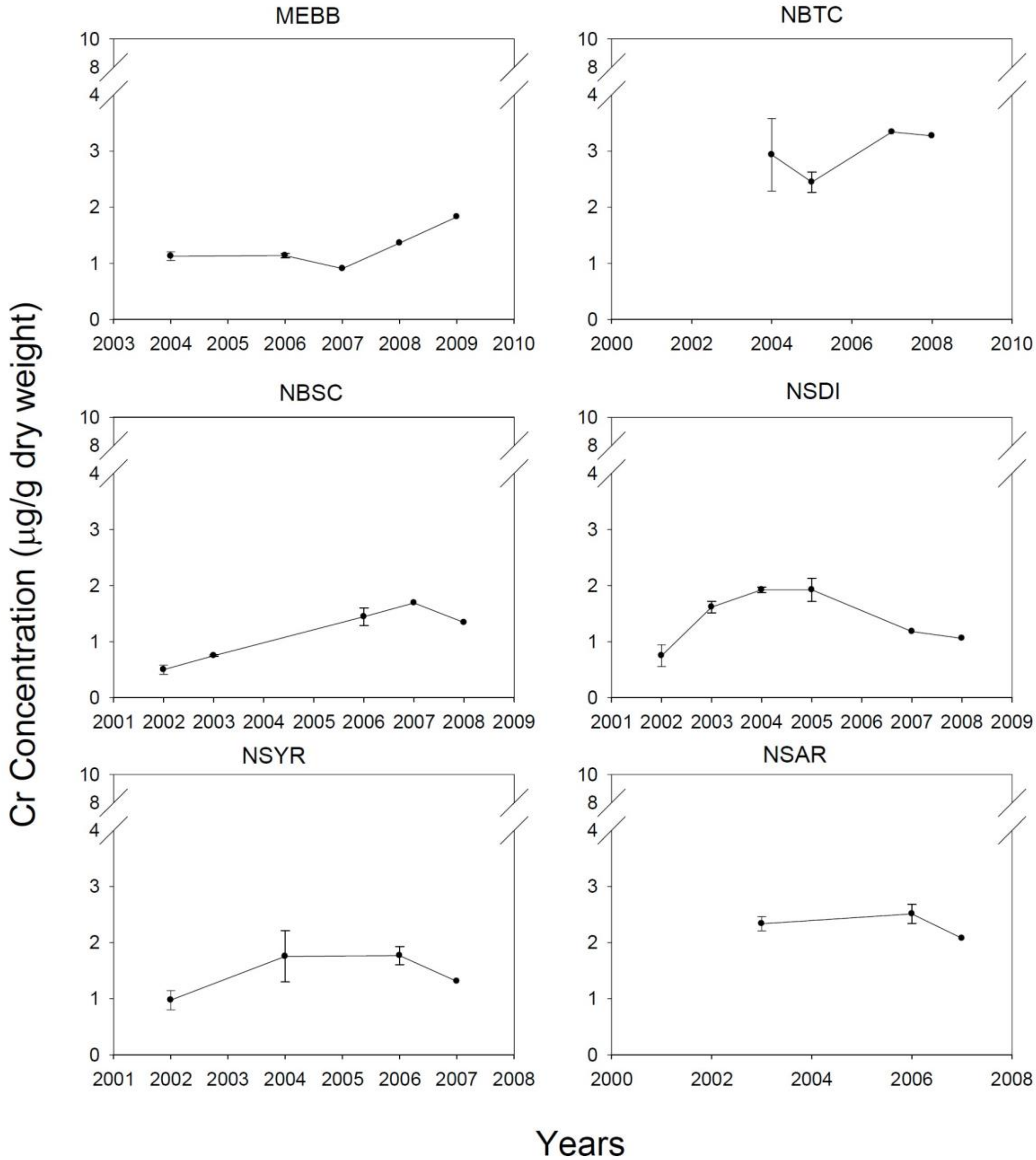

Figure 17. Trend of tissue concentrations of chromium in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

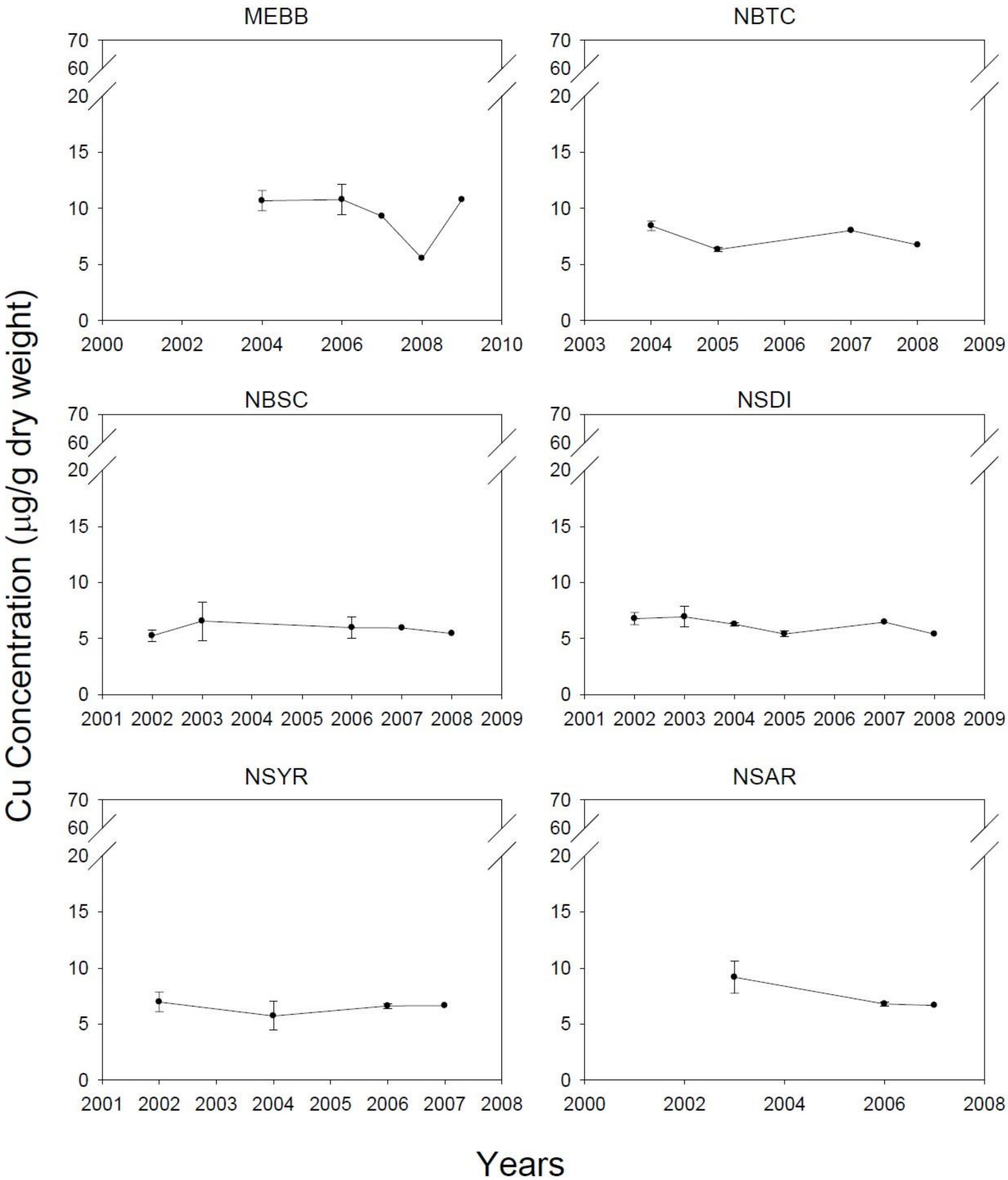

Figure 18. Trend of tissue concentrations of copper in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

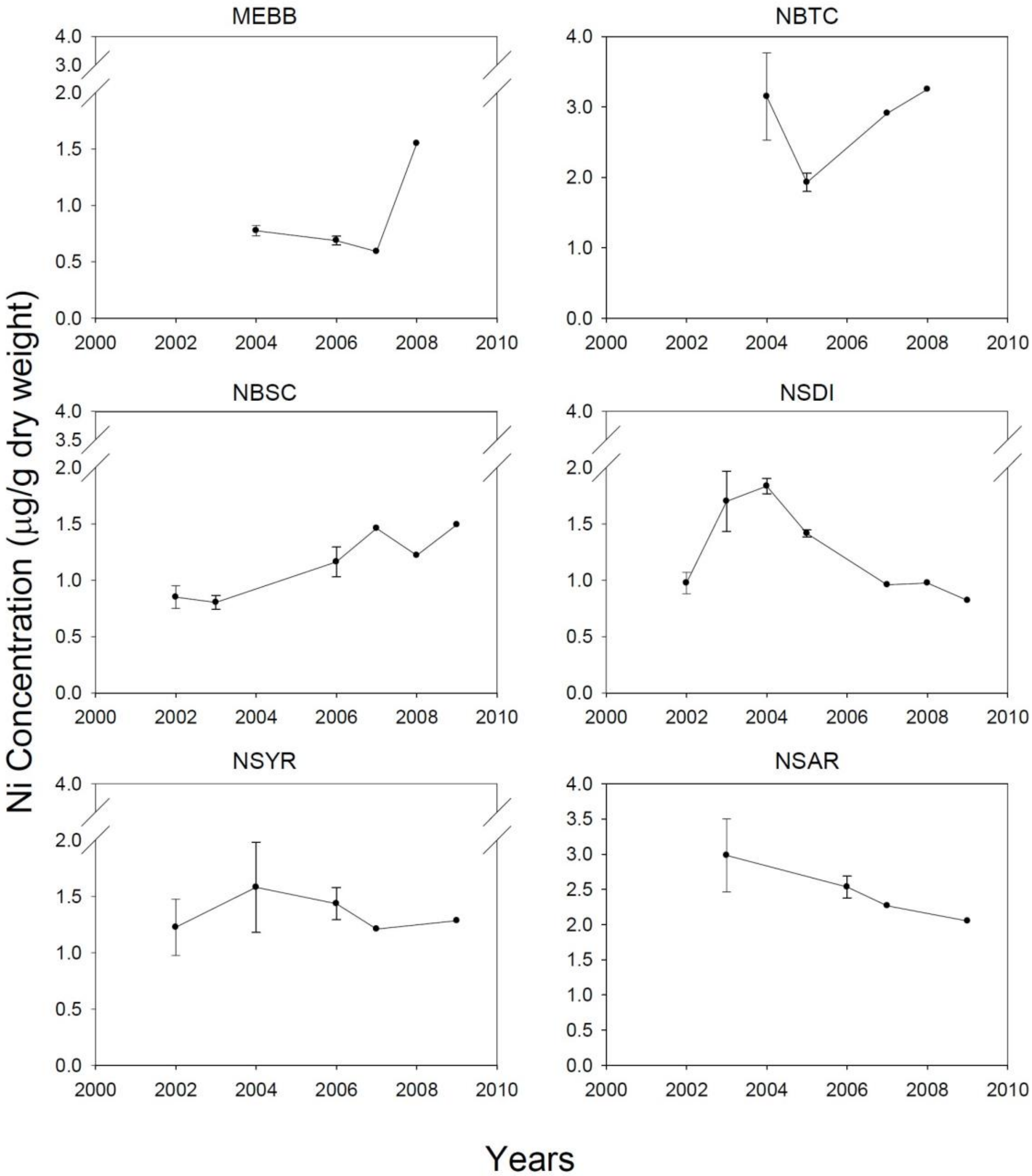

Figure 19. Trend of tissue concentrations of nickel in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

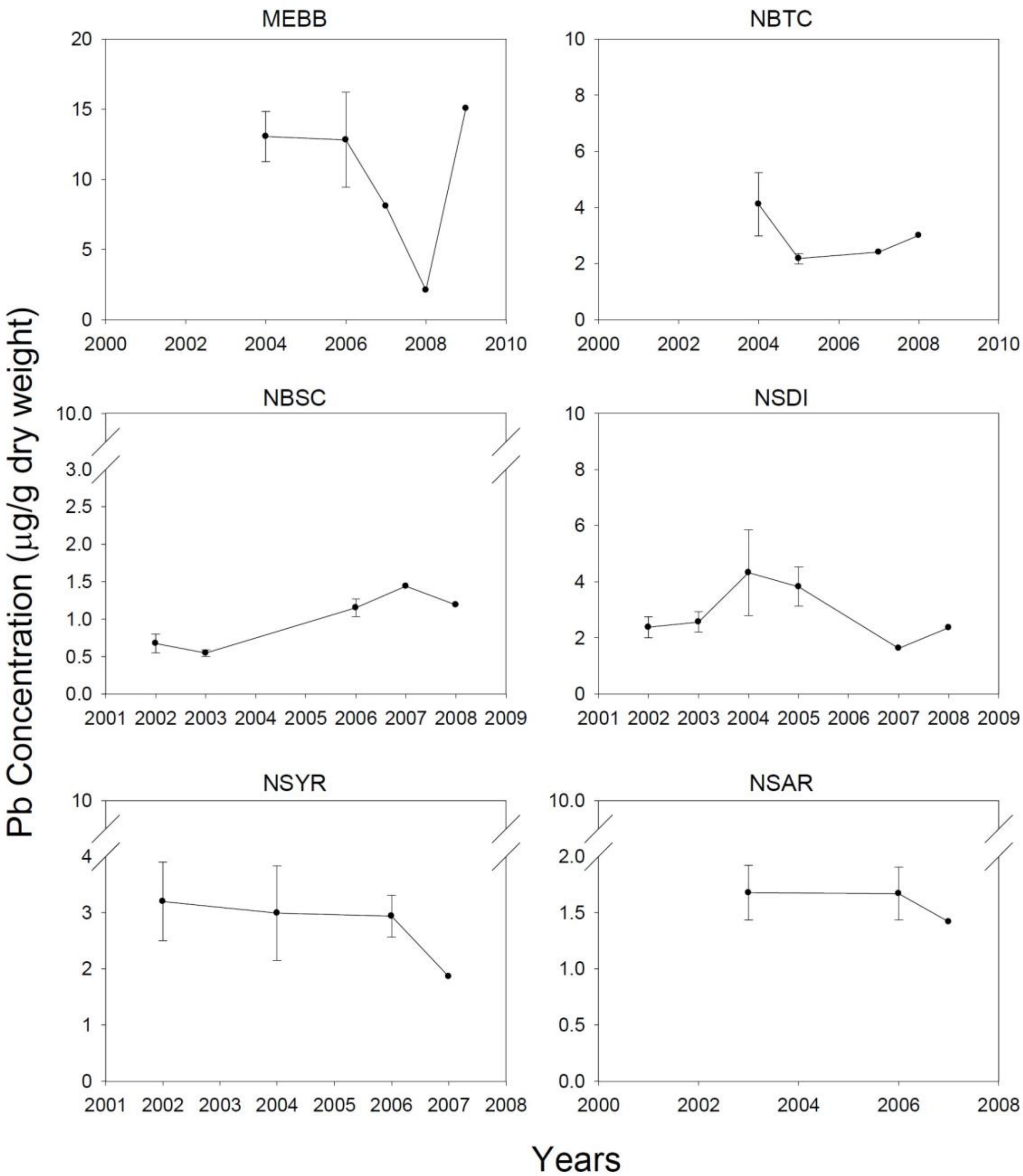

Figure 20. Trend of tissue concentrations of lead in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

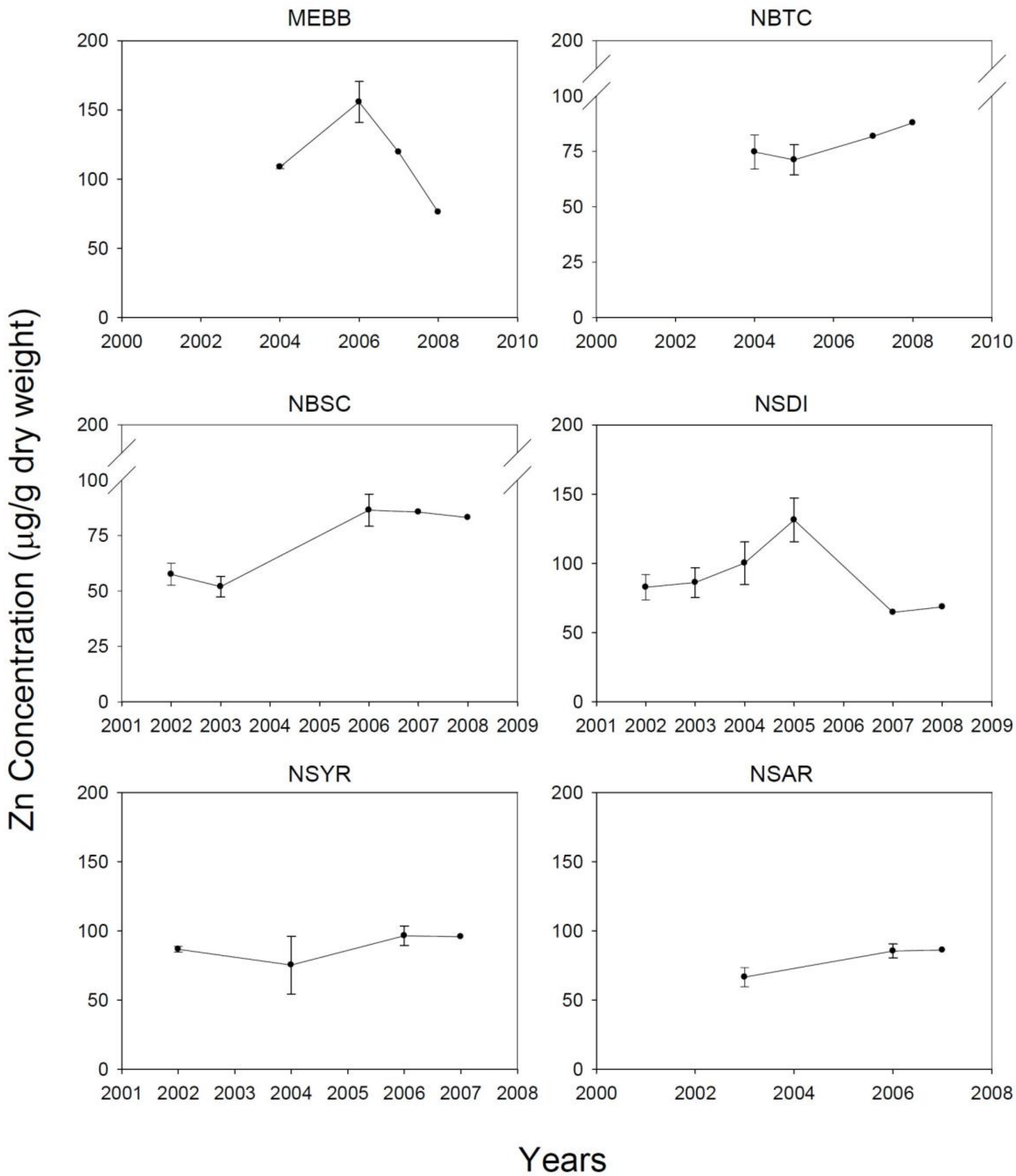

Figure 21. Trend of tissue concentrations of zinc in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. One site in Maine (West Boothbay Harbour) is included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

<u>Crustaceans</u>: Digestive glands of lobster from the Bay of Fundy showed concentrations of key contaminant metals—copper, cadmium and silver—which had a similar spatial distribution in the environment to environmental concentrations (Chou et al. 1998, 1999, 2000, 2003). Low and relatively uniform levels were observed overall with the highest reaching 22.9 µg Cd/g, 856 µg Cu/g, 11.5 µg Ag/g, and 129 µg Zn/g wet weight (Chou et

al. 2003). High copper concentrations in lobsters from the inner Bay of Fundy (600 to 800 µg Cu/g wet weight) were found in Cobequid Bay, Cumberland Basin, and Shepody Bay and lower concentrations (110 µg/g) in Minas Channel (Chou et al. 2000, 2002a, 2002b). Lobster from the Musquash Estuary Marine Protected Area (MPA) showed that levels of silver, cadmium, copper, mercury, and zinc concentrations are within the range reported for for the Maritimes including the outer Bay of Fundy, ranging from 5.6 to 271 µg/g wet weight (Chou et al. 2004).

Levels of heavy metals in Rock Crab in the Minas Channel, Minas Basin and Cobequid Bay of the inner Bay of Fundy follow similar geographic patterns to those of lobster (Chou et al. 2002b) with highest concentrations in the inner, easternmost parts. Copper concentrations in the digestive glands are significantly higher in the inner Bay of Fundy (Minas Channel to Cobequid Bay) than in the southern Gulf of St. Lawrence (Dalhousie, New Brunswick) and other areas reported in the literature (Chou et al. 2002b). Highest levels occur in Minas Basin (mean 150 µg/g wet weight), including the Parrsboro area (mean 215 µg/g wet weight) and Cobequid Bay (mean 165 µg/g wet weight), and lower levels at two sites in Minas Channel (means of 70 to 80 µg/g wet weight) (Chou et al. 2002b). Similar patterns were observed for zinc and cadmium, but not for silver or manganese (Chou et al. 2002b). There were no obvious anthropogenic sources of heavy metals in these areas and the overall origin is unknown (Chou et al. 2002b).

6.2.2. Organic Contaminants in Biota – Bay of Fundy/Gulf of Maine

Various organic contaminants reflecting the spectrum of those both classical (e.g., persistent organic pollutants including PAHs, PCBs, chlorinated pesticides) and emerging contaminants (e.g., PBDEs) potentially can enter the Bay of Fundy from various sources and be taken up by organisms. Emerging contaminants with potential for impacting marine organisms are usually identified by researchers in academia and government, and targeted for screening studies.

Levels of DDT reported in tissues of marine animals in the Bay of Fundy, including its component suite of forms—p,p'-DDD, p,p'-DDE, p,p'-DDT, o,p'-DDD, o,p'-DDE and o,p'-DDT—in many cases showed high risk factors for harm based on tissue levels known to cause effects (Mercer and Kidd 2015). Lotze and Milewski (2002) summarized PCB and DDT concentrations from various studies of mussels from the Quoddy Region (Tables 24 and 25). DDT has not been a focus of studies recently (i.e., after about 1980). Twenty-five percent (1 of 4) of the bird species and 11 percent (1 of 9) of the fish species in the Bay of Fundy, for which potential risk of DDT toxicity was assessed based on levels observed in tissues, may be at risk (Mercer and Kidd 2015). It was not possible to calculate risk quotients (RQs) for marine mammals and invertebrates due to the paucity of data (Mercer and Kidd 2015). DDT levels in tissues of fish or invertebrates pose a risk to wildlife eating them; eight of nine fish species and three of four invertebrate species would have some risk for consumers such as seabirds and raptors and other wildlife, based on tissue concentrations of DDT (Mercer and Kidd 2015).

Table 24. PCB residues in mussels in the inner Quoddy Region. Sources: Gulfwatch: Sowles et al. 1996 and Chase et al. 1998. Note: ng/g = ppb. Reproduced from Lotze and Milewzki 2002.		
Year	**Location**	**Total PCBs (all congeners)**
1993	L'Etang Estuary	6.5-8.6
	Hospital Island	2.0-4.7
	Todds Point	17-23
1997	Lime Kiln Bay	7.2-11.6
	Chamcook	0
	Niger Reef	1.7-2.5

Table 25. DDT residues in mussels in the Passamaquoddy Bay/Fundy Isles area. Sources: Sprague et al. 1969; Gulfwatch: Sowles et al. 1996 and Chase et al. 1998. Note: ng/g = ppb. (Reproduced from Lotze and Milewski 2002).			
Year	**Location**	**DDT (ng/g)**	**DDE[1] (ng/g)**
1969	St. Andrews	40.0	50.0
1993	L'Etang Estuary	<2.0	<2.0-6.2
	Hospital Island	<2.0	<2.0-4.4
	Todds Point	<2.0	<2.0
1997	Lime Kiln Bay	<0.7-<1.3	<1.1-6.2
	Chamcook	<0.7-<1.3	<1.1-3.4
	Niger Reef	<0.7-<1.6	<1.1-3.6

[1]p,p[1]-DDE and o,p[1]-DDE.

<u>Birds:</u> All organochlorines (DDE, PCBs, hexachlorobenzene, dieldrin, oxychlordane, beta-hexachlorocyclohexane and mirex) measured in a study of long-term contaminant trends in the bioregion showed declines in concentration in seabird eggs (Double-crested Cormorant, Leach's Storm-petrel, Atlantic Puffin and Herring Gull) from 1972 to 1996, sampled at Manawagonish, Kent and Machias Seal Islands in the outer Bay of Fundy (Burgess and Garrity 1999). The patterns of decline differed between species, suggested to reflect response to different pollutant effects in feeding areas.

Many of the same compounds—PCBs, DDT breakdown products (DDE and DDD), oxychlordane, trans-nonachlor, mirex and hexachlorobenzene—have been detected in blood of Common Loons from lakes in coastal areas of New Brunswick in 1995 (24 lakes in the Lepreau area and one in Fundy National Park). The species breeds inland but also occupies marine and estuarine coastal areas for much of the year. Loons from the Lepreau area had low levels in blood of PCBs, DDE, oxychlordane, trans-nonachlor, mirex and hexachlorobenzene, with PCBs and DDE predominating. Levels were on the low end of the range reported for other large birds (e.g., Bald Eagle) in North America (Burgess et al. 2005).

Perfluorinated chemicals (PFCs) have been measured, although at comparatively low levels, in Herring Gull eggs from the southwestern Bay of Fundy (Gebbink et al. 2011).

Levels in Herring Gull eggs sampled in 2008 on Kent and Manawagonish Islands were among the lowest of both perfluroinated sulfonic acids and perfluorinated carboxylic acids in gull eggs from across Canada (Gebbink et al. 2011).

The influence of diet on contaminant impacts to birds and in identifying contaminant sources has been documented for flame retardants in the eggs of Herring Gull in the bioregion (Kent Island, Manawagonish Island, and Sable Island) using stable nitrogen and carbon isotopes as dietary tracers. PBDE congeners, hexabromocyclododecane and *Dechlorane Plus* flame retardant types were detected in eggs, with PBDE congeners most dominant in egg samples (n=10) at all locations (Kent Island ($\bar{x}$ = 245 ng/g wet weight), Manawagonish Island ($\bar{x}$ = 127 ng/g wet weight), and Sable Island ($\bar{x}$ = 140.7 ng/g wet weight) (Chen et al. 2012). These levels were low compared to inland Canadian colonies. Levels of another flame retardant group, hexabromocyclo-dodecanes (HBCDs), are also low in Herring Gull eggs from colonies in the Bay of Fundy (Chen et al. 2012). Overall, there is good evidence for food chain magnification of PBDEs in the Gulf of Maine ecosystem based on measurements of tissues in mussels, herring, Harbour Seal, White-sided Dolphin and Bald Eagle eggs (Harding 2013).

Volatile methylsiloxanes (VMSs) and organophosphate esters (OPEs) are organic compounds of environmental concern but whose bioaccumulation in organisms has not been studied (Lu et al. 2017). Industrial use of OPEs has increased in recent years to replace the banned PBDEs. Volatile methylsiloxanes have been detected in gull eggs from across Canada (Herring Gull from NWT and Saskatchewan eastward; Glaucous-winged Gull and California Gull in Alberta and British Columbia). Levels in Herring Gull eggs at Kent Island, in the outer Bay of Fundy, New Brunswick (mean total VMS = 49.2; range 2.7-161 ng/g wet weight, with 4 of 6 VMS target compounds found) were among the lowest in Canada—about one-quarter to one-third the concentrations in the St. Lawrence Estuary, Hamilton Harbour and Newfoundland, the latter where the authors attributed the elevated levels to feeding at landfills (Lu et al. 2017). Across Canada, OPEs were detected, although at low levels and with a low frequency for different compounds surveyed in gull eggs. At Kent Island, New Brunswick, five of eight target OPEs were detected at low levels up to 9.1 ng/g wet weight (Lu et al. 2017). Overall low levels indicate low contamination and low bioaccumulation potential of these contaminants in Canadian gulls and suggest that low dietary exposure or rapid metabolism of accumulated OPEs occurs in aquatic feeding birds (Lu et al. 2017).

Some water-associated birds that feed on adult stages of aquatic insects have a body burden of various contaminants. Tree swallow nestlings in New Brunswick and Nova Scotia in the bioregion have detectable levels of PCBs, organochlorine pesticides, dioxins, furans, and metals in the vicinity of the St. Croix River estuary and L'Etang Rivers in the Quoddy Region, as well as near Sydney Harbour, Cape Breton (Burgess et al. 2000). Total dioxin and furan toxic equivalency factors (TEQs) are highest in the Miramichi and St. Croix areas of New Brunswick, but below levels which would cause reproductive impairment (Burgess et al. 2000); and levels of contaminants overall are less than for birds from the Great Lakes and St. Lawrence and Hudson Rivers (Burgess et al. 2000).

Marine Mammals: Contamination in marine mammals by organic compounds of various kinds has been a concern, both in terms of the effects of buildup of harmful contaminants on the biology of the organisms, and as indicators of overall levels and types of contamination in the marine environment to which they are exposed. Studies on contaminants in cetaceans are summarized in Table 19 (Section 6.1.4). Concentrations and accumulation patterns of organochlorine contaminants in the blubber of Harbour Porpoise (*Phocoena phocoena)*, sampled from commercial fishery by-catch in the Bay of Fundy, reflect feeding on organisms exposed to sources of contamination, such as local municipal and industrial outfalls and facilities (Westgate et al. 1997, Westgate and Tolley 1999). In particular, chlordanes, DDTs, PCBs, HCHs (*Lindane*) and chlorinated bornanes (e.g., the pesticide *Toxaphene*) have been detected in Harbour Porpoise sampled from fisheries bycatch in the Bay of Fundy-Gulf of Maine, including Jeffreys Ledge and Grand Manan. Levels exceed those in porpoises from coastal waters around the Avalon Peninsula, Newfoundland and the Gulf of St Lawrence (Gaspé Peninsula, Quebec) (Westgate and Tolley 1999, Westgate et al. 1997). However the contaminant composition in Bay of Fundy-Gulf of Maine porpoises was similar to animals from Newfoundland and the Gulf of St. Lawrence (Westgate et al. 1997) and showed male-female differences. Male Harbour Porpoise tend to accumulate organochlorines throughout their lives, whereas levels in females tend to decrease, presumably due to the losses incurred transplacentally to the fetus during gestation and through lactation (Gaskin et al. 1971, 1976, 1983; Westgate et al. 1997; Westgate and Tolley 1999).

North Atlantic Right Whales (*Eubalaena glacialis*) in the Gulf of Maine have various organochlorine compounds in their tissues (Weisbrod et al. 2000). Skin and blubber sampled in 1994 and 1995 contained 30 PCBs (total PCB, 5.7 ± 8.9 µg/g lipid) and 20 pesticides (total pesticides, 11.4 ± 15.4 µg/g lipid), and levels varied seasonally due to prey selection and seasonal depletion of lipid reserves in the winter. Winter blubber samples had half the metabolizable PCBs and hexachlorobenzene concentrations of those collected in summer. Tissue concentrations were two to three orders of magnitude higher than organochlorine concentrations in zooplankton prey, *Calanus finmarchicus,* from the Bay of Fundy, though the relative proportions of organochlorines in biopsies matched those from zooplankton prey. Age and gender-related differences that include metabolic capability and prey selection were minor factors in the bioaccumulation of the organochlorines measured, but for some metabolizable PCBs and trans-chlordane, males had higher concentrations than females as they aged, while concentrations of other compounds such as 4,4'-DDE were similar between genders at equal ages (Weisbrod et al. 2000).

Concentrations of various organochlorine compounds have been measured in White-sided Dolphins (*Lagenorhynchus acutus)* and Long-finned Pilot Whales (*Globicephala melas)* stranded or caught in nets around the Gulf of Maine, and in Long-finned Squid, Atlantic Mackerel and Atlantic Herring, which are common prey (Weisbrod et al. 2001). Concentrations were from one to three orders of magnitude higher than in the prey. Squid appear to be a significant source of PCBs, while mackerel, herring and presumably other prey at the same trophic level are a probable source of 4,4'-DDE (Weisbrod et al. 2001). Total PCB concentrations in blubber measured for White-sided

Dolphin were 13 ± 7.1 µg/g fresh weight with PCB congeners Cl_6 (153) and Cl_6 (138) having the highest concentrations. Total organochlorine pesticides reached 20 ± 13 µg/g fresh weight (Weisbrod et al. 2001) with 4,4'-DDE, and trans-nonachlor having the highest concentrations (Weisbrod et al. 2001). Although both Long-finned Pilot Whales and White-sided Dolphins feed at the same trophic level and store a similar suite of contaminants, dolphins accumulated higher and potentially hazardous 4,4'-DDE and PCB concentrations (Weisbrod 2001). This study also found hexachlorocyclohexane (HCH) isomers and low levels of the organochlorine pesticide dieldrin in these species.

Concentrations of hexabromocyclododecanes (HBCDs, another flame retardant compound) in blubber of White-sided Dolphin sampled from the U.S. east coast between 1993 and 2004 were low—between 3 and 340 ng/g lipid—and also lower than in cetaceans from Western Europe, and didn't show a temporal trend over the period surveyed (Peck et al. 2008). This study used tissues stored in the U.S. National Marine Mammal Tissue Bank (NMMTB), which has been operated by the U.S. government (NOAA) since 1992 to preserve samples from selected species obtained from strandings, by-catch of commercial fisheries, and Native American subsistance fisheries. Levels of HBCDs were also detected in livers of most Harbour Seals sampled from coastal New England strandings (including coastal Maine) between 2001 and 2006 (Shaw et al. 2012), but no regional gradient was observed (Shaw et al. 2012).

Halogenated organic compounds have been analyzed since the early 1970s in Harbour Seals in coastal areas of New England from Maine to New York (e.g., Shaw et al. 2005, 2007, 2014). Harbour Seals are indicators of the degree of contamination and bioaccumulation of contaminants, but also are potentially affected physiologically, in particular in lowering resistance to disease and contributing to disease outbreaks experienced in seal populations in North America and Europe since the 1980s (Shaw et al. 2007). Although predominantly coastal, Harbour Seals (*Phoca vitulina concolor*) range offshore in the Gulf of Maine and Scotian Shelf-Bay of Fundy ecosystem. Exposure to these contaminants could occur there in marine mammals through feeding on the migratory fish that move through both ecosystems.

Harbour seals from New England coastal areas, including the Maine coast, have significant body burdens of PCBs (measured in both blubber and liver), which decrease from south to north, reflecting the gradient in industrialization and population from the most industrialized areas (New York to Massachusetts) to eastern Maine (Shaw et al. 2005, 2007, 2014). PCB concentrations in Harbour Seal blubber sampled in 2001-2002 (concentrations ranging from 5.7 to 151 µg/g on a lipid weight basis) were similar to levels reported in seals from polluted areas of Europe and Asia (Shaw et al. 2005, 2007); and dioxins and furans (PCCDs and PCDFs) have been detected, although at low levels, indicating exposure in the ecosystem to these highly toxic contaminants (Shaw et al. 2007). Concentrations of PCBs in blubber in the seals sampled in 2001-2002 were similar to those from animals sampled in 1991, indicating a lack of temporal trend over that period (Shaw et al. 2005, 2007). Similar spatial and temporal patterns of PCB concentrations were found in liver tissues of harbour seals sampled from 2001-2006 (Shaw et al. 2014). Most of the animals sampled in these studies were pups. In the 2007 study, Shaw et al. (2007) showed that total PCB concentrations in blubber were highest in young seals, mid-range in males, and lowest in females, consistent with a pattern observed for lipophilic organohalogenated compounds in which females transfer a large proportion of their body burden during lactation (Shaw et al. 2007). A different pattern of accumulation was observed for PCB concentrations in liver, where highest concentrations were found in male pups, mid-range in adult males, and lowest in female pups with no adult females reported (Shaw et al. 2014).

When seals and other animals metabolize PCBs and PBDEs, they change the chemical structure, creating modified compounds which are also harmful (Weijs et al. 2014). Several of a suite of these resulting compounds—hydroxylated PCBs, and methoxylated and hydroxylated PBDEs—have been detected in tissues of Harbour Seal pups from the New England coast including the Gulf of Maine (Weijs et al. 2014). These compounds disturb hormonal and endocrine systems and are likely an added physiological stressor to the pups (Weijs et al. 2014).

Chlorinated pesticides detected in blubber of stranded Harbour Seals from the coast of New England including coastal areas of Maine in 2001-2002 included predominantly DDT (dichlorodiphenyltrichloroethane) and its metabolite p,p′-DDE (DDE), and chlordane-related compounds (CHLs) (Shaw et al. 2005). Levels of mirex, hexachloro-cyclohexane isomers (HCHs), dieldrin, and hexachlorobenzene (HCB) were low, and concentrations of aldrin, endrin, endrin aldehyde, endrin ketone, and methoxychlor were lower than detection limits (Shaw et al. 2005). Levels of total DDT ranged from 1.4-57.5 μg/g lipid weight, CHLs (0.3-17.6 μg/g), mirex (3.2-605 ng/g), HCHs (22-425 ng/g), and dieldrin (3-1060 ng/g); and HCB was detected at trace levels (Shaw et al. 2005). The occurrence of chlorinated organic pesticides and PCBs, particularly at elevated levels, indicates potential health effects on the seals and has been suggested as a contributing factor in the recurring disease outbreaks reported among Harbour Seals since the late 1970s (Shaw et al. 2005). DDT concentrations in Harbour Seal blubber have declined from the high levels reported in the early 1970s, but were stable over the ten-year period 1991-2001 (Shaw et al. 2005).

Harbour Seals from the New England coast from Maine to Long Island have elevated levels of PBDEs (Shaw et al. 2008). Mean ∑PBDE concentrations in blubber were 3645 ± 7388, 2945 ± 5995, 1385 ± 1265, and 326 ± 193 ng/g lipid weight in pups, yearlings, adult males, and adult females, respectively (Shaw et al. 2008). Levels were an order of magnitude higher than those recently reported in marine mammals from European waters, and at the high end of the concentration range reported for PBDEs in marine mammals around the world (Shaw et al. 2008). No differences in concentrations occurred between urban-dominated and rural/remote coastal areas (i.e., Maine); and no significant temporal trend was observed between 1991 and 2005, although congener profiles shifted over time (Shaw et al. 2008). These levels were many times those found in fish sampled in 2006 from similar coastal areas, indicating bioaccumulation through the food web (Shaw et al. 2009a). Biomagnification factors (the ratio of the concentrations in seals to levels in fish) ranged from 17 to 76 for different PBDE compounds (Shaw et al. 2009a).

Perfluorochemicals (PFCs)—persistent industrial compounds consisting of fluorinated carbon chains and which are an increasing environmental concern in the environment, wildlife, and humans worldwide—have been found in tissues of harbour seals from New England (coastal Maine to New York) (Shaw et al. 2009b). These chemicals bioaccumulate in the food web, although unlike persistent organic pollutants (POPs) they are not lipophilic (i.e., not preferentially accumulated in fats) and likely reach the ocean from local production and atmospheric transport (Shaw et al. 2009b). Perfluorooctane sulfonate (PFOS) (measured in liver tissue of the seals) predominated at concentrations of 8-1388 ng/g wet weight, followed by perfluoroundecanoic acid (<1-30.7 ng/g wet weight) (Shaw et al 2009b) among ten compounds detected in livers of seals stranded from 2000-2007. Concentrations do not show a regional trend corresponding to level of industrialization or density of population along the coast (i.e., from New York to Maine—and by inference to the Bay of Fundy/Gulf of Maine system); however levels increased from 2000-2007 in adult seals for perfluoroctane sulfonate and perfluorocarboxylic acids (Shaw et al 2009b). Physiological effects of PFCs are not well known but their presence at elevated levels is a potential stressor for this and other species.

Invertebrates: High dioxin levels measured in lobster in the St. Croix River estuary in inner Passamaquoddy Bay and in the outer Bay near Eastport in the mid-1990s (Maine DEP 1996 from Lotze and Milewski 2002, Passamaquoddy Tribe and CBRC 2001) led the State of Maine to recommend that lobster tomalley not be eaten by the public after 1994 based on a food guideline for cancer risk of 1.5 ppt (TEQ) (Lotze and Milewski 2002). Levels in lobster meat, cod, scallops and clams from Passamaquoddy Bay were lower, but approximated the Environment Canada guideline for consumption by mammals (0.71 TEQ) (Environment Canada 2001, Maine DEP 1996 from Lotze and Milewski 2002, Passamaquoddy Tribe and CBRC 2001).

In general, Canadian Gulfwatch sites (LeBlanc et al. 2011) have the lowest levels of organic contaminants (PAHs,[47] PCBs and pesticides) in Blue Mussels, and show levels that have been relatively stable since the early 2000s (Figure 13). PCB levels from New Brunswick and Nova Scotia sites were lower than for the rest of the Gulf of Maine; several sites showed non-detectable levels; and none of the levels were of environmental concern

[47] The suite of from 24 to 40 PAH compounds, 21 PCB congeners and 21 pesticides measured in the Gulfwatch Program to provide estimates of total PAH, total PCB, and total pesticides is consistent with those used in the U.S. National Status and Trends Program protocol (NOAA 1989 from LeBlanc et al. 2011). The Gulfwatch mussel watch program (O'Connor 1992, 1998; Sowles et al. 1997) and some research studies cited in this report (e.g., Hellou et al. 2005b in Halifax Inlet) include some PAHs and related compounds in addition to the 16 priority PAHs analyzed most frequently, giving rise to the term Polycyclic Aromatic Compounds (PACs). The summary measure "total PAH" is comparable, despite the differing number of compounds, which are often present at low levels. Commercial labs usually have higher (less sensitive) detection limits than available in Gulfwatch and other research studies. The EPA list of 16 Priority PAHs was developed as a standard measure to be used for assessing human health risks from drinking water and was in some ways artificial—for example, the compounds were in part selected because of availability of standards (Hellou et al. 2012) and thus it omits groups of PACs which are considered important (Andersson and Achten 2015). However, it has almost universally become the main tool for assessing PAH risk in a wide range of environmental studies.

(i.e., exceeding the U.S. National Status and Trends (USNST) program 85th percentile) (LeBlanc et al. 2011) (Figure 13). Pesticide levels were similarly lower at Canadian sites, and were primarily the DDT metabolites DDE and DDD, and no sites had values exceeding the USNST 85th percentile. From the 1960s to the early 1990s, the long-term trend in levels of the organochlorine pesticide, dieldrin, in Gulfwatch mussel samples was downward, showing a ten-fold drop, but the decline subsequently leveled off over the 1993 to 2008 period (Jones et al. in prep from Harding 2013). The compound is least prevalent in the Gulf of Maine compared with other U.S. Mussel Watch sites, with only single Gulf of Maine and Nova Scotia sites showing detectable dieldrin (and its stereoisomer endrin) between 1993 and 2008 (Harding 2013). For other organochlorines, the Gulfwatch samples showed relatively stable levels at Gulf of Maine sites recently despite a decline from the early 1970s to the mid-1980s, and a subsequently decreasing trend of chlordanes from 1986 to 2008 at U.S. east coast sites overall (O'Connor and Lowenstein 2006 from Harding 2013). There were low recent levels or non-detection, and low frequency of detection primarily in the mid-1990s of lindane, the only form of hexachlorocyclohexane detected in Gulfwatch samples (Harding 2013); rare and low-level detection of hexachlorobenzene, the only measureable organochlorine detected in Gulfwatch samples, in the 1990s and early 2000s (O'Connor et al. in prep from Harding 2013); an exponential decline with time to a stable trend currently and a regional southwest to northeast trend in the Gulf of Maine in ∑DDT (O'Connor et al. in prep from Harding 2013); and no temporal trend in ∑PCB levels in mussels from the 1940s, which can be locally high (e.g., Boston area), but decrease from the southwest Gulf of Maine to the northeast towards the Scotian Shelf Bioregion (Harding 2013). Recent trends of PAH, PCB and chlorinated pesticide compounds at selected sites in Gulfwatch are shown in Figures 22 to 24.

Some physiological indicators of endocrine disruption, as well as elevated levels of organic contaminants (PCBs, chlordane, DDT and breakdown products DDE and DDD) in mussels were found in the Passamaquoddy Bay-L'Etang Inlet area of New Brunswick (five sites) but not in Annapolis Basin, Nova Scotia (three sites), which spanned a similar spectrum of anthropogenically-impacted and reference areas (Engel et al. 2006).[48, 49] Among contaminants, metal levels in mussel tissues were similar between sites in both areas, while only PCBs, chlordane, DDT, DDE, and DDD were slightly elevated near a ferry dock, finfish aquaculture sites, and municipal sewage in New Brunswick, above those at reference sites (Table 26). The sites chosen for exposure to potential human impacts also showed a higher incidence of leukemia in mussels compared with reference areas (Engel

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[48] Physiological biomarkers included reproductive biomarkers (extractable gonadal proteins and vitellogenin-like proteins), indicators of gametogenesis activity (aspartate transcarbamoylase activity); coprastanol and cholesterol levels; incidence of leukemia; and estrogenicity of sediment collected at the sites. Metals and organic contaminants examined in the study included PCB Gulfwatch congeners; pesticides (aldrin, chlordane, DDD, DDE, DDT, dieldrin, endosulfan, endrin, heptachlor, benzenehexachloride, methoxychlor, mirex, HCB, nonachlor); and Emamecten benzoate (sea-lice control agent, at sea farms only) (Engel et al. 2006).

[49] Sites in Passamaquoddy Bay Area, New Brunswick: sewage treatment plant, St. Andrews; Kilmarnoc Head aquaculture site, Chamcook; Lake Utopia pulp mill, St. George; Lime Kiln aquaculture site, Back Bay; Grand Manan ferry and fish plant, Black's Harbour; Dead Man's Harbour (less impacted site). Sites in Annapolis Basin, Nova Scotia: Karsdale, near Port Royal, (less impacted site); aquaculture site, Rattling Beach; sewage treatment plant, Digby.

et al. 2006). Estrogenic activity in sediments in all areas was low; vitellogenin levels (an indicator of an endocrine effect) and gametogenic activity only showed an effect at one site, a sewage plant in New Brunswick.

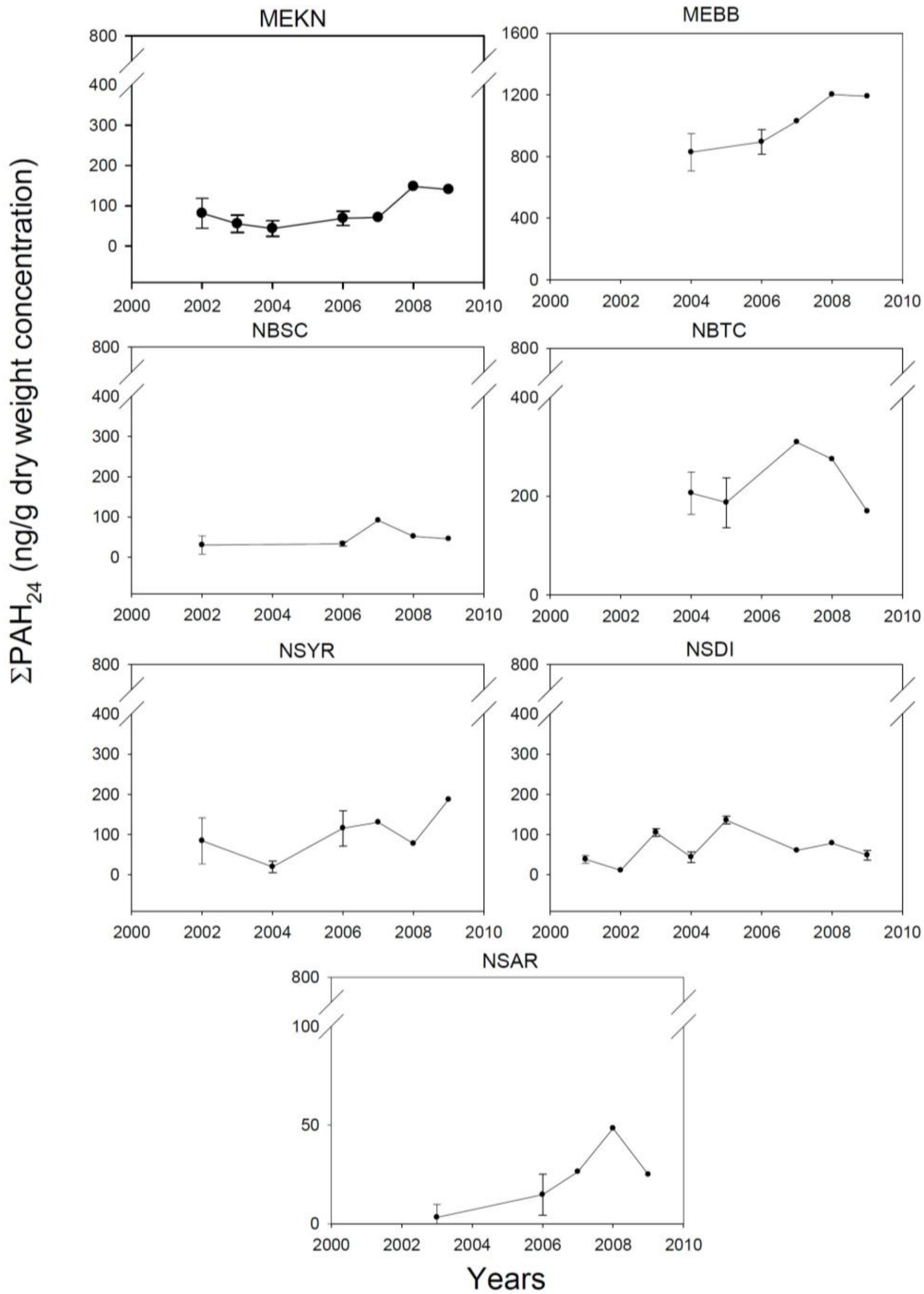

Figure 22. Trend of tissue concentrations of 24 PAH compounds in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. Two sites in Maine (Kennebec River and West Boothbay Harbour) are included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

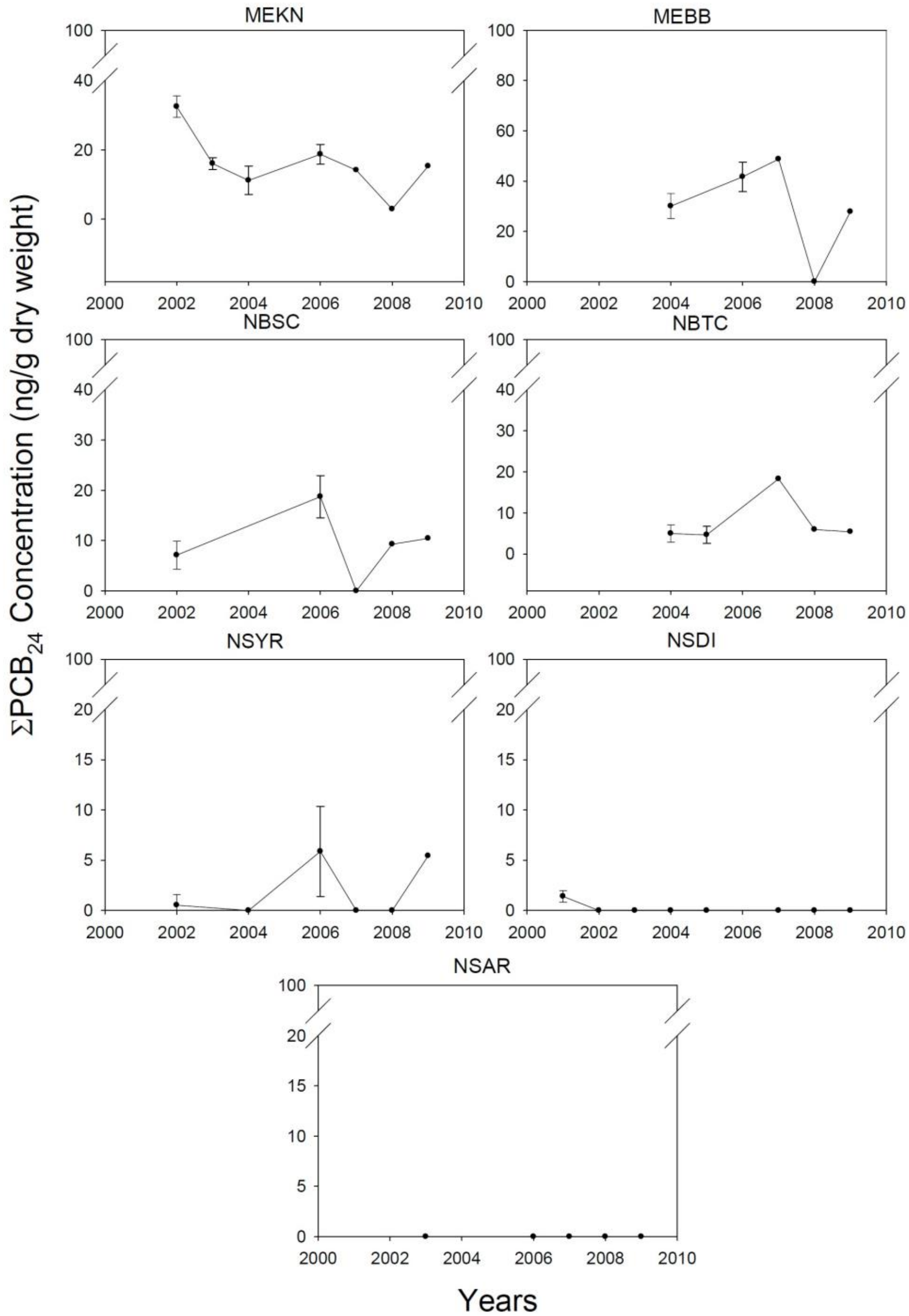

Figure 23. Trend of tissue concentrations of 24 PCB congeners in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. Two sites in Maine (Kennebec River and West Boothbay Harbour) are included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

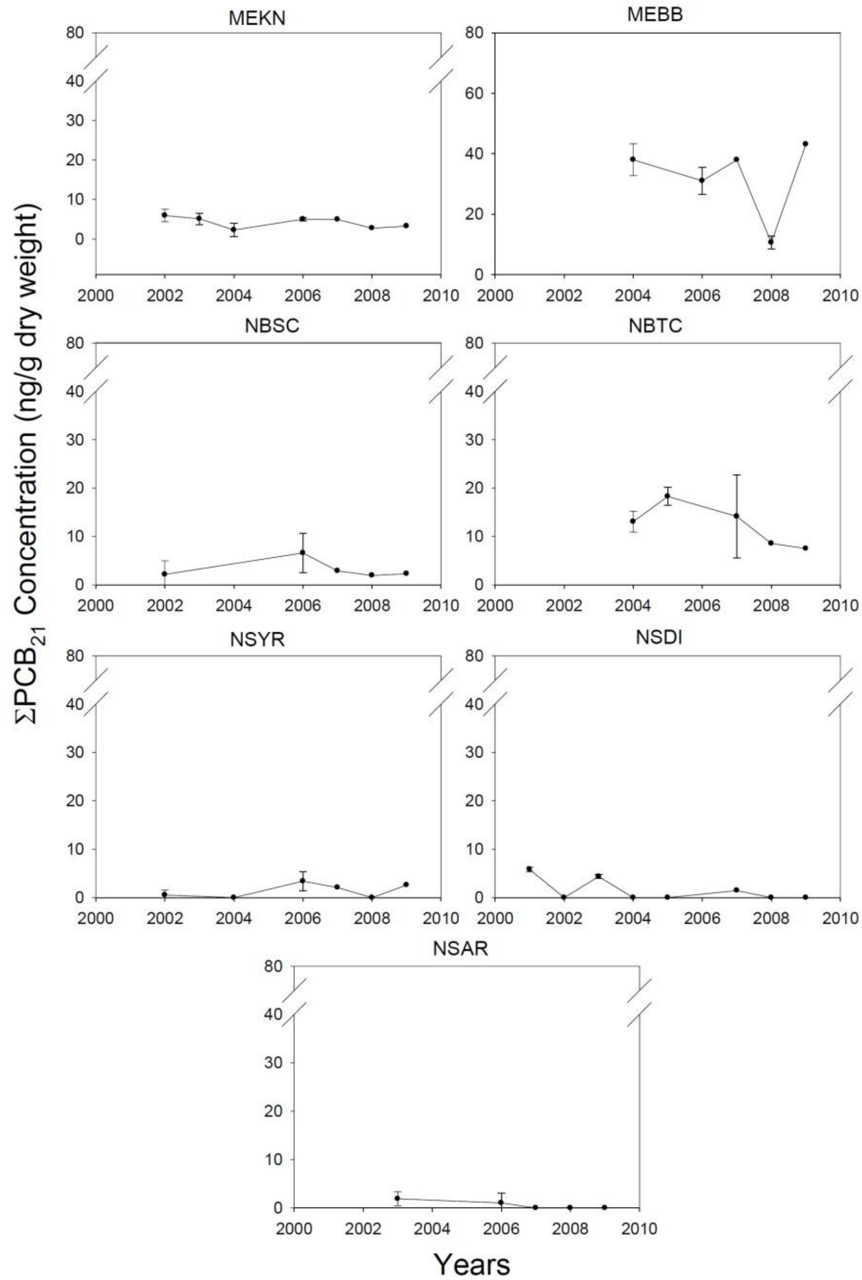

Figure 24. Trend of tissue concentrations of 21 chlorinated pesticides in mussels sampled in Gulfwatch at New Brunswick and Nova Scotia sites in 2001-2009. Two sites in Maine (Kennebec River and West Boothbay Harbour) are included for comparison. Codes for Nova Scotia and New Brunswick sites are in the caption for Figure 12. Arithmetic mean ± 1 standard deviation for multiple pools, or a single point if only one pool was analyzed (Source: LeBlanc et al. 2011).

Table 26. Concentrations of PCBs and pesticides in homogenized soft tissue of mussels at sites studied for the incidence of physiological abnormalities (Engel et al. 2006).											
	Distance from site (m)	Low impact site NS	Low impact site NB	Aquaculture site Digby, NS	Aquaculture Site Kilmarnoc Head, NB	Aquaculture site Lime Kiln Bay, NB	Digby sewage treatment plant, NS	St. Andrews sewage treatment plant, NB	Grand Manan ferry, NB	Lake Utopia pulp mill, NB	Fish plant, NB
	(ng/g wet weight)										
PCB	0	<2	2	<2	<2	3	5	<2	72	16	54
	500	<2	2	<2	<2	8	11	<2	27	--	--
	1000	<2	2	<2	<2	5	2	2	71	--	--
Chlordane	0	--	1.5	<1	<1	<1	<1	<1	7	2.5	14
	500	--	<1	<1	<1	<1	<1	<1	2.5	--	--
	1000	--	<1	<1	2.5	<1	<1	<1	2.5	--	--
Benzene hexachloride	0	<1	2	<1	<1	<1	<1	<1	<1	2	1
	500	<1	<1	<1	<1	<1	<1	<1	<1	--	--
	1000	<1	<1	<1	<1	<1	1	<1	<1	--	--
DDT and congeners	0	2	18	<2	10	5	2	25	45	34	71
	500	<2	8	<2	8	5	2	13	20	--	--
	1000	<2	8	<2	12	20	2	7	55	--	--
Dieldrin	0	6	5	5	3	3	3	7	5	12	6
	500	3	4	3	3	5	5	3	4	--	--
	1000	6	2	5	3	3	3	2	4	--	--

Fish: No dioxins or furans were detected in Atlantic Tomcod tissues in Saint John Harbour in the vicinity of the Irving Pulp and Paper Mill in 1994-1995, in environmental effects monitoring carried out under the Canadian Pulp and Paper Regulations (Parker and Smith 1999). Low levels of several organochlorine pesticides were found in mackerel and herring in the commercial weir catch at Grand Manan in the southern Bay of Fundy; and in squid caught in the Gulf of Maine in the mid-1990s (Weisbrod et al. 2001) (Table 27). Mirex—an organochlorine pesticide which had been used extensively and phased out in the late 1970s—was not detected in these samples although it can be found in organisms high in the food chain (i.e., White-sided Dolphin, Long-finned Pilot Whale and Harbour Seals) (Weisbrod et al. 2001, Shaw et al. 2005). Other organochlorines detected in herring, mackerel and squid included PCBs, hexachlorobiphenyls, HCHs, heptachlor and heptachlor epoxide, chlordanes, DDT and metabolites, hexachlorobenzene, and dieldrin (Table 27). PBDEs and hexabromo-cyclododecane (HBCD) (used primarily in expanded polystyrene foams and styrene resins) were found in groundfish and pelagic fish sampled in coastal Maine in 2006

(Shaw et al. 2009a). PBDEs were detected in all species tested, including Silver Hake (*Merluccius bilinearis*), White Hake (*Urophycis tenuis*), Atlantic Herring (*Clupea harengus*), American Plaice (*Hippoglossoides platessoides*), Alewife (*Alosa pseudoharengus*), Winter Flounder (*Pseudopleuronectes americanus*), and Atlantic Mackerel (*Scomber scombrus*). HBCD was detected in three species—Atlantic Herring, Alewife and Atlantic Mackerel—which were analyzed specifically for the compound. Many of the species sampled have wide-ranging distributions in the Northwest Atlantic and concentrations may indicate levels and contaminant patterns in the bioregion. The occurrence of HBCDs in fish tissues provided a first indication that this compound occurs in the Gulf of Maine food web; subsequently the compounds were detected in liver tissue and blubber of Harbour Seal pups and adults stranded along the New England coast from Maine to New York from 2000-2007 (Covaci et al. 2009). Most liver and all blubber samples contained HBCDs, typically at levels of < 100 ng/g of lipid in livers and < 30 ng/g of lipid in blubber. Whereas commercial HBCD mixtures consist mainly of γ-HBCD, HBCDs in marine biota are dominated by α-HBCD, and selective enrichment of this isomer is observed with increasing trophic level in the food web (Covaci et al. 2009). HBCD concentrations reported in cetaceans from the eastern U.S. coast are one to two orders of magnitude lower than those detected in marine mammals from Europe (Covaci et al. 2009).

Table 27. Levels of organochlorine contaminants of selected pelagic fish species and squid from the Bay of Fundy/Gulf of Maine in 1995, which are prey of White-sided Dolphin and Long-finned Pilot Whale (from Weisbrod et al. 2001).

	Concentration (ng/g wet weight)		
	Squid	Mackerel	Herring
∑PCBs	22.5-24.5	21.6	15.2
∑Hexachlorocyclohexane (HCH)	n.d.-0.04	4.48	1.67
Heptachlor	0.04	0.51	n.d.
Heptachhlor epoxide	n.d.	0.47	0.28
∑Chlordanes	0.40-0.45	5.36	3.81
∑DDT	0.13-0.16	7.91	7.55
Hexachlorobenzene	n.d-0.02	0.4	n.d.
Dieldrin	0.02-0.04	1.44	2.36
Mirex	n.d.	n.d.	n.d.

n.d. = not detected.

Low levels of several persistent organic pollutants (POPs) were found in tissues of farmed Atlantic salmon from the Bay of Fundy and coastal Maine in the early 2000s (Shaw et al. 2006), the result of contamination at the time in oils and meals which constituted the feed. PCBs, DDT and its metabolites, chlordane-related compounds (CHLs), hexachlorocyclohexane isomers (HCHs), and hexachlorobenzene (HCB) were regularly detected, but dibenzo-p-dioxins (PCDDs) and furans (PCDFs) were rarely found (Shaw et al. 2006). Concentrations were similar between farmed fish from Maine and the Bay of Fundy; were low compared with levels measured globally; and were lower than in salmon grown in Norway (Shaw et al. 2006). Industry has since changed feed sources which presumably has lowered levels of POPs expected in farmed salmon (Shaw et al. 2006).

6.2.3. Radionuclides in Biota – Bay of Fundy/Gulf of Maine

Levels of tritium measured in marine organisms at the Point Lepreau Nuclear Generating Station exceeded pre-operational baseline levels and reflect discharges from the reactor (Nelson et al. 2007 MS). Tritium levels have generally been slightly greater in organisms collected near the cooling water outfall compared to those collected near the intake, indicating a cooling water source (Figure 25). Elevated levels of tritium in biota are rarely measured at distances greater than a few kilometres from the outfall. Levels are not of health concern (Nelson et al. 2007 MS). More recent monitoring by Energie NB Power (2015) has indicated low and acceptable levels in biota near the site.

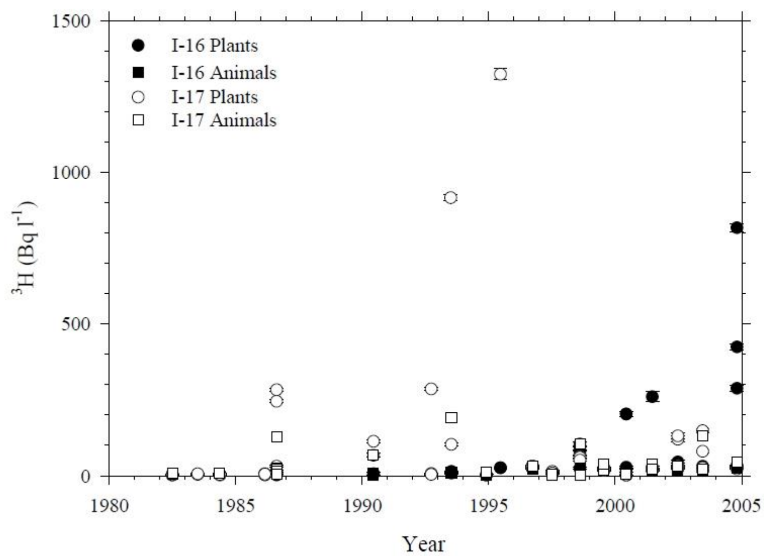

Figure 25. Tritium time series (1980-2005) for marine plants and animals collected near reactor cooling water intake (I-16) and discharge (I-17) sampling sites (Source: Nelson et al. 2007 MS).

7.0 OTHER FORMS OF CONTAMINATION – SCOTIAN SHELF BIOREGION

7.1. PLASTICS AND MARINE DEBRIS

There are no recent summaries reflecting the relative contamination of coastal areas by other categories of contamination, such as bacterial contamination or organic enrichment effects. The occurrence of a form of plastic debris—microplastics—is an emerging contaminant issue worldwide. Mathalon and Hill (2014) demonstrated the presence of microplastic fibres in intertidal sediments, worm casts and in the gut of wild Blue Mussels harvested near Halifax and farmed mussels from the island of Newfoundland. Microplastics are the small plastic particles of various kinds, either those manufactured as components of various chemical products such as daily-use personal care products (primary microplastics), and fibres from a variety of industrial products, as well as plastic particles arising from the breakdown of other plastics and litter in the environment (secondary microplastics). The small particles which range in size from microscopic beads up to fragments 5 mm in size, have the potential to harm the marine ecosystem by interfering with particle-feeding marine organisms and as a vehicle for transferring other contaminants, such as harmful organic chemicals (e.g., hydrocarbons, PCBs and organic pesticides) adsorbed on their surfaces or in their structure into the food chain. Because of concerns over these potential impacts, in June 2016 the Canadian federal government listed microbeads as a toxic substance under CEPA to allow for regulation of their use in Canada.

Plastic fiber occurrence in water, as measured in European continuous plankton recorder studies, has been increasing globally in line with general increases in production of synthetic fibres (Thompson et al. 2004 from Yeats et al. 2008). As of 2008, similar data was not available for the Scotian Shelf. The Mathalon and Hill (2014) study demonstrated ubiquitous contamination by microplastic fibres in sediments from the intertidal zones of one exposed beach and two protected beaches along Nova Scotia's Eastern Shore, in wild mussels harvested near Halifax, and in farmed mussels bought in Halifax but grown on the island of Newfoundland. Possible sources of the microplastics in the mussels were the polypropylene lines on which the farmed mussels were grown, but also anthropogenic inputs from the community near which the mussels were grown or contamination during transport to market. Microplastic fibers were the predominant microplastic form that appeared in the intertidal samples, with concentrations of 20 to 80 microplastic items per 10 g of sediment, and farmed mussels had higher concentrations than wild mussels—up to 178 microplastic fibres were found in individual mussels (Mathalon and Hill 2014). Concentrations in intertidal sediments observed in this study were higher than observed in Belgian Coast sediments, but lower than observed in sediments from the Frisian Islands in Northwestern European waters (Mathalon and Hill 2014). Absolute comparisons cannot be made, however, since this field of study is comparatively new and there is little information locally and globally on microplastics levels in different types of sediments and different regions.

Marine debris of various kinds occurs over the Scotian Shelf and nearby waters of the Atlantic Ocean, as it does throughout the world's oceans, where it can be found drifting in the water column, on the seabed, or accumulating on shorelines. Plastic debris in the marine environment has been identified by the United Nations Environment Programme (UNEP) as a critical emerging global environmental issue and amounts have been increasing (Provencher et al. 2015).

Parts of the Scotian Shelf Bioregion may be more prone than others to the presence of marine debris. Sable Island is near the centre of a local oceanic gyre on the Scotian Shelf that concentrates and deposits marine debris, much of it plastic, on the Island's beaches (Lucas 1992 and Hannah et al. 2001, both from Bond et al. 2014). Quantities of large floating plastic debris in the Gully, the largest submarine canyon on the Scotian Shelf, decreased in three surveys from 1990 to 1999, but there was no trend in quantities of smaller debris collected with plankton nets (Table 28) (Dufault and Whitehead 1994, Scarfe unpublished MS from Yeats et al. 2008).

Table 28. Floating debris in the Gully, 1990-1999 (Scarfe unpublished MS, from Yeats et al. 2008).

Year	**1990**	**1996/1997**	**1999**
Large debris (visual observations, items/km^2	105.4	36.1	20.3
Small debris (neuston nets, mg/m^2)	0.012	0.145	0.025

Consumption of forms of debris by marine wildlife is a widespread problem but detailed plastic ingestion data are available in the bioregion for only six seabird species (Provencher et al. 2015). Plastic ingestion by seabirds can have negative consequences for individuals and populations, including increased contaminant burden, reduced fledging success, lower body mass, and damage to the gastrointestinal tract (Bond et al. 2014). Great Shearwater (*Puffinus gravis*) and Northern Fulmar (*Fulmarus glacialis*), pelagic seabirds which occur seasonally and abundantly in Nova Scotia offshore waters in the outer Bay of Fundy-Gulf of Maine, are particularly prone to accumulating plastic debris (Provencher et al. 2014)—some 71 percent and 51 percent respectively of birds of these species can have some plastic items in their stomachs, with up to 36 items reported in a single Great Shearwater sampled in the Northwest Atlantic. These species and Sooty Shearwater found beached on Sable Island showed high frequencies of plastic ingestion (Bond et al. 2014), with over 72 percent of individuals having plastic debris in their gastrointestinal tract. In one of the species—Northern Fulmar—the average weight of plastics (1.09 ± 1.93 g, n=176) exceeded the OSPAR (2008) Ecological Quality Objective level (EcoQO) for that species in the North Sea. The EcoQO is no more than 10 percent of Northern Fulmars with >0.1 g of plastic in their stomach. Northern Fulmar from Sable Island showed the second highest proportion of birds above 0.1 g (66 percent) in all studies worldwide for that species. The life cycle of the seabirds examined, in particular shearwaters, includes long distance migrations and use of extensive areas of ocean from which the plastic could be acquired. Other seabirds, including Cory's Shearwater, which was also sampled on Sable Island, may not be affected to the same degree (Bond et al. 2014, Provencher et al. 2015). User plastics made up the majority of the items the birds had ingested, with industrial pellets representing only a small proportion in the samples. Of the 4375 pieces of plastic identified, the majority (76 percent) were plastic fragments, 7 percent were industrial pellets, 7 percent were sheet-like, 6 percent were foam, and 2 percent were thread-like pieces (Bond et al. 2014). Coastal ducks and sea ducks also ingest plastic and other debris. In the Bay of Fundy, plastic debris has been found in the stomachs of 46.1 percent (6/13) of mallards and 6.9 percent (6/87) of Black Ducks, and metal in 30.8 percent (4/13) and 2.3 percent (2/87) of those species respectively (English et al. 2015a). Debris ingested was usually small (0.5-5 mm long and 0.25-3 mm wide) consisting of user plastics and small metal fragments (English et al. 2015a).

7.2. OTHER CONTAMINANT ISSUES

Contamination of the marine environment can be attributed to many other human activities or natural sources. Fish plant effluent often is a source of conventional contaminants, including ammonia, dissolved organic carbon and organic particulate matter, total solids, total suspended solids (TSS), hardness, total nitrogen, nitrate, nitrite, total phosphorus, conductivity, and “oil and grease” (Lalonde et al. 2007), but as well may include metals, organochlorines and other organic contaminants. Lalonde et al. (2007) presented the results of a national study of fish plant effluents in which most facilities were from Atlantic Canada. PBDEs were found at levels which were higher than measured in surface waters globally (Lalonde et al. 2007). Potential sources of the PBDEs are contact of the effluent with polymer mouldings, panels, synthetic rubbers and moulded plastics within the plant (Lalonde et al. 2007). Mercury frequently occurs in fish plant effluents at levels above the CCME guideline of 0.016 μg/L for the protection of marine aquatic life. The highest mercury level in fish plants in the Lalonde et al. (2007) study was 0.57 μg/g in effluent from a lobster plant. Detectable PCBs and organochlorine pesticides (Dieldrin, DDE and alpha-benzenehexachloride) occur occasionally (Lalonde et al. 2007). Locations of the sites within Atlantic Canada were not specified, but were selected to be representative of the industry.

The ocean is becoming more acidic through increasing carbon dioxide levels in the atmosphere, which has resulted in increased carbon dioxide levels in the surface ocean, causing changes in water chemistry. DFO monitors ocean acidity (pH and atmospheric CO_2 concentration) through sensors on ocean buoys, twice-yearly on the AZMP monitoring cruises on the Scotian Shelf and in the Bay of Fundy and opportunistically on other ocean survey programs in the area (K. Azetsu-Scott, Research Scientist, DFO, Dartmouth, N.S., Personal Communication, 2018). Changes have been observed for the Scotian Shelf, corresponding to a decrease of 0.002 pH units per year from the 1930s to the early 2000s (Yeats et al. 2008). Current estimates indicate that pH of the surface ocean will reach 7.8 by 2100 (from a pH of 8.2 in 1750) (IPCC 2007b from Curran and Azetsu-Scott 2013). The rate of decrease on the Scotian Shelf is slightly greater than the average global ocean decrease observed over the same time period (DFO 2009a).

Other localized sources of contaminants are shipwrecks and debris of various kinds, such as unexploded ordinance which can occur in offshore areas (Ford and Serdynska 2013).

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1. OVERVIEW

Contaminants in the marine environment is a topic with a large scope and diverse implications. In completing this review it has become clear that while there has been some exceptional research and energy applied to various problems involving contaminants in the marine environment of the bioregion, there are significant gaps, and research into the topic is not well-coordinated. It is also evident that sophisticated knowledge and skills of many researchers (ranging from analytical chemists to sedimentologists and geochronologists to name some disciplines) are necessary and have advanced the understanding of this large problem. Multidisciplinary approaches continue to be important in answering some of the major questions about contaminants in the environment.

The information generated in the review has shown that low levels of many substances considered to be contaminants occur in the bioregion, but has not shown how low levels affect the physiology and populations of animals of various kinds, particularly fisheries species. The research activities of various groups of researchers, both within and outside government, are responsive to emerging contaminant issues; in these efforts the capabilities for basic research into oceanography and marine biology and chemistry should be maintained as core activities. An example would be the use of radiochemistry capabilities for determining sediment geochronologies, which has been used to study a wide variety of contaminant issues. However, an additional research focus on contaminant and trophic dynamics would be a valuable addition to current capabilities and would improve the understanding of the scope and potential impacts of contaminants on the marine ecosystem of the bioregion.

8.2. GLOBAL PERSPECTIVE

The Scotian Shelf Bioregion is relatively small in global or even regional terms and is also comparatively unindustrialized. The small human population in Nova Scotia and New Brunswick, with large areas of land occupied by forests and agriculture, and few, comparatively small urban centres and harbours, has had comparatively little impact on the marine environment of coastal areas and the nearby offshore, with the exception of the more heavily industrialized harbours. Nonetheless, the bioregion is exposed to influences originating outside the area: atmospheric transport, ocean currents and international shipping all lead to detectable levels of certain contaminants in parts of the Scotian Shelf Bioregion. Ubiquitous marine plastics, including microplastics, enter into and are found in the bioregion, and which may be contributing contaminants of various kinds as well as accumulating on some shorelines such as those on Sable Island.

Contaminants that occur in the bioregion often originate in the industrialized areas of the St. Lawrence Lowland of Canada and the U.S. Northeast, brought to the area by rivers, transport from the St. Lawrence Estuary and Gulf of St. Lawerence, and atmospheric transport. Where they appear locally in the bioregion, they are indicators or tracers of human and industrial activity. Potentially harmful substances are released continuously in varying concentrations by human society, including new substances created for commercial purposes and released into the environment through human use. In general, few cases of substantial contamination or effects of contaminants in the bioregion have been documented, although its marine environment has experienced many of the same effects and impacts of industrial activities as elsewhere in the world. A large community of researchers globally have focused on such contaminant issues, and their findings have informed work done here to provide information on the scope of these issues.

8.3. COVERAGE

Since 1995—the period covered by this review—and for several decades before, a comparatively large amount of information has been generated on levels of contaminants in the bioregion. Some of it has come from management activities of government, such as regulation of ocean disposal and maintainance of large and small harbours. Other sources of information are baseline data obtained prior to the establishment of coastal and offshore industries, environmental reviews of major ports and industrial centres, as well as research studies conducted by government, academia and the private sector on the influence of various forms of known contamination on the marine environment. Examples include studies on the effects of toxic compounds (e.g., tributyltin) whose use has been subsequently restricted, efforts to determine the effects of high concentrations of PAHs in industrial harbours—in particular Sydney Harbour where the Sydney Tar Ponds was a major influence—and monitoring of offshore hydrocarbon production activities. Research efforts focusing on both metals and organic contaminants and pathways have been undertaken. Monitoring efforts such as Gulfwatch in the Gulf of Maine have yielded comparative information on levels of metals and organic contaminants in the bioregion in relation to the nearby, more industrialized U.S. coast. In some cases hot spots of particular contaminants have been shown. In general, the studies have shown concentrations of contaminants of various kinds to be at natural levels, and if elevated, generally localized.

8.4. CONTAMINANTS IN ECOSYSTEM MANAGEMENT

8.4.1. Perspective

A review such as this one, of a subject as complex as contaminants in the Scotian Shelf Bioregion, presents at best an incomplete picture of the status of contaminants, largely because the scope is so large and varied, and the underlying information is often highly fragmented, typically geographically local, and often sparse—the product of the broad spectrum of research, regulatory, and management objectives for contaminants, and the complexity and size of the marine environment. Although comparatively unfocused for these reasons, this review has served as a sort of meta-analysis, providing in a broad overview the results of various assessments and conditions with respect to contaminants in the marine environment in this region. In itself not an assessment, this review provides information which can be used to formally, albeit broadly, assess the state of marine environmental quality in the bioregion.

Contaminant issues in the bioregion have been shown, for the most part, to be the same as those found globally. No pressing problems have been identified here which are particularly important in the global picture. However, the scattered and very unfocused nature of contaminants information in bioregion is a major deficiency for understanding the importance of contaminants for further management. Going forward, it is suggested that a focused approach to contaminants in the ecosystem of the bioregion is needed—

a plan for assessing and monitoring contaminants, which would support future and long-term management efforts. Initially, the plan should include all substances presently considered to be, or to have potential to be, contaminants, which could then be focused through risk assessment processes. The absence of such a defined program for contaminant assessment and monitoring is a major deficiency in approaches to managing the marine ecosystem of the bioregion. The plan should include a long-term monitoring program for marine contaminants, including a research program to determine their fate and pathways, with a view of providing information on relative importance and trends to be used for ongoing ecosystem management.

Apart from this general need, the review has documented a range of knowledge gaps relating to contaminants in the bioregion. An overview of some of these concerns is presented below and summarized in Tables 29 a-c. A challenge in all future efforts will be to not lose sight of the role of basic research on the biological, physical and chemical processes in the bioregion, but to use existing knowledge to best advantage and to carefully assess where contributions to the knowledge of effects of contaminants can be made.

8.4.2. Monitoring and Management

An overall program is needed for assessing the current state and impact of contaminants on the marine ecosystem of the Scotian Shelf Bioregion. Presently the research efforts and studies conducted are diverse and broad. An overall program would include both monitoring and management aspects, such as:

- A plan to determine a list of contaminants for monitoring, focused on the marine environment, which would include determination of the relevance of existing contaminants monitoring and applicability of existing guidelines to the marine environment.

- A database for monitoring information.

- A list of monitoring compartments and organisms with a focus on indicators suitable for particular environmental compartments.

- Identification of representative monitoring locations throughout the bioregion, including physical/geomorphic features such as coastal areas, basins, banks, submarine canyons and parts of the continental slope, as well as oceanic features such as the Labrador Current, Slope water, Gulf Stream etc. Monitoring compartments should include: water, sediments, water/sediment interface, biota at all trophic levels including benthic infauna and epifauna, zooplankton, fish (groundfish, pelagic fish), marine mammals and seabirds.

- The ability to identify and add emerging contaminants to the program.

In particular, as noted above, there is a need to develop a list of substances of concern in the marine environment, including existing and emerging contaminants, and to identify priorities for baseline measurements and monitoring. Current approaches have tended to focus on contaminants highlighted for various regulatory reasons or particular threats, as well as to address specific issues. Only rarely have studies assessed impacts of various contaminants on the functioning of the ecosystem as a whole.

Emerging contaminants with potential for impacting marine organisms are usually identified by researchers in academia and government, and targeted for screening studies. It is important that the federal government be capable of contributing to tracking the state of the science globally in order to provide a sound scientific basis for monitoring and management of existing and emerging contaminants.

No monitoring is being conducted in the bioregion of pathways of any contaminants—natural or otherwise—from sources to food chain compartments to ultimate receptors (i.e., upper trophic level receptors including seabirds, marine mammals, fish and humans). There is, further, almost complete absence of information which would allow assessment of natural variability and trends of various contaminants, classical or emerging, in any compartment, and with an ecosystem effects focus. A minimum approach to monitoring would be to carefully monitor indicators, in particular marine mammals and seabirds, since they are often biocaccumulators of many contaminants due to their high trophic level.

As one of the only monitoring programs for a broad spectrum of environmental contaminants, the Gulfwatch Mussel Watch program in the outer Bay of Fundy and Gulf of Maine is an example of a success story for providing information to be used in assessing marine environmental quality by detecting presence of chemicals of concern in a biological indicator organism, and allowing evaluation of long-term trends. A recent initiative to collect sediments and measurements of eutrophication indicators near mussel watch sites (ESIP 2017) may also prove useful in a similar role in future. ECCC operates an ocean disposal site monitoring program, funded by proceeds of ocean disposal permit applications, to monitor specific physical conditions and contaminants in sediments at disposal sites—only two of which are in the bioregion, the Strait of Canso and Saint John Harbour—at five- to ten-year intervals. Otherwise, there are no institutional monitoring programs for contaminants in the physical and biological environment in Scotian Shelf Bioregion which could detect and provide an overview of issues and trends to aid in ecosystem management. Monitoring of persistent organic pollutants in marine mammals and seabirds, for example in research programs carried out within DFO and the monitoring of a wide range of POPs and pesticides in seabird eggs by the Canadian Wildlife Service, are often carried out as an add-on to specialized research programs, and therefore are not repeated as frequently.

Opportunities for including contaminant monitoring in existing ocean monitoring programs include DFO's Atlantic Zone Monitoring Program (AZMP) which currently tracks the state of the ocean on the Scotian Shelf (DFO 2017b). It may be possible to expand its reach by adding sampling for contaminant monitoring. As noted elsewhere in this publication, DFO's annual research trawl surveys, which cover the entire bioregion, are a possible platform to allow contaminant monitoring in fish.

Table 29a. Institutional/management gaps identified in current review.
Lack of an overall management plan for contaminants in the bioregion, focused on ecosystem function.
Absence of an overall framework to guide environmental sampling and research in relation to contaminant issues and the marine ecosystem.
Absence of a monitoring plan to address management information needs.
Lack of guidance for researchers on data needs in terms of ecosystem management.
Absence of relevant databases (i.e., on contaminants in the marine ecosystem) to be used to monitor levels and assess change.
Absence of risk assessments for contaminants in terms of impacts on physical, chemical and biological components of the environment.
Absence of risk assessments of various industries (e.g., agriculture, aquaculture, marine transportation, fishing, etc.) as well as inputs such as urban sewage, in terms of contaminant outputs and relative influence on the marine ecosystem.
Lack of availability of contaminant information for fish and seafood collected by seafood industry and government agencies responsible for food safety (e.g., CFIA, Health Canada).
Need for adequate research and analysis capability for contaminants within federal government departments and for those capabilities to be maintained and augmented.

Table 29b. General scientific information gaps identified in current review.
Overall lack of information necessary to contribute to an understanding of processes involving contaminants in the marine environment of the bioregion. • Lack of monitoring data or effort to assess natural levels and variability of contaminants for any environmental compartment. • Little information on natural sources of contaminants (e.g., heavy metals). • Overall lack of distribution information for any contaminant, anywhere in the bioregion. • Lack of trend information and chronologies of all contaminants, in particular metals, in the bioregion.
Need to establish trends in contaminant inputs, in particular in sediments, through geochronology studies.
Overall absence of trophic level analysis for any contaminant. • Need for information on pathways of contaminant transfer through the marine ecosystem of the bioregion. • Need to establish a suite of biological contaminant indicators at various trophic levels for monitoring—at a minimum indicator organisms at the highest trophic levels should be monitored, such as fish, shellfish, marine mammals and seabirds.
Need a meaningful priority list of contaminants for management and monitoring, and a rationale. • Need for screening of all types of contaminants to determine those to be monitored and for a focus of research studies on transfer within the ecosystem. • Need for expanded geographic coverage for existing monitoring programs such as the Gulfwatch Mussel Watch program and oiled seabird surveys on Sable Island, which should be expanded to coastal areas throughout the bioregion and further maintained and supported.
Lack of information on distribution of litter and marine plastics in coastal and offshore areas throughout the bioregion, and their role in transfer of contaminants to organisms.
Absence of recent summaries reflecting the relative contamination of coastal areas by other categories of contamination, such as bacterial contamination or organic enrichment.

Table 29c. Scientific information requirements for species or specific geographic areas identified in current review.
Few studies have been done on contaminants in marine mammals, including cetaceans (whales, porpoises and dolphins) and pinnipeds (seals and walrus) in the Scotian Shelf Bioregion.
Sources and pathways of copper in lobster and rock crab in the inner Bay of Fundy.
Dynamics in the ecosystem of cadmium (i.e., sources and fate) which is frequently above guideline levels in sediments in coastal inlets and harbours.
Dynamics of metals and organic contaminants in mudflats of the Bay of Fundy, in relation to transfer to shorebirds.
Absence of research studies on metals and organic contaminants in seawater in the Bay of Fundy.
Need for local monitoring of hotspots (e.g., harbours such as Halifax Harbour, Saint John Harbour and Sydney Harbour) to establish contaminant status and trends.
Contaminants in sediments in DFO Small Craft Harbours should be monitored to determine if improvements to fishing operations and vessel maintenance and practices are leading to overall improvements to contamination of sediments.
Causes of exceedances of guidelines for metals and organic contaminants in sediments in many DFO Small Craft Harbours are not known.
Patterns, extent and effects of organic enrichment and any resulting anoxia of bottom waters and sediments due to sewage inputs, runoff from agriculture, aquaculture facilities and other sources should be established.
Need for assessment of potential effects of sediment anoxia on release of metals from sediments where elevated legacy concentrations of mercury and other metals occur (e.g., the St. Croix Estuary).
Need for evaluation and monitoring of contaminants known to be released in the fish farming industry including metals, pesticides for treating sea lice, antibiotics, PCBs, DDE etc., which are not routinely measured in the vicinity of sites.
Need for continued monitoring of tributyltin and effects (i.e., imposex in whelks) throughout the bioregion in major ports, Small Craft Harbours, and other working harbours and marinas in the bioregion.

There are no databases on contaminants in the marine environment of the Scotian Shelf Bioregion. DFO maintains a database of oceanographic parameters from the water column in the region (*BioChem,* http://www.dfo-mpo.gc.ca/science/datadonnees/biochem/index-eng.html), but it does not contain information on contaminants. ECCC's Ocean Disposal Section in the Atlantic Region has a database which it uses to track basic contaminant information on sediments collected in management of ocean disposal activities (ECCC 2017). A database should be an integral part of a monitoring program of contaminants in the marine environment of the bioregion.

Apart from classical contaminants, there is a need for surveys for representative emerging contaminants at all levels of the food chain. The number of new contaminant substances created by human society is clearly too large to analyze them all; however, a suitable management strategy would focus efforts on key compounds and representative ecosystems. Such studies are currently limited to detection of emerging contaminants in higher organisms, in particular marine mammals and birds, although to a limited degree presence in the marine environment has been assessed through mussel watch monitoring. Presently information on presence of particular contaminants at different trophic levels is extremely limited.

8.4.3. Background and Baseline

Coverage of natural distribution of contaminants, including metals and hydrocarbons, in sediments on the Scotian Shelf is lacking. In comparison, at least one broad geographic survey of metals has been done for the Bay of Fundy (Loring 1979). Similarly, geochronologies with respect to metal distributions, including potential contaminants, and flux to sediments are needed, at least to establish baseline conditions for long-term monitoring. Chemical oceanographic studies of metals in the Atlantic Ocean waters in the bioregion have given valuable insight into influences of water masses such as those originating in the St. Lawrence River; similar studies have not been done in the Bay of Fundy to examine the relative role of that region in the overall balance in the bioregion. No recent surveys are available anywhere in the bioregion to provide an overview of the broad distribution and levels of hydrocarbons in sediments. Consequently, changes over time cannot be determined, such as improvements in the management of the main sources of contaminants over the past two decades covered by this review.

8.4.4. Trophic Pathways and Effects

Apart from our knowledge, and lack of knowledge, of levels of contaminants in the bioregion, our understanding of how they are moved throughout the ecosystem is also limited. Indicators, such as levels of trace metals in offshore waters or in mussels sampled in parts of the bioregion, or presence of metals of concern such as mercury in sediments and biota, have shown that overall the ecosystem can be locally exposed to elevated concentrations of some contaminants, or more subtly exposed to contaminants of various kinds at low levels over wide areas. Ascertaining the degree that is likely to be immediately harmful, either locally or to the marine ecosystem of the bioregion as a whole, is a complex and difficult problem. Although particular contaminants such as certain heavy metals have been highlighted by society as being of particular concern (e.g., mercury), the process has omitted a wide range of other metals that exist in the environment (e.g., selenium, barium) which are not considered priority contaminants for various reasons (e.g., potential toxicity at high levels), but whose behaviour and effects at an ecosystem level are virtually unknown. Mercury and other substances which have the potential to disrupt the physiology of marine organisms may have long-term effects that are not known; in contrast, the effects of other contaminants, such as the effect of tributyltin on whelks, have been obvious and immediate, although quite localized. The appearance of contaminants in a wide variety of species and areas—for example Northern Bottlenose Whale in The Gully, Grey Seals on Sable Island, and Herring Gull eggs on Kent Island, New Brunswick—shows that the influence of contaminants generated by humans extends over the entire bioregion, but the physiological changes they cause and population impacts are largely unknown. For fish and invertebrates, studies have largely been concentrated on commercial fisheries species. Most organism groups are underrepresented with respect to contaminant studies. In contrast, specific organisms have been overrepresented in studies of particular contaminants (i.e., organics and emerging contaminants in marine mammals and seabirds).

Although the pathways of some contaminants have been partly worked out—for example for mercury and its alkylated form, methyl mercury—there are big information gaps on the transfer of other important contaminants through the ecosystem. Unanswered questions from studies presented in this review include the natural source of elevated copper concentrations in American Lobster and Rock Crab in the inner Bay of Fundy (Chou et al. 2002b, 2003) and an explanation for elevated cadmium in scallops from Georges Bank discovered in the 1970s and 1980s (Uthe and Chou 1987, Ray et al. 1984). One unstudied pathway for mercury (and other heavy metals and contaminants) in the ecosystem of the bioregion is in the transfer to shorebirds during their important annual migratory stopover on mud flats in the inner Bay of Fundy. The mudflat-shorebird food web is well-monitored in terms of trophic dynamics (e.g., carbon flow) (e.g., Quinn 2011, Quinn and Hamilton 2012), but is not so far in terms of contaminants.

The role of cadmium in the ecosystem may be an important focus for studies in the bioregion. Cadmium is widely found in coastal areas of the Scotian Shelf Bioregion. Cadmium levels in sediments showed the largest number of exceedences of sediment and environmental quality guidelines in DFO Small Craft Harbours (from a preliminary analysis in our report) and also showed the greatest likely incidence of contamination in the Loring et al. (1996) study of coastal inlets. The metal is otherwise not well-documented in coastal waters, nor are its effects understood.

Comparatively, there is a lack of information on marine litter in most coastal areas, compared to more densely populated areas (e.g., Halifax/Dartmouth area). There is little information on the role of plastics in the bioregion as a factor in concentrating, serving as a source of, and transferring contaminants to marine organisms.

Although contaminants such as metals and chemicals have been shown to be released from aquaculture operations, the local distribution in sediments and, more importantly, ecosystem-wide effects (although most likely small) have only been assessed to a limited degree and are not routinely monitored. These sources may only have localized impacts; however, further research is needed.

Overall, adopting an ecosystem management focus of contaminant studies may help to expand the understanding of impacts of contaminant sources of all types.

8.5. CHANGING THE FOCUS

Much of the past research on contaminants, both across Canada and regionally, has been driven by specific contemporary issues. These have included the threat of and management of oil spills and offshore hydrocarbon development; occurrence of toxic phytoplankton; monitoring of radionuclides; persistent organic pollutants, both locally and in a global context; food quality and the awareness of mercury as a contaminant in fish tissue in the 1970s; specific urban contamination issues such as sewage; impacts of the pulp and paper industry; impacts of aquaculture; etc. However there has been little emphasis specifically on effects of contaminants at the ecosystem level. In particular, although various contaminants have been identified in the environment of the bioregion, as noted, comparatively little is known about the process of accumulation and magnification through the food chain—what the long-term outcome of the slight elevations in concentration and gradual uptake into the marine ecosystem will be.

Limitations imposed by the different jurisdictional responsibilities—marine mammals and fish through DFO, seabirds through the Canadian Wildlife Service (ECCC), food quality and contaminants in fish and shellfish through Health Canada and the CFIA—currently do not contribute to a broader focus on the dynamics of contaminants in the ecosystem. As well, the recent approach of monitoring contaminants in water and sediments only as related to particular industrial projects has contributed to a fragmented view of contaminants. In order to achieve a broader view, research expertise within government that would focus wholly on ecosystem- or trophically-based studies of contaminant dynamics should be developed, and thus could address some of the important questions on ecosystem dynamics of contaminants. Such a capability would use and help to focus the capabilities of these agencies to assist in answering some of the important questions concerning impacts of contaminants on the ecosystem of the bioregion. The lack of an overall management plan and risk assessment process for contaminants in the ecosystem of the bioregion, including suitable databases and monitoring, are also important gaps. It is suggested that a lead coordination role would be within DFO's overall responsibilties to manage fisheries and protect fish, as well as its requirement to take an ecosystem approach to management as mandated by the *Oceans Act*.

Such a focus would not only advance the understanding of contaminants, it would be valuable to improve the understanding of the fisheries, how they are changing, and impacts of environmental changes on the marine ecosystem. Within DFO, such a discipline could legitimately—i.e., within its mandate—incorporate energetics and contaminant dynamics, and would access the multidisciplinary capabilities already present. Previously, multidisciplinary expertise in biological oceanography has only occasionally been focused on trophic transfer of contaminants such as metals and persistent organic pollutants. For example, Harding (1986) looked at trophic transfer of organochlorines in the Gulf of St. Lawrence and Dalziel et al. (2010) and Sunderland et al. (2012) examined mercury budgets for the Bay of Fundy as a whole.

8.6. ROLE OF THE BAY OF FUNDY AND COASTAL INLETS IN CONTAMINANTS STUDIES

By its structure, the Bay of Fundy lends itself naturally to modeling and budget calculations for contaminants of all kinds; in addition it has a mix of habitat types, from the mudflats of the inner Bay of Fundy to the exposed oceanic coasts of Grand Manan. Similarly, the inlets which occur widely in the region—both in the Bay of Fundy and along the Atlantic Coast—provide opportunities for producing mass budgets for metals and other contaminants on a local scale and representative of a wide range of geological and geochemical source conditions. The low level of industrial contamination in most of these areas would be advantageous to understanding these processes at a basic level, in particular understanding dynamics primarily of natural contaminants, such as heavy metals (e.g., cadmium and copper), which could be applied to understanding the fate of other contaminants in the marine ecosystem of the bioregion and elsewhere around the world.

8.7. MONITORING AND REMEDIATION OF HOT SPOTS

Efforts should be made to conduct risk assessments and possibly remediate several "hotspots" of contaminant input identified in this review. PCBs are still found in sediments in many areas of Atlantic Canada such as the Strait of Canso. Although there are no longer the major centres of contamination such as the Sydney Tar Ponds in Cape Breton, the existence of smaller localized areas of contamination should inform activities, so that coastal activities are adequately managed to minimize further releases into the environment. One area in central Saint John harbour—Tin Can Beach—stands out for elevated levels of several contaminants, including mercury in mussels identified by Gulfwatch and PCBs and PAHS in sediments identified in recent monitoring under the Gulf of Maine Council Ecosystem Indicators Partnership (ESIP 2017). This area of the harbour, as well as the coastline from Courtenay Bay to Mispec Point on the eastern side of Saint John Harbour, has shown elevated levels of specific contaminants in past and perhaps should be subject to a program of shoreline remediation to remove these areas as sources of these contaminants. A similar approach might be suitable for hotspots which are found in all the major industrialized harbours in the region.

For some hotspots which may be difficult or impossible to remediate, such as the upper St. Croix River Estuary and parts of Passamaquoddy Bay where high levels of total mercury in sediments occur through historic releases from pulp and paper production (Sunderland et al. 2006, Sunderland et al. 2004), the Strait of Canso, and parts of Sydney Harbour where sediments contaminated with PCBs occur (Ernst et al. 1999, Lee 2002, Tay et al. 2010), an appropriate approach may be to initiate long-term monitoring. Apart from the assessment, remediation, and/or monitoring of hotspots, management of the marine ecosystem in the bioregion should include risk assessment at a broader level of the range of contaminants and also the major sources (e.g., atmospheric transport, urban sewage, fish processing etc.) to help focus resources.

8.8. BIOACCUMULATION

Measurements of levels of contaminants in the commercial fish catch would be useful in determining the dynamics of contaminants. Some species caught in the commercial fishery are apex predators; others are prey for fish, birds and marine mammals and thus offer a potential conduit for trophic transfer of contaminants. Various studies prior to the period covered by this review measured mercury and trace metals in commercial species, but no similar, comprehensive surveys have been done recently (Stewart and White 2001). Information from catch quality testing carried out by industry, required for foreign shipments, is proprietary. Health Canada and CFIA, although tracking contaminant issues in fish (e.g., mercury, PCBs and PBDEs), rarely provide overviews of their findings with regards to contaminant levels in fish. An industry-wide program to provide this data anonymously for inclusion in a database would be useful for determining exposures of higher animals that feed on fish. Alternately, DFO Annual Research Trawl Surveys and sentinel surveys could provide samples for analysis of contaminants of various kinds, including emerging contaminants, if it could be coordinated through a research program focused on contaminant dynamics, as noted above.

Ultimately, an assessment of the impact of contaminants on the ecosystem of the Scotian Shelf Bioregion cannot be done without continued studies of the biology of the organisms themselves—to establish the normal behaviour, biology and long-term patterns—and of the ecosystem as a whole. The impacts of the accumulation of DDT on birds would not have been found if field studies had not shown that reproductive success was reduced in certain species. Base levels of studies of the ecosystem, to continue to understand its dynamics, will detect changes, which will allow for the appropriate management responses to be developed.

8.9. OVERALL ASSESSMENT

The environment in the Scotian Shelf Bioregion is comparatively uncontaminated. The area is largely not industrialized and some of the major sources of contaminants arise from areas of the industrialized northeast U.S. and from the Canadian industrial areas of the St. Lawrence Lowland and along the St. Lawrence Estuary. Other localized sources such as shipwrecks and debris of various kinds such as unexploded ordinance have not been investigated, but likely have only a small impact on overall contaminant levels. Hydrocarbons from marine tanker traffic and shipping are found at low levels and contaminate waters where they can impact seabirds. Microplastics and other marine debris are ubiquitous but no real estimates of abundance or long-term impact are available. Particular industries have largely a localized impact at the harbour or inlet level but occur throughout the bioregion, from Passamaquoddy Bay, New Brunswick, to Cape North in Nova Scotia. Cumulative effects are not a major issue except in a few areas, due to an overall low density of activity. Industrial and urban areas, particularly the centres of high population such as Saint John, Halifax-Dartmouth, the Strait of Canso, and Sydney, as well as the Quoddy Region, have an important local impact, although their effects may be declining through better sewage treatment and control of major industrial sources. Coastal areas of the Scotian Shelf Bioregion which support major industries, such as ports with oil refining and ship maintenance and repair facilities, are the main potential sources of contamination to the environment. Such areas should be a focus of management, remediation, and research activities.

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APPENDIX TABLES

Table A1. Heavy metal, PCB and PAH levels in sediments, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Nova Scotia Offshore											
JWEL (2000)	*June and November 1998-99*	*Eastern Margin of Sable Island Bank at the Gully (n=23)*	2 (<2-2)	<0.3	<2	3.0 (2-6.6)	<0.01	6.0 (4-18)	--	<0.05	--
	June and November 1998-99	*Venture (n=165)*	2.3 (1-5)	<0.3	2.5 (2-6)	6.0 (2.3-7.9)	0.02 (<0.02-0.05)	12.3 (2-52)	--	<0.05	--
	November 1998; June and November 1999	*North Triumph (n=134)*	2 (<2-2)	<0.3	2.1 (2-4)	4.8 (1.4-7.7)	<0.01	9.5 (2-28)	--	<0.05	--
	November 1998; June and November 1999	*Thebaud (n=136)*	1.5 (2-4)	<0.3	2.5 (2-15)	4.7 (1.8-9.1)	<0.01	10.1 (4-24)	--	<0.05	--
Nova Scotia Coastal and Inshore											
Envirosphere Consultants (1996)	*1995*	*Outer Lunenburg Harbour (n=9)*	15.8 (10-20)	<0.5	19.4 (12-34)	6.4 (52-10)	0.014 (0.01-0.05)	20.6 (17-24)	--	--	<5
Little et al. (2015)	*2005*	*Wine Harbour (n=229)*	66 (4-568)	--	16.8 (6.81-30.3)	16.5 (5.43-53.4)	813 (<5-7435)	52.3 (26.1-77.6)	--	--	--
Doe et al. (2017)	*2004*	*Seal Cove, Mouth of West River (n=6)*	629 (457-767)	--	--	--	0.34 (0.21-0.49)	--	--	--	--
	2005	*Seal Cove, Shore Locations (n=9)*	39.9 (<20-79)	--	--	--	0.20 <0.02-0.97)	--	--	--	--

Table A1. Heavy metal, PCB and PAH levels in sediments, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Carter et al. (2004)	*2001-2002*	*Halifax Harbour Shipyards (n=4)*	17-34	<1- 1.3	64-533	67-555	--	179-1429	--	--	--
Carter et al. (2004)	*2001-2002*	*Bedford Basin (n=1)*	30.8	1.0	90.7	183.7	--	258.3	--	--	--
Carter et al. (2004)	*2001-2002*	*Chezzetcook Harbour (n=3)*	4.5-< 5	<1.0	5.0-8.1	4.8-8.6	--	19.8-35.6	--	--	--
Carter et al. (2004)	*2001-2002*	*South Shore and Oak Island Marinas (n=2)*	13.4-21.5	<1.0-1.5	120.9-251.9	41.2-48.8	--	86.1-90.1	--	--	--
Walker et al. (2013 a and b)	*2010?*	*Sydney Harbour*	4-33	0.3-1.10	2.2-71.0	4-120	0.1-0.49	31-210	--	--	--
Tay et al. (2010)	*1999*	*Strait of Canso, Disposal Site (n=8)*	--	0.04 (±0.01)	22.8 (±2.4)	21.0 (±1.4)	--	91.8 (±4.0)	52.8 (±13.2)	0.67 (±0.28)	--
	2004	*Strait of Canso, Outside Disposal Site (n=15)*	--	0.24 (±0.03)	26.5 (±0.9)	30.9 (±32.3)	--	110.6 (±2.1)	76.7 (±5.1), max 535 up to 535	2.27 (±0.18) (max 3.2-3.3)	--
	2004	*Strait of Canso, Disposal Site (n=6)*	--	0.56 (±0.12)	25.0 (±1.5)	29.3 (±1.4)	--	113.0 (±6.9)	229.9 (±41.7)	1.73 (±2.43) max 3.1	--
SNC-Lavalin, Inc. (2015)	*2015*	*Bear Head*	--	ND	6-8	11-12	0.01	37-48	<10-71.6	<0.05	16.2-26.6
Stewart and White (2001)	*To 1995*	*Strait of Canso*	--	<0.010-0.79	7-56.6	23.9-120	0.03-3.1	50-130	48-1395	0.04-2.94	21-515.3

Table A1. Heavy metal, PCB and PAH levels in sediments, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Loring et al. (2008)	*2008*	*Sydney Harbour, River (n=7)*	16.4 (±6.5)	0.89 (±0.31)	39.4 (±14.9)	85 (±27)	0.11 (±0.07)	173 (±41)	--	--	--
Loring et al. (2008)	*2008*	*Sydney Harbour, Estuary (n=22)*	20.6 (±8.0)	0.86 (±0.38)	69.5 (±30.2)	161 (±78)	0.18 (±0.11)	237 (±91)	--	--	--
Loring et al. (2008)	*2008*	*Sydney Harbour, Central South Arm (n=25)*	26.2 (±11.2)	1.25 (±0.72)	81.3 (±67.4)	201 (±124)	0.33 (±0.34)	316 (±156)	--	--	--
Loring et al. (2008)	*2008*	*Sydney Harbour, Outer South Arm (n=15)*	21.1 (±8.1)	0.63 (±0.41)	42.8 (±15.1)	110 (±52)	0.10 (±0.07)	201 (±88)	--	--	--
Loring et al. (2008)	*2008*	*Sydney Harbour, North West Arm (n=27)*	15.7 (±5.3)	0.45 (±0.13)	34.0 (±11.7)	71 (±31)	0.04 (±0.02)	139 (±36)	--	--	--
Loring et al. (2008)	*2008*	*Sydney Harbour,Central Harbour (n=16)*	14.5 (±2.9)	0.26 (±0.08)	30.9 (±7.0)	50 (±19)	0.10 (±0.28)	115 (±32)	--	--	--
Stewart et al. (2001a)[2]	*1999*	*Sydney Harbour, Inner, Outer and Northwest Arm (n=29)*	10-56	0.1-1.88	7-110	12-408	0.01-0.71	36-460	40-2580	1.2-326	--
Stewart et al. (*2001b*)[2]	*2000*	*Sydney Harbour, Inner, Outer and Northwest Arm (n=43)*	8.5-52.9	0.05-2.21	7-140	12.7-379	0.01-1.36	39-1100	27-7117	0.7-353.6	--
Tay et al. (2003)	*1999*	*Sydney Harbour, South Arm (n=8)*	21-41	0.7-1.64	41-110	99.5-408	0.09-0.48	182-474	0.20-3.38	16.9-246.4	--

Table A1. Heavy metal, PCB and PAH levels in sediments, Scotian Shelf Bioregion.											
Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)											
Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
	1999	*Sydney Harbour, Outer Harbour and Northwest Arm (n=2)*	16-19	0.16-0.54	19-39	25.5-101.5	0.04-0.09	78-174	0.005-0.045	4.77-20.98	--
Environment Canada (2000)	*1997*	*Sydney Harbour, South Arm (n=4)*	10-41	0.15-1.17	22.7-101.3	32.0-285.7	0.04-0.71	91-866	ND-2095	2.10-110.8	--
	1997	*Sydney Harbour, Outer Harbour (n=1)*	9.7	0.08	13	31	0.02	56.2	ND	0.29	--
	1997	*St. Ann's Harbour[1] Reference (n=1)*	15.7	0.25	37	37	0.055	84.2	ND	0.15	--
Bay of Fundy Coastal and Inshore											
Hung and Chmura (2006)	*1997-2002*	*Salt Marsh Sediments, New Brunswick*	--	--	--	--	(0.007-0.078)	--	--	--	--
Kostaschuk et al. (2008)	*2006*	*Allen Creek Salt Marsh, Cumberland Basin*	12.5	--	12	15	--	60	--	--	--
Irving Oil (2009)	*2006*	*Saint John Harbour, Mispec Point (n=12)*	4.33 (3-6)	<0.1	6.92 (4-11)	8.06 (4.8-11.6)	<0.01-0.1	39.08 (28-57)	<0.05	0.28 (0.09-0.78)	4.46 (1.70-12.0)
Brylinsky (2005)	*2005*	*Whites Point, Digby Neck, N.S. (n=3)*		< 0.5	11-17	14-17	<0.01-0.1	42-52	<0.01	<0.01	--
Chou et al. (2003)	*2000?*	*Bay of Fundy*	--	0.02-0.04	0.3-17.0	--	--	35.1-65.5	--	--	--

Table A1. Heavy metal, PCB and PAH levels in sediments, Scotian Shelf Bioregion.											
Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)											
Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Van Geest et al. (2015)	*2011-2013*	*Saint John Inner Harbour (n=112)*	6.9 (±0.1)	0.08 (±0.004)	7.7 (±0.2)	9.4 (±0.2)	0.012.0 (±0.001)	47.0 (±1.0)	8.2 (±0.89)	0.18 (±0.02)	--
	2011-2013	*Saint John Outer Harbour (n=101)*	6.0 (±0.2)	0.09 (±0.004)	5.6 (±0.4)	8.8 (±0.2)	0.008 (±0.0003)	43.0 (±1.0)	3.8 (±0.5)	0.14 (±0.01)	--
Bay of Fundy Offshore											
Loring (1979)	*Late 1970s*	*Outer Bay of Fundy, Subtidal*	8 (4-15)	0.22 (0.03-0.52)	15 (5-32)	20 (8-42)	0.03 (0.02-0.09)	51 (18-104)	--	--	--
1. St. Anns Harbour, 46 15 21.0 N; 60 33 35.6 W. 2. Sediment sampled from surface to 15-20 cm depth.											

Table A2. Heavy metal, PCB and PAH levels in water, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (ug/L) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Nova Scotia Offshore											
JWEL (2000)	*June and November 1998-99*	*Eastern Margin of Sable Island Bank at the Gully (n=23)*	2 (<2-2)	<0.3	<2	3.0 (2-6.6)	<0.01	6.0 (4-18)	--	<0.05	--
	June and November 1998-99	*Venture (n=165)*	2.3 (1-5)	<0.3	2.5 (2-6)	6.0 (2.3-7.9)	0.02 (<0.02-0.05)	12.3 (2-52)	--	<0.05	--
	November 1998; June and November 1999	*North Triumph (n=134)*	2 (<2-2)	<0.3	2.1 (2-4)	4.8 (1.4-7.7)	<0.01	9.5 (2-28)	--	<0.05	--
	November 1998; June and November 1999	*Thebaud (n=136)*	1.5 (2-4)	<0.3	2.5 (2-15)	4.7 (1.8-9.1)	<0.01	10.1 (4-24)	--	<0.05	--
Nova Scotia Coastal and Inshore											
Little et al. (2015)	*2005*	*Wine Harbour (n=229)*	66 (4-568)	--	16.8 (6.81-30.3)	16.5 (5.43-53.4)	813 (<5-7435)	52.3 (26.1-77.6)	--	--	--
Doe et al. (2017)	*2005*	*Seal Cove, West River at Mouth (n=1)*	380	--	--	--	<0.05	--	--	--	--
Doe et al. (2017)	*2005*	*Seal Cove, Seawater over Mudflats (n=1)*	370	--	--	--	<0.05	--	--	--	--

Table A2. Heavy metal, PCB and PAH levels in water, Scotian Shelf Bioregion.											
Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)											
Sampling Program	Date	Location	Concentration (ug/L) (mean, range, number of samples)								
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	PCB	TPAH	TPH
Doe et al. (2017)	*2005*	*Seal Cove, Seawater shoreline sites (n=7)*	39.9 (<20-79)				<0.05				
Bay of Fundy Coastal and Inshore											
Hung and Chmura (2006)	*1997-2002*	*Salt Marsh Sediments, New Brunswick*	--	--	--	--	(0.007-0.078)	--	--	--	
Irving Oil (2009)	*2006*	*Saint John Harbour, Mispec Point (n=12)*	4.33 (3-6)	<0.1	6.92 (4-11)	8.06 (4.8-11.6)	<0.01-0.1	39.08 (28-57)	<0.05	0.28 (0.09-0.78)	4.46 (1.70-12.0)

Table A3. Heavy metal, PCB and PAH and dioxins levels in biota, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples) (Wet Weight)									
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	Other metal	TPAH	PCB	Dioxins and furans (ppt TEQ)
Nova Scotia Offshore												
Nova Scotia Coastal and Inshore												
Little et al. (2015)	*2005*	*Wine Harbour (n=229)*	66 (4-568)	--	16.8 (6.81-30.3)	16.5 (5.43-53.4)	813 (<5-7435)	52.3 (26.1-77.6)	--	--	--	
Doe et al. (2017)	*2004*	*Seal Harbour, Softshell Clams (n=10)*	160 (67.4-309)	--	--	--	0.10 (0.07-0.15)	--	--	--	--	--
	2005	*Seal Harbour, Softshell Clams (n=8)*	50.0 (9.1-259)	--	--	--	0.11 (0.09-0.13)	--	--	--	--	--
	2005	*Seal Harbour, Blue Mussels (n=8)*	6.3 (4.6-7.9)	--	--	--	0.09 (0.07-0.10)	--	--	--	--	--
Whaley-Martin et al. (2012)	*2005*	*Seal Harbour, Blue Mussels (n=8)*		--	--	--		--	--	--	--	--
Doe et al. (2017)	*2005*	*Wine Harbour, Softshell Clams (n=1)*	6.8	--	--	--	0.06	--	--	--	--	--
Doe et al. (2017)	*2005*	*Wine Harbour, Blue Mussels (n=2)*	7.1 (6.9-7.3)	--	--	--	0.14 (0.13-0.14)	--	--	--	--	--
Doe et al. (2017)	*2005*	*Miscellaneous coastal sites in gold mining areas, Softshell Clams (n=4)*	14.8 (2.5-45.8)	--	--	--	0.06 (0.04-0.11)	--	--	--	--	--

Table A3. Heavy metal, PCB and PAH and dioxins levels in biota, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples) (Wet Weight)									
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	Other metal	TPAH	PCB	Dioxins and furans (ppt TEQ)
Doe et al. (2017)	*2005*	*Miscellaneous coastal sites in gold mining areas, Blue Mussels (n=5)*	4.1 (1.82-10.6)	--	--	--	0.05 (<0.05-0.06)	--	--	--	--	--
Doe et al. (2017)	*2005*	*New Harbour (uncontamin-ated site), Softshell Clams (n=1)*	1.6	--	--	--	0.05	--	--	--	--	--
Doe et al. (2017)	*2005*	*New Harbour (uncontamin-ated site), Blue Mussels (n=1)*	1.8	--	--	--	0.07	--	--	--	--	--
Walker and Grant (2015)	*2008*	*Isaacs and Country Harbours, Blue Mussels*	1.3-2.0	0.16-0.19	0.8-6.7	0.15-1.31	0.02-0.05	7.4-11	--	--	--	--
	2008	*Isaacs Harbour, Lobster hepato-pancreas*	5.0-10.0	<0.3		<0.5	0.06-0.12	24-35				
Walker and MacAskill (2014)	*2009-2012*	*Sydney Harbour, Blue Mussels*	1.5-3.9	0.14-0.29	0.8-1.9	<0.18-0.43	<0.01-0.03	10-24		<0.05-0.38	<0.05-0.07	

Table A3. Heavy metal, PCB and PAH and dioxins levels in biota, Scotian Shelf Bioregion.

Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)

Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples) (Wet Weight)									
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	Other metal	TPAH	PCB	Dioxins and furans (ppt TEQ)
Walker et al. (2013c)	*2009-2012*	*Sydney Harbour, Rock Crab (*Cancer irroratus*)*	3.6-15.3	0.5-6.9	9.8-28	<0.18	<0.01-0.04	11.7-28.9		<0.05-0.14	0.12-4.5	
Carter et al. (2004)	*2004*	*Halifax Harbour, Blue Mussels (n=6 pools), dry weight*	8.9 (6.9-10.7)	0.7 (0.5-0.9)	8.1 (6.1-9.4)	2.3 (0.8-5.4)		110.9 (71.9-132.9)				
	2004	*Chezzetcook Inlet , Blue Mussels (n=1 pool), dry weight*	8.7	0.98	6.0	2.8		46.6				
Yeats et al. (2008)	*2003*	*Halifax Harbour, mussels (n=12 pools), dry weight*	1.8 [0.2]	0.12 [0.02]	2.3 [0.6]	0.17 [0.02] Up to 0.39		23 [3]	Chromium , 0.15 [0.05]; Silver, 33 [11], up			
Bay of Fundy Coastal and Inshore												
Lotze and Milewski 2002	*1996*	*Passama-quoddy Bay, lobster tomalley*	--	--	--	--	--	--	--	--	--	10.2-- 11.2
Passama-quoddy Tribe and CBRC (2001)	*1996*	*Passama-quoddy Bay, lobster meat (n=2 pools)*	31-72 (dry weight)	<0.1-0.18	100-125	<0.4-0.4	0.57-1.01	140-180	Selenium, 5.2-5.7	--	--	0.85-0.95
	1996	*Passama-quoddy Bay, lobster tomalley (n=2)*	15-37	7.2-44.4	225-500	<0.4	0.19-0.37	65-81	Selenium, 3.6-4.4	--	--	8.6-12.8

Table A3. Heavy metal, PCB and PAH and dioxins levels in biota, Scotian Shelf Bioregion.												
Example Data Presentation: Mean and Standard Deviation 21.1 (±8.1); *Mean and Range* 21.1 (4.5-9.2); *Range* (4.5-9.2)												
Sampling Program	Date	Location	Concentration (mg/kg) (mean, range, number of samples) (Wet Weight)									
			Arsenic	Cadmium	Copper	Lead	Mercury	Zinc	Other metal	TPAH	PCB	Dioxins and furans (ppt TEQ)
	1996	*Passama-quoddy Bay, Softshell Clam (n=1 pool)*	8.1	0.4	13	1.2	0.33	74	Selenium, 2.4	--	--	0.9
	1996	*Passama-quoddy Bay, cod tissue (n=1 pool)*	11	<0.1	3.1	0.4	0.31	45	Selenium, 2.8	--	--	1.20
	1996	*Passama-quoddy Bay, Sea Scallop (n=1 pool)*	4.6	0.26	1.4	<0.4	0.16	53	Selenium, 1.24	--	--	0.69
Sowles (1997)	*1995*	*Coastal Maine including Passama-quoddy Bay, lobster tomalley*	16.75 (dry weight)	7.69	253.75	1.06	0.33	54.25	Selenium, 2.63	--	--	
	1995	*Coastal Maine including Passama-quoddy Bay, lobster tissue*	19.0 (dry weight)	0.15	60.75	0.84	0.83	127.5	Selenium, 2.65	--	--	--
Chou et al. (2000, 2003)	*1999*	*Bay of Fundy, lobster tissue*	--	5.1-22.9	10.4-896	--	--	27-129	--	--	--	--