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15

Emerging Contaminants of Concern in Canadian Harbours:

A case study of Halifax Harbour

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SYNOPSIS

As part of the Ocean Pollution Research Program, the Coastal Ocean Research Institute (CORI) at the Vancouver Aquarium (VA) has collaborated with Dr. Lucia Fanning, Marine Affairs Program at Dalhousie University, to carry out a work that highlights contaminant issues of emerging concern in Halifax Harbour, Nova Scotia. Dr. Carmen Morales-Caselles, research scientist at the CORI-VA, has worked together with Wenhui Gao, a Master student from the Marine Affairs Program at Dalhousie University, to write this report. During the preparation of this work Ms. Gao has participated in an internship at the CORI-VA where she was involved in a workshop organized by the CORI-VA for stakeholders on “Solutions to Ocean Pollutions”. The findings of this interesting and successful workshop have been applied to the present assessment for Halifax Harbour. In addition to this report Ms. Gao will present her Master Thesis in December 2015 under this theme. A scientific manuscript is in preparation in order to present the results to the scientific community.

1. INTRODUCTION

Occupying 71% of the Earth's surface, the ocean has been supporting human activities in a variety of ways, including marine transportation, seabed mining, fishing and aquaculture, residential developments, and sewage inputs. Historically, starting from 1920s, the marine industry has grown rapidly, and hundreds of countries are now developing in offshore drilling and the exploitation of oil and gas. In addition, maritime transportation of oil has reached more than 2 billion tons annually (El-Said, 2013). For fisheries industries, annual catch of the fish and shellfish is nearly 100 million tons (Stewart and White, 2001; Dahlen et al 2006), and has become the major source of protein intakes for daily lives. Nowadays, over 60% of the world population lives within 60 km of the sea, and depend directly or indirectly on coastal and marine ecosystem for their livelihood (UNEP-WCMC, 2011; Velmurugan et al., 2015).

Canada's ocean ecosystem health and functioning is critical to sustaining a strong maritime economy and resilient coastal communities (Bailey et al., 2016). Along with the development of science and technology, the awareness on ocean health has increased, especially for the coastal areas along harbour cities. Since the ocean is able to influence humans and global environment in many ways, a healthy coastal environment is crucial for the health of human and marine biota. In recent decades, among various global maritime issues, ocean pollution is causing a surge of attentions and has become one of the heaviest pressures faced by human beings and the environment.

Harbour sediments have historically tended to be hotspots of contamination due to direct and/or indirect causes related to anthropogenic activities developed in the area such as shipping-related activities, industries, presence of highly populated areas, rivers and other discharges. Dredging and disposal processes can release pollutants bound to contaminated sediments and make them available to the biota, therefore the understanding of background levels of contaminants in harbour sediments is crucial to assess sources and eventually dredging and disposal activities.

Contaminants released into the ocean can cause harmful effects on marine organisms and the habitat in which they live. Some species are important from a commercial, recreational or traditional foods perspective. Other species, such as resident killer whales, provide a conservation imperative, as these 'endangered' animals remind us of the need to protect long-live, mobile creatures from our unintended impacts. Environmental health is also closely related to human health, therefore there is an urgent need to understand the impact of contaminants in the food web in order to inform policy in an effective way.

The urgent need to know baseline levels in harbours converges with the necessity to understand the impact of pollutants in the food web in order to design appropriate decision support tools to inform effective policy that protects human health and the natural environment. Currently, there are numerous national and international initiatives focused on the control of pollutants to conserve the natural environment and protect human health, such as the Stockholm Convention on Persistent Organic Pollutants (POPs) which is a global treaty that aims to protect human health and the environment from the negative effects of POPs by restricting and ultimately eliminating their production, use, release and unsafe disposal. In Canada, the Canadian Environmental Protection Act (CEPA), 1999, consistent with the principles of the London Convention, oversees Disposal at Sea activities (Lachmuth et al., 2010). Environment Canada administers the Disposal at Sea Program by means of a permitting process, regulating the disposal of dredged material, fisheries waste, ships or other structures, inert inorganic geological matter, uncontaminated organic matter of natural origin and bulky substances.

Notwithstanding national and global initiatives, limitations on data accessibility, lack of harmonized monitoring and target congeners and matrixes, pose a limitation for understanding legacy and emerging contaminants in harbours and their risks to human and ocean health.

2. CONTAMINANTS IN HARBOURS

2.1 The importance of sediments in pollution research and management

Human activities in coastal areas, such as harbours, usually involve an input of contaminants to the natural environment that becomes evident in the decreased quality of coastal sediments (Morales-Caselles et al., 2007). The importance of the environmental quality of the sediments and its intimate connection to the sustainable coastal environment has been acknowledged and studied since early 1990s (Munawar et al., 1999; Crane, 2003; Branch, 2013). In recent years, science and technology have revealed more comprehensively on the important role played by marine sediments. Compared to water quality, sediment quality in harbour areas are affecting human health and the biological environment in a more powerful way (Willford et al., 1987; Munawar et al., 1999; Forbes et al., 1998; El-Said, 2013).

To begin with, most of contaminants released to the water will eventually end up in the sediments. Research and monitoring using a variety of study designs in the field have been critical in prioritizing pollutants of concern in contaminated areas, devising mitigation strategies and documenting environmental responses to such mitigation. Sediments have been routinely used to evaluate integrated pollutant inputs into aquatic environments, as they are regarded as both ‘sinks’ and potential ‘sources’ for adjacent food webs (Adams et al., 1992; Tolun et al., 2001; Moreira et al., 2006; Grant et al. 2011; Burd et al., 2014). Studies show that harmful contaminants, such as pathogens, nutrients, metals, and organic chemicals, tend to sorb onto both inorganic and organic materials that eventually settle and lead to accumulation in the sediments of rivers, reservoirs, lakes, estuaries, and marine waters (Burton, 2002; Robinson et al., 2009).

Secondly, there is a variety of ways for humans and the biota to be exposed to the sediment contaminants. Starting from the benthos from the sediment at bottom of the food web, the contaminants will be accessed through the consumption of seafood and local foods. If the loading of these contaminants into the waterways is large enough, the sediments may accumulate excessive quantities of contaminants that directly and indirectly disrupt the ecosystem, causing significant contamination and loss of desirable species (Burton, 2002). The impacts on the ecosystem from sediment-associated contaminant have been found to have a wide range (Burton, 2002), from direct effects on benthic communities (Canfield et al., 1994; Swartz et al., 1994) to substantial contributions to contaminant loads and effects on upper trophic levels through food chain contamination (e.g., for tree swallows, Bishop et al.,1999; McCarty and Secord, 1999; for mink, Foley et al., 1988; for Caspian terns Ludwig et al., 1993). According to Mackay (1991) and Burton (2002), "the ecosystem is an interconnected series of pathways whereby chemical, physical, and biological contaminants move between the four primary compartments of air, surface and ground waters, land, and biota (MacKay, 1991)" (P.66). Therefore, the sediment quality will eventually affect the health situation of the whole marine ecosystem. More significant harmful effects can be observed at higher tropic levels, such as sharks and marine mammals including killer whales, sea lions, sea otters, etc. In this sense, tracing and ensuring the quality of the sediments is crucial and fundamental from a management perspective in order to protect the marine endangered and threaten species listed under the Species At Risk Act (SARA). For human health issues, when contaminants bioaccumulate in food sources such as shellfish, trout, salmon or ducks, they pose a threat to human health (El-Said and Draz, 2010; El-Sikaily and El-Said, 2010; Qiao et al., 2010; US EPA, 2012; El-Said, 2013). Possible long-term effects of eating contaminated fish include cancer and neurological defects (US EPA, 2012). Therefore, it is highly possible for human and biota to have acute exposures to multiple harbour contaminants in a wide range.

Furthermore, in recent decades, urbanization and the expanding population in coastal areas have increased the sources of pollutants entering harbour environments, triggering more challenges in terms of effective management approaches and risks for environmental health.

Pollutants such us trace metals, plastics, oils, pesticides, household chemicals herbicides and cleaning agents, Pharmaceuticals and Personal Care Products (PPCPs), radioactive substances, nutrients and solid waste (Buckley et al., 1995; Federico and Henderson, 2001; Dahlen et al., 2006; Ruus et al., 2013), might come from industry waste discharge, urban sewage, shipping and harbour activities, aquaculture and agriculture, run-offs, as well as tourism businesses among others. Compared to the low rate of natural decomposition, the daily metabolic wastes from the cities are far higher than what nature can bear. Moreover, many chemicals will transform or react with each other into more complex and toxic contaminants, which makes it even more difficult to predict and anticipate the risk of pollutants.

The effects of sediment contaminants might also be long-term and chronic (Tueros et al., 2009; Elhakeem and Elshorbagy, 2013). After World War II, a large number of chemical weapons were dumped and buried into the ocean, most of them along harbour areas. Pouring into the ocean was a major treatment for the excess chemical and military weapons (Burton, 2002). It remains unclear the amounts of pollutants released through this type of activities, including in the Esquimalt and Halifax Harbours, the two important military ports in Canada. In addition, prior to 1990s, there was a lack of information and understanding of marine pollution and sediment contamination among researchers and managers. The absence of sewage treatment at the initial period of urbanization has led to the discharge of large amounts of untreated waste waters directly into the ocean. Halifax, for example, did not have any sewage treatment program before 2000 (Buckley et al., 1995; Timoney, 2007), and all the urban sewage and industrial waste water use to be released into the harbour without any previous treatment. Once in the water column, contaminants might settle and accumulate in sediment of certain areas such as those where the water flows slowly. Studies in these types of lotic systems have detected toxicity in both the bottom and mobile suspended seston components (Munawar et al., 1999). The natural decomposition process takes a long time, and some contaminants such as trace metals and microplastics can be considered as non-degradable. The risk posed by historical contaminated sediments is that they might resuspend due to a storm, a boat propeller or dredging activities. The resuspension of contaminated sediments into the water column will directly expose other organisms, not just the bottom-dwelling organisms, to toxic contaminants (US EPA, 2012).

Last but not least, up until now, there has not been a completely safe and effective way to purify contaminants from sediments. A variety of remediation technologies exist for cleanup, but they tend to be expensive and the most common method is still dredging (Averett et al., 1990; Burton, 2002). The downside of this technique is that dredging will stir the bottom of the ocean and release a certain amount of contaminants that will became available to other organisms of the aquatic system. Therefore, dredging works may sometimes increase the exposure of human and biota to the contaminants. In this sense, research and management efforts should focus on preventing the contaminants from entering in the harbours as a more effective approach.

2.2 Priority pollutants and emerging contaminants of concern in harbours

Atmospheric deposition, wastewater treatment plants, urban and agricultural run-off, oil spills, and industrial effluent (Ross and Desforges, 2014) have been identified as priority pollutant source pathways. Harbour contaminants might include sewage, oil, trace metals, pesticides, PCBs, radioactive substances, nutrients and solid waste among others (Belan, 2004; Morales-Caselles et al., 2008). Several classes of contaminants have been previously identified as potentially related to port activities, while others may originate from external sources (Table 1).

Table 1. Putative contaminants of concern.

CONTAMINANTS OF CONCERN		
Known - Port related activities	**Likely – Port related activities**	**Likely –external sources**
Metals	Flame retardants	Organochlorine Pesticides
Hydrocarbons	Perfluorinated compounds	Current Use Pesticides
Polychlorinated biphenyls	Dioxins	Pharmaceuticals
Organotins (TBT)	Furans	Personal Care Products
	Alkylphenols	Microplastics
		Neonicotinoid pesticides
		Phthalate ester
		Chlorinated paraffins

Aquaculture, shipping and harbour loading, ship painting and cleaning including the release of ballast water and dredging of sediments can be considered major inputs of deleterious substances. In addition, for busy maritime areas such as Halifax and Victoria/Esquimalt Harbours in Canada, the risk of oil spills increase. This together with the naval uses place these two harbour areas in an even more unique situation. Hydrocarbons contamination poses a particular concern, especially in areas with high maritime traffic, and has caught the attention of scientists, public and the social media. According to statistics, 45% of hydrocarbons inputs in the marine environment come from marine transport whereas 32% are spilled through routinely loading operations and boat cleaning (Morales-Caselles et al., 2008). Trace metals might come from industrial pollution such as the burning of coals and municipal waste incinerations. Pesticides and cleaning agents are mainly derived from agriculture, forestry and aquiculture, as well as urban sewage and run-off.

Both Esquimalt and Victoria harbours are considered "hotspots" for sediment contamination in British Columbia (Grant and Ross, 2002). The main historical sources of contamination in the harbours might include the following (Bright and Willson, 2007):

- Storm sewer discharges
- Sediment transport from the upper harbour
- Sediment transport from areas influenced by sanitary sewage discharge
- Spills, leaking underground and above-ground storage tanks, and/or fuel transport
- Historical use of contaminated fill in foreshore areas
- Operations of rail yards and historical roofing and tar company
- Major dock operations, including metal founding and forgery, boat repair and sand blasting
- Use and spillage of coal in late 1800s-early 1900s
- Chemical/materials manufacture (e.g. historical chemical company; paint factory)
- Discharge from boats and bilge (e.g. fuel and lubricant spills)
- Leakage from PCB-containing transformers and other electrical equipment.
- Contaminated ground-water

It is known that overflow of raw sewage occurs during intense rain events when sewers overflow into storm drains that flow directly into the Victoria Harbour. These stormwater, sanitary and combined overflows, and other discharges, particularly into the surface waters in

Victoria's harbours, present more pressing environmental issues than the current offshore submarine sewage discharges (Chapman, 2007., Chapman et al, 2008).

Based on the combined drivers of analytical chemistry and emerging toxicity profiles, certain classes of chemicals are increasingly featured within the peer-reviewed literature (Roose et al., 2011). Attention continues to focus on persistent, bioaccumulative and toxic substances and as scientific knowledge advances, the scope of concern goes beyond what it is currently covered by international programs (le Farre et al., 2008). In recent years, and together with the increasing population and the urbanization, PCBs, PPCPs, solid waste, microplastics and other substances have increased dramatically (Federico and Henderson, 2001; Belan, 2004; AMEC, 2011; Ruus et al., 2013), leading to higher safety risks for marine environment and human health. Newly emerging contaminants such as pharmaceuticals and personal care products (PPCPs) still need to be examined for their potential to bioaccumulate and biomagnify (Lachmuth et al., 2010). Many of the compounds in these products are common in waste water effluent and may affect the health of living organisms (Table 2). The effects of global warming including gradual increase of water temperature and ocean acidification, might lead to the release of the contaminants and secondary reactions.

Nowadays harbour areas are facing multiple, wide range of challenges. Through the development of comprehensive, high quality and harmonized monitoring, harbours and other hotspots of contamination can provide early warning signs of emerging contaminants in a very useful way. Historical problems combined with newly emerging contaminants makes costal environment more vulnerable than ever before, and thus are urgently in need of better scientific understandings, public awareness, and regulatory approaches (Lachmuth, 2010).

Table 2. A brief description of priority contaminants of concern in harbours, including existence or not of Canadian Sediment Quality Guidelines for the protection of aquatic life (CCME SQGs)

CONTAMINANT	SOURCE	PERSISTENCE AND TOXICITY	LEGISLATION	CCME SQGs
Trace Metals	Heavy metals occur naturally, but are also products or by-products of human activities. Common anthropogenic sources include mining and industrial wastes, vehicle emissions, lead-acid batteries, fertilizers, paints and treated woods.	Metals can accumulate in marine life and can be locally problematic. Metals vary in their toxic effects. Some effects include oxidative stress and carcinogenicity. For example lead interferes with a variety of body processes and is toxic to many organs and tissues including the heart, bones, intestines, kidneys, and reproductive and nervous systems. The organometallic forms methylmercury and tetraethyl lead can be extremely toxic.	Regulations in food and environmental guidelines	Some
PAHs	Polycyclic Aromatic Hydrocarbons are often byproducts of petroleum processing or combustion; some PAHs are used to make dyes, plastics, and pesticides. Forest fires and prairie fires, agricultural burning, and fossil-fuels are the major contributors of PAHs to the environment.	There exist thousands of PAHs in the environment, with individual PAHs varying in behaviour. Lighter PAH compounds are generally more water soluble and can therefore be more bioavailable to aquatic life where they may pose risk of acute toxicity. However, breakdown times are much shorter than for heavier compounds. PAHs with more than four rings, being less volatile and soluble, favor adherence to solid particles. They are generally found in soil and sediment as complex mixtures. Alkylated PAHs are more persistent than their parent PAHs. Many of these compounds are highly carcinogenic at relatively low levels. The heavier PAH compounds tend to be associated with more chronic health effects. US EPA has identified 16 priority PAHs that are thought to be carcinogenic through multiple routes of exposure, and can affect the immune, reproductive, nervous and endocrine systems. The most toxic PAH is benzo(a)pyrene	CEPA 1999 Schedule 1 - List of Toxic Substances: new restrictions in Europe (ECHA: EU No 1272/2013).	Total, some congeners

PCBs	Polychlorinated biphenyls have been used as heat exchange fluids, in electric transformers and capacitors, and as additives in paint, carbonless copy paper, and plastics.	Their persistence in the environment corresponds to the degree of chlorination, and half-lives can vary from weeks to decades. Of the 209 different types of PCBs, 13 exhibit a dioxin-like toxicity. PCBs are toxic to fish, causing reproductive failures at relatively low doses. Large numbers of people have been exposed to low to moderate levels of PCBs through food contamination. Since PCBs are persistent, bioaccumulative and toxic, they accumulate in aquatic food webs and attain high levels in some marine mammals. PCBs have been associated with toxic effects in marine mammals such as endocrine disruption, which can cause impairment of reproduction, development, and other hormonally mediated processes, and immunotoxicity, giving rise to an increased susceptibility to infectious diseases and cancers.	Listed under Annex A with specific exemptions and under Annex C of the Stockholm Convention. The import, manufacture, and sale (for re-use) of PCBs were made illegal in Canada in 1977 and release to the environment of PCBs was made illegal in 1985. However, Canadian legislation has allowed owners of PCB equipment to continue using PCB equipment until the end of its service life. The storage of PCBs has been regulated since 1988. Handling, transport and destruction of PCBs are also regulated, mostly under provincial regulations. Canada is signatory to several international agreements on the phase-out of a number of persistent toxic substances including PCBs. Environment Canada has therefore repealed the *Chlorobiphenyls Regulations* and the *Storage of PCB Material Regulations* on September 5, 2008 and made the *PCB Regulations* under the *Canadian Environmental Protection Act*, 1999 (CEPA 1999) that set specific dates for the destruction of PCBs in service and in storage.	Total, some congeners

PCDDs	Polychlorinated dibenzo-p-dioxins are produced unintentionally due to incomplete combustion, as well during the manufacture of pesticides and other chlorinated substances. They are emitted from the low-temperature incineration of hospital, municipal, and hazardous wastes, and also from automobile emissions, peat, coal, and burning of salt laden wood in coastal pulp and paper boilers, iron sintering and electric arc furnace steel manufacturing. There were releases of large amounts of dioxins from pulp and paper mills in Canada prior to regulations restricting the use of elemental liquid chlorine.	There are 75 different dioxins, of which seven are considered to be of concern. High capacity to accumulate in biological tissues. Dioxins have been associated with a number of adverse effects in humans, including immune and enzyme disorders and chloracne, and they are classified as possible human carcinogens.	Listed under Annex C of the Stockholm Convention. Dioxins and furans are slated for virtual elimination under the Canadian Environmental Protection Act, the federal Toxic Substances Management Policy and the CCME Policy for the Management of Toxic Substances.
PCDFs	Polychlorinated dibenzofurans are produced unintentionally from many of the same processes that produce dioxins, and also during the production of PCBs. They have been detected in emissions from waste incinerators, automobiles and from pulp mills. There were releases of large amounts of dioxins from pulp and paper mills in Canada prior to regulations restricting the use of elemental liquid chlorine.	Furans persist in the environment for long periods. High capacity to accumulate in biological tissues. Furans are structurally similar to dioxins and share many of their toxic effects. There are 135 different types, and their toxicity varies. Furans are classified as possible human carcinogens. Food, particularly animal products, is the major source of exposure for humans. Furans have also been detected in breast-fed infants.	Listed under Annex C of the Stockholm Convention. Dioxins and furans are slated for virtual elimination under the Canadian Environmental Protection Act, the federal Toxic Substances Management Policy and the CCME Policy for the Management of Toxic Substances.
Brominated Flame Retardants	Brominated Flame Retardants appear in manufactured materials, such as furnishings, electronics, plastics and textiles; a major source is diffuse leaching from products into wastewater streams from users, households and industries.	Many of the BFRs are considered toxic, persistent and bioaccumulative. Largely distributed in organisms (including marine mammals) from various geographic regions. Long-range atmospheric transport and deposition. PBDEs bioaccumulate in blood, breast milk, and fat tissues. Health effects of PBDE exposure include damage to the neurological, reproductive, immune, and hormonal systems. The most widely used chemical in this group, decaBDE, is also a suspected carcinogen. HBCD causes reproductive toxicity. TBBPA degrades to bisphenol A and to TBBPA dimethyl ether; TBBPA has demonstrated toxicity in a variety of aquatic and terrestrial species, its chronic toxicity is predicted at very low concentrations.	PBDEs "toxic", as defined under the Canadian Environmental Protection Act, 1999. Regulations prohibit the manufacture of all PBDEs in Canada, and restricting the import, use and sale of PBDEs found in commercial mixtures of greatest concern (Penta- and OctaBDE). DecaBDE is under assessment. Stockholm Convention on Persistent Organic Pollutants decided in May 2013 to list hexabromocyclododecane in Annex A (for elimination) to the Convention with specific exemptions. TBBPA is currently in the pre-registration phase of REACH. The Government of Canada is considering the implementation of risk management measures to reduce releases of TBBPA from industrial source if required, while maintaining the use of TBBPA where deemed necessary

PFCs	Perfluorooctane sulfonic acid (PFOS) and its salts, perfluorooctane sulfonyl fluoride and Perfluorooctanoic acid (PFOA) are known as perfluorinated compounds. They can be found in electronic parts, firefighting foam, photo imaging, hydraulic fluids and textiles. PFOS was the key ingredient in Scotchgard, a fabric protector made by 3M, and numerous stain repellents.	PFCs are persistent in the environment. PFOA and PFOS are considered to be resistant to degradation in soil. Bioaccumulate and persist in protein-rich compartments of fish, birds, and marine mammals. PFCs are toxic including neonatal mortality. Studies of PFOA indicate that it can cause several types of tumors and neonatal death and may have toxic effects on the immune, liver, and endocrine systems.	Added to Annex B of the Stockholm Convention on Persistent Organic Pollutants in May 2009. EPA has designated rules for the use of PFCs. EU and other countries developing strategies to reduce their use. The Government of Canada added PFOS, its salts, and its precursors to the Toxic Substances List under Schedule 1 of the Canadian Environmental Protection Act, 1999.	NO
Alkylphenols	Alkylphenols including nonylphenol, are used to make alkylphenol ethoxylates (APEs), chemical compounds that are mainly used as synthetic surfactants used in detergents and cleaning prod-ucts. Used as antioxidants, oil additives, detergents, emulsifiers, and solubilizers, precursors of non-ionic surfactants, cosmetic, pesticides.	Alkylphenols can take months or longer to degrade in surface waters, soils, and sediments. Long distances transportation and global reach. Alkylphenols are endocrine disruptors due to their ability to mimic estrogen and in turn disrupt the natural balance of hormones in affected organisms. Prenatal and perinatal exposure to nonylphenol has been linked with developmental abnormalities. Nonylphenol exposure has also been associated with breast cancer.	European Union and Canada have banned the use of nonylphenol ethoxylates (NPEs) in detergents	NO
OCPs	Organochlorine Pesticides; also known as legacy pesticides; they were widely used in a griculture and pest control until research and public concern regarding the hazards of their use led to government restrictions and bans. Despite restrictions and bans on the use of many organochlorine pesticides in the 1970s and 1980s, they continue to persist in the environment today.	Despite restrictions and bans on the use of many organochlorine pesticides in the 1970s and 1980s, they continue to persist in the environment today. Organochlorine pesticides are hydrophobic, lipophilic and extremely stable. Toxicity appears to be via disruption of neural function and specific disturbances vary by chemistry. Studies support both acute and chronic effects of OC pesticides, potentially via damage to reproductive and neurological functions, carcinogenesis and endocrine disruption	Nine of the 12 most haz-ardous persistent organic pollutants (POPs) targeted by the Stockholm Convention in 2001 are OC pesticides.	Some
Neonicotinoid pesticides	During the 1970s and 1980s after the detrimental effects of pesticides like DDT became known, OC pesticides were replaced with less persistent pesticides. These new pesti-cides had different physical-chemicals properties than OCs and different environmental fates.	Long-term persistence in soil and water. The neonicotinoids show reduced toxicity compared to previously used organophosphate and carbamate insecticides. The use of neonicotinoids was linked in a range of studies to a number of adverse ecological effects, including honey-bee colony collapse disorder (CCD) and loss of birds due to reduction in insect populations.	Temporary suspensions and bans on the use of different neonicotinoids in several countries.	NO

CUP	Current use pesticides.	Current use pesticides are generally more target specific and are less persistent in the environment than legacy pesticides. They may be more acutely toxic than old pesticides. Studies have shown that exposure to OP pesticides can affect the neurological and immune systems in animals. Once in the body, many OP compounds metabolize into dialkyl phosphate metabolites. Atrazine is linked to ovarian cancer and can be toxic to freshwater fish, invertebrates, and aquatic plants.	Some banned in the EU	NO
TBTs	Tributyltins is a pesticidal compound applied to the hulls of ships and small boats to protect against an accumulation of barnacles and other fouling organisms on underwater surfaces. TBT is one of a class of compounds called organotins and was introduced in the 1960s. Ships painted with TBT needed repainting every 4-5 years.	Highly persistent, bioaccumulative and biomagnifies in the food chain. Compared to earlier copper-containing antifouling coatings, TBT was more toxic to fouling organisms and lasted longer. Toxic effects at all trophic levels. Endocrine disruptive (i.e. masculinization of gastropods), it affects immune system in vertebrates.	Completely banned in 2008 by the International Convention on the Control of Harmful Anti-fouling Systems on Ships of the International Maritime Organization.	NO
Phthalate esters	Plastics that contain phthalates are commonly used in applications that include building materials, clothing, cosmetics, perfumes, food packaging, toys, and vinyl products; primarily used to make polyvinyl chloride (PVC) or vinyl flexible and pliant	They will tend to persist for long periods in anaerobic sediments. Endocrine disruptors, teratogenic effects, mortality.	Lower-molecular-weight phthalates (3-6 carbon atoms in their backbone) are being gradually replaced in many products in the United States, Canada, and European Union over health concerns.	NO
Chlorinated paraffins	Short-Chain Chlorinated Paraffins (SCCP)s are used as lubricants and coolants in metal cutting and metal forming operations and as secondary plasticizers and flame retardants in plastics.	They can remain in the environment for a significant amount of time and can bioaccumulate in animal tissues, increasing the probability and duration of exposure. Even relatively small releases of these chemicals from individual manufacturing, processing, or waste management facilities have the potential to accumulate over time to higher levels and cause significant adverse impacts on the environment. They are classified as toxic to aquatic organisms.	CEPA 1999 Schedule 1 - List of Toxic Substances. The EU has restricted SCCP use in metalworking fluids. Currently EPA is taking an action plan, under which regulations to restrict or even ban all short-chain paraffins (together with eight phthalates, and two types of perfluorinated compounds: perfluorinated sulfonates and perfluoroalkyl carboxylates) are being considered.	NO

PPCP	Pharmaceuticals and Personal Care Products get into the marine environment from wastewaters from areas of intense urbanization and animal production.	Although some degrade quickly, they can be considered pseudo-persistent in the environment because of continual inputs. The ability of triclosan (and others) to bioaccumulate is affected by its ionization state in different environmental conditions. Their toxicity varies, and it can affect hormone levels, carcinogenicity, etc. Triclosan is toxic to aquatic bacteria at levels found in the environment. It is highly toxic to various types of algae and has the potential to affect the structure of algal communities, particularly immediately downstream of effluents from wastewater treatment facilities that treat household wastewaters. Triclosan has been observed in multiple organisms, including algae aquatic blackworms, fish and dolphins.	BPA considered "toxic substance" and added it to schedule 1 of the Canadian Environmental Protection Act, 1999. The Risk Assessment by EC proposed that triclosan meets the criterion as set out under paragraph 64(a) of CEPA 1999; it was also proposed that triclosan meets the criterion for bioaccumulation but not the criteria for persistence as set out in the Persistence and Bioaccumulation Regulations (Canada 2000).	NO
Microplastics	Micro-plastics have a range of compositions and can be demarcated by usage and origin as: i) 'primary', pellets used as a feedstock in the plastics industry, and in certain applications such as abrasives; and, ii) 'secondary', fragments resulting from the degradation and breakdown of larger items. Artificial particles < 5mm. wastewaters (Land-based sources are considered to contribute the largest input of plastics), marine litter, shipping, fishing and the military transport. Micro-plastic particles can arise through four separate processes: i) deterioration of larger plastic fragments, cordage and films over time, with or without assistance from UV radiation, mechanical forces in the seas (e.g. wave action, grinding on high energy shorelines), or through biological activity (e.g. boring, shredding and grinding by marine organisms); ii) direct release of micro particles (e.g. scrubs and abrasives in household and personal care products, shot-blasting ship hulls and industrial cleaning products respectively, grinding or milling waste) into waterways and via urban wastewater treatment; iii) accidental loss of industrial raw materials (e.g. prefabricated plastics in the form of pellets or powders used to make plastic articles), during transport or transshipment, at sea or into surface waterways; iv) discharge of macerated wastes, e.g. sewage sludge.	Their persistency is high. Microplastics can be ingested by marine organisms. Entanglement and ingestion with the potential for: physical disruption and abrasion; toxicity of chemicals in the plastic; and, toxicity of absorbed persistent, bioaccumulative and toxic (PBT) substances.	No regulations. Some companies have promised a voluntary phase-out of plastic microbeads. Some US Sates (e.g. Michigan) are banning microbead-containing products.	NO

3. GENERAL OVERVIEW OF THE HALIFAX HARBOUR (Nova Scotia)

Halifax Harbour is a natural harbour located on the Atlantic coast of Nova Scotia, in the Halifax Regional Municipality (Figure 1). The harbour, called Jipugtug (Chebucto) by the Mi'kmaq first nation, is a strategic port for navigation, naval and industrial activities.

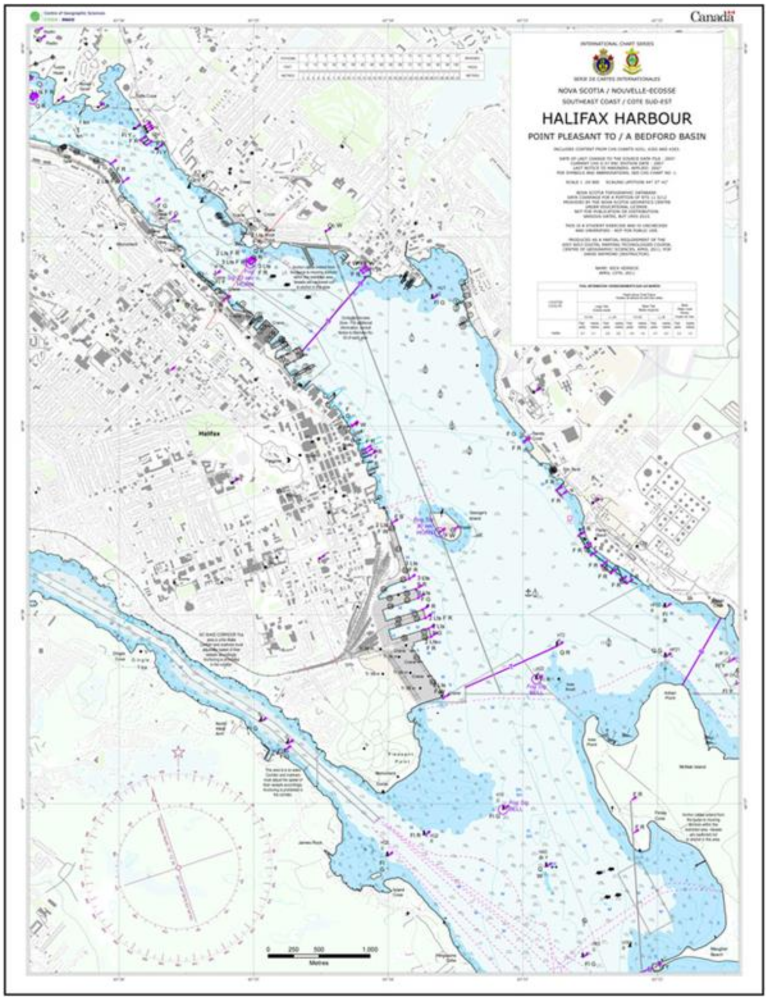

Figure 1. Chart of Halifax Harbour (Source: GOOGLE IMAGES)

3.1 Oceanography

Halifax Harbour is one of the world's deepest harbours at a depth of 18m at low tide (AMEC, 2011). It is sheltered, spacious, and has minimal currents and tides. The ice free port leaves the harbour accessible year round and it is the closest port of call for ships operating the North Atlantic, Round-the-World and Suez routes (AMEC, 2011). "The harbour receives a high influx of freshwater from the Sackville River, which flows into the northern end of the Bedford Basin (Figure 2), and through sewage outfalls along its margins. Because of this influx and its semi-enclosed shape, Halifax Harbour ideally has a two-layered-flow estuarine circulation model in which marine water enters through the harbor mouth below the fresh water that in turn flows over the denser seawater out of the harbor (Figure 3). Stormy weather disrupts this circulation pattern, with ocean waters entering near the surface and fresh waters exiting near the bottom (Fader, 2008), especially during tropical storms and hurricanes (Shan, 2010)" (Dabbous and Scott, 2012, P.188).

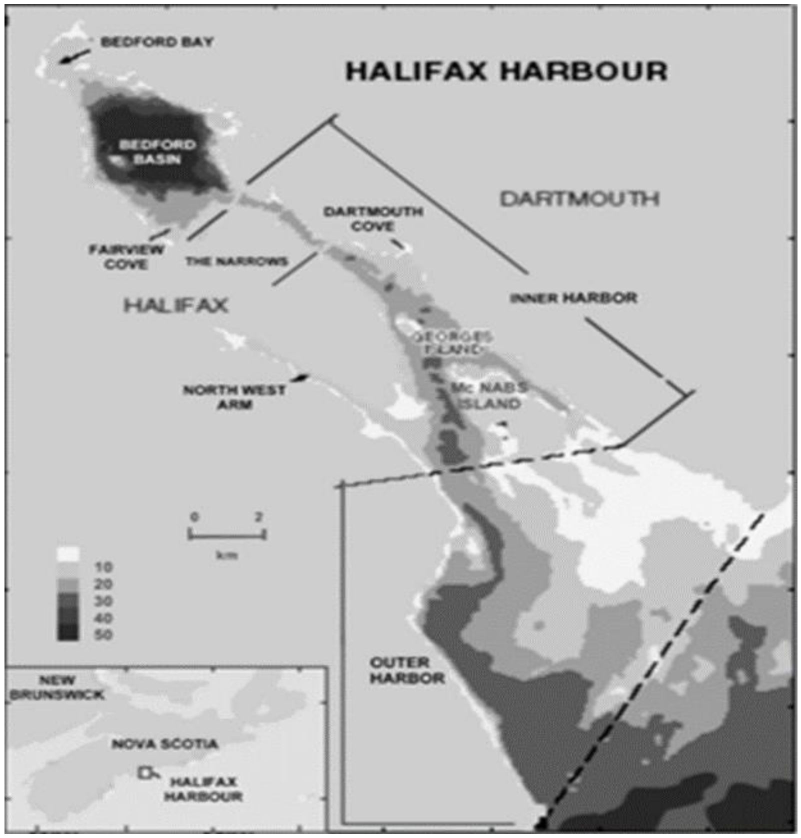

Figure 2 Map showing location, geographic divisions, and water depths of Halifax Harbour (from Dabbous and Scott, 2012, after Gordon B. Fader, 2008).

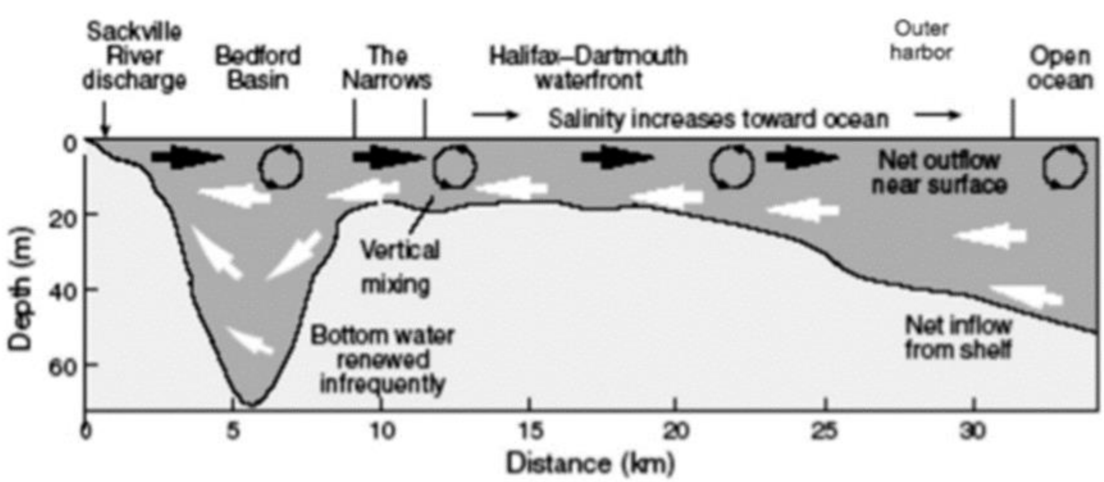

Figure 3. Simplified water circulation model of Halifax Harbour from Bedford Basin to the harbor mouth (Fader, 2008; Dabbous and Scott, 2012).

3.2 Biology

Halifax Harbour is a diverse environment being the home of low trophic-level organisms such as phytoplankton, seaweeds and benthic invertebrates as well as individuals higher in the food chain including fish, birds and marine mammals. In short, this harbour has as extraordinary ecological value. However, the Harbour's ecosystems have progressively been placed under stress as a result of intensive human activity along its shorelines. Since the colonization of the area 250 years ago, Halifax Harbour has been a receptacle for raw sewage and industrial wastes (Federico and Henderson, 2001) what has impacted the ecological equilibrium of the area.

3.3 Human activities

The advantageous natural conditions have made Halifax Harbour one of the largest commercial ports in Canada and home of Canada's east coast Navy. In addition to being a major shipping port, industrial centre, naval centre and research centre, Halifax Harbour is surrounded by one of the fastest growing urban regions in Atlantic Canada (Chairpefkon et al., 1993). Nova Scotians and tourists value the Harbour's recreational opportunities and the aesthetic dimension it adds to this urban centre. The population of Halifax is booming, year 2007 to 2013 has witnessed the population growth from 223,000 to 504,000 in five years (The Greater Halifax Partnership, 2014). A 3.8% increase was calculated from year 2001 to 2006, and reached 8.1% from 2005 to 2010. Shipping activities are also becoming busier. In May 2009, The CKYH Alliance, which includes five Southeast Asia shipping lines, commenced service with the Port of Halifax from Asia, via the Panama Canal, with eight Panamax vessels, which are one of the world's biggest ships. Two major oil companies are putting more into offshore exploration in Nova Scotia than any other offshore in the world (The Greater Halifax Partnership, 2014). In addition, the local businesses have increased and will still keep accelerating within 10 years. One of the urban plan including building a vibrant and attractive Regional Centre that attracts $1.5 billion of private investment and 8,000 more residents by 2016 (HRM, 2014).

3.4 Historical overview from the contaminants perspective

The harbor has been a disposal site for urban waste materials since the founding of the city of Halifax in 1749 (Dabbous and Scott, 2012). As a result of increasing concerns about environmental problems in Halifax Harbour, in year 1970 and 1974, two small scaled sewage treatment plants were built in Bedford and on the Eastern Passage. Since then a lot of research has been conducted to assess the presence of chemical contaminants in water and sediments from the harbour. Studies show that "the main sources of pollution are approximately 100 untreated sewage outfalls that come from private homes, light industry, government and university laboratories, military bases, and hospitals (Buckley et al., 1995; Scott et al., 2005). These outfalls discharge 181 ML/day of organic and inorganic pollutants into the harbor (Halifax Regional Municipality, 2006). Polycyclic aromatic hydrocarbons (PAHs), one of the most widespread organic compounds recorded in harbour sediments, are considered persistent pollutants with levels above the minimum established by environmental quality guidelines (Hellou et al., 2002). In addition, large amounts of trace metals, such as copper, zinc, lead, and mercury, annually enter the harbor from different sources including sewage outfalls, shipyards, and a former municipal landfill. It is estimated that the annual input of these metals to Halifax Harbour as follows: copper (10,700 kg/yr), zinc (36,000 kg/yr), lead (34,600 kg/yr), and mercury (185 kg/yr). These amounts are among the highest recorded in marine harbors worldwide (Buckley et al., 1995; Dabbous and Scott, 2012). These contaminants are not only able to affect the human health and marine biota, as well they give an odorous smell to the harbor, diminishing its recreational value (Arvai et al., 2002; Halifax Regional Municipality, 2006; Timoney, 2007). Diagenetic alteration of sediments deposited in Halifax Harbour during the last 150 a probably has an important effect on sequestering of contaminants (Buckley et al. 1995).

In November 1990, the federal and provincial Ministers of the Environment jointly appointed an independent Environmental Assessment Panel to conduct a review of the proposal by Halifax Harbour Cleanup Inc. (HHCI) to design and construct a Halifax-Dartmouth Metropolitan Sewage Treatment Facility (the "Halifax Harbour Cleanup Project") (Chairpefkon et al., 1993). The implementation of this program has made dramatic improvements on the source control of Volatile Organic Compounds (VOC) and other chemical contaminants to Halifax Harbour, and thus has improved the water quality (JWEL et al., 2001).

Halifax Harbour started the Harbour Solutions Project in the 2000s. In 2007, the Halifax Regional Municipality (HRM) began construction of a three-plant treatment system (one in downtown Halifax, downtown Dartmouth, and Herring Cove on the southwest side of the harbor, as well as extensive collector piping to close all sewage outfalls into the harbour and redirect sewage into the treatment plants) to provide advanced primary treatment of the sewage outfalls that pour into the harbor. The three facilities, projected to cost $400 million (Canadian), were expected to improve conditions in the harbor dramatically (Figure 4). The first to open on

February 11, 2008, was the Halifax Waste-Water Treatment Facility (WWTF). In August 2008, the water quality in Halifax Harbour had greatly improved and two harbour beaches re-opened to the public. But "the opening of the other two plants, although scheduled for later that year, was delayed until 2010 after sampling for this research project was completed. The Halifax plant incurred a massive failure after one year of operation, and raw sewage flowed again into the harbor, causing extensive odor and large floater problems. By June 2010, the three WWTFs were fully operational and began treating sewage." (Dabbous and Scott, 2012, P.189-191). The present operating approaches are still raw and immature. Environmental assessments show that acute chemical components in the water and sediments still have great potential hazards to the health of human and biota (AMEC, 2011).

Figure 4. Squares show the location of waste-water treatment facilities (WWTFs) in Halifax, Dartmouth, and Herring Cove (from Dabbous and Scott, 2012)

Currently management vulnerabilities in Halifax Harbour are increasingly prominent. Studies show that about 80% of Halifax Harbour sewershed still entered Halifax Harbour untreated (AMEC, 2011). Under the present advanced primary sewage operating approach, only the solids are removed, dewatered and transported, other chemical components which dissolved in the liquid, such as pharmaceuticals and agrochemicals, are still not properly managed. A study from 2012 indicates the outer harbour (except inside Herring Cove) is polluted by a waste -water outfall discharge of ~15 ML/day, and that little significant environmental change are observed in untreated areas of Halifax Harbour (Dabbous and Scott, 2012). Other studies show that "regardless of the propensity of the studied chemicals to reach mineralization in either seawater or sediments of Halifax Harbour, the rate if discharge is such that they persist at trace levels… and so additional research is needed to examine the role of additional sewage treatment plants constructed after 2007 relative to the fate of contaminants in this waterway that is now increasingly used for recreational purposes." (Robinson and Hellou, 2009, P.5718)

In the Halifax Harbour Task Force report (Fournier, 1990) it was suggested that in order to improve the water and sediment quality in the harbour, it is essential to control and monitor the potential sources. In the case of Halifax Harbour, the multiple uses of harbour areas lead to various potential contaminant sources. Thus comprehensive and systematic management strategies are urgently in need to satisfactorily protect the sediment and water column quality, as well as the public health. However, up until now, depending on the existing policies, the controls of contaminant sources are mainly focusing on land-based pollution, which is important but not enough. Even though it is well studied that shipping is a major source of hydrocarbons and other anthropogenic contaminants, relative regulation approaches are weak. According to Stewart and White (2001), "Associated with ship traffic are incidental and accidental releases of hydrocarbons from tank and ballast water clearing and bilge operations; releases of metals from sacrificial anodes (plates of metals such as lead and zinc which corrode preferentially in seawater and leave other ship metal intact) and antifouling paints; marine litter and garbage disposal from routine disposal from routine disposal practices; and spills of fuel chemicals, and ship debris and cargoes from ship accidents. Accidental releases of hydrocarbons from vessel and tanker traffic account for more hydrocarbons reaching the marine environment than the occasional major oil spills." (P.20).

In addition, among various shipping activities, the military use of the harbour for navy activities is another important and unique component. Studies show that water and sediments in many bays, harbours and coastal waters used by navies are contaminated with potentially harmful metal and organic compounds (Chadwick and Lieberman, 2009).

These unique conditions of Halifax Harbour discussed above have increased the sensitivity and vulnerability of the Harbour environment, leading to concerns for both the health of the public and the marine biota that frequent the harbour, including any threatened and endangered species that fall under Canada's Species at Risk Act. However, the existing regulatory approaches in Halifax Harbour have poorly addressed monitoring the contaminants in order to protect the public health or quality of the marine environment.

4. REGULATORY FRAMEWORK OF POLLUTANTS IN HALIFAX HARBOUR

The current diversity of harbour activities and stakeholders determine a unique and complex situation in Halifax Harbour in terms of environmental management. No single government agency is completely responsible for addressing the problem of contaminated sediments. A variety of laws give municipal, regional, provincial, and federal agencies authority to address sediment quality issues. Private industry and the public also have roles to play in contaminated sediment prevention (US EPA, 2012). International agreements such as the Stockholm Convention or those signed under the International Maritime Organization, aim to protect the marine environment from deleterious substances.

The following environmental related governance frameworks are focused on achieving a healthy ecosystem. Even though some of these regulations or initiatives are not targeting sediments per se, their approaches ultimately affect sediment quality in the harbour.

4.1 National framework

Multiple federal legislations are related to environmental health. Related government sectors are taking responsibilities and regulations to implement the law and by-laws. At this level, legislation is the major tool to provide guidance. Related federal department include Canadian Council of Ministers of the Environment (CCME); Environment Canada (EC), Department of Fisheries and Oceans (DFO), Department of National Defence (DND), Transport Canada (TC), Halifax Port Authority (HPA), Health Canada (HC). Related legislation and regulation frameworks are listed Table 3.

Table 3. Overview of General Management Frameworks for Human Health, Ecological Risk Assessment, and Their Key Features (Canada)

Government Agency	Legislations and Policy Frameworks	Description and key features
The Interdepartmental Committees on Oceans	Oceans Action Plan (OAP)	It includes federal departments and agencies involved in the oceans, to promote collaboration, synergies and economics
Environment Canada	Canadian Environmental Protection Act (CEPA 1999)	An act respecting pollution prevention and the protection of the environment and human health in order to contribute to sustainable development. The Canadian Environmental Protection Act, 1999 came into force on March 31, 2000 and has been updated to include all amendments.

Government Agency	Legislations and Policy Frameworks	Description and key features
	Canadian Environmental Quality Guidelines	
	Federal Contaminated Sites Action Plan (FCSAP)	
	Persistence and Bioaccumulation Regulations (2000)	
	Canadian Marine Sediment Quality Guidelines	
	Canadian Freshwater Sediment Quality Guidelines	
	Canadian Sediment Quality Criteria	
	Ontario Ministry of Environment Screening Level Guidelines	
	Tissue Residue Guidelines	
	Regulations and the Storage of PCB Material Regulations	
Department of Fisheries and Oceans	Oceans Act 1997	Three principles: Sustainable development; integrated management; the precautionary approach (DFO, 2015a)
	Fisheries Act	Key Priorities: Environmental sustainability; economic viability; the inclusion of stakeholders in decision-making processes
	Species at Risk Act (SARA)	To protect wildlife species at risk, including fish, reptiles, marine mammals and molluscs.
	Aboriginal Fisheries Strategy/An Integrated Aboriginal Policy Framework	
	A Fishery Decision-Making Framework Incorporating the Precautionary Approach	
	Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas	
	Ecological Risk Assessment Framework (ERAF) for Coldwater Corals and Sponge Dominated Communities	
	Vessel Replacement Rules and Procedures on Atlantic Coast – Discussion Paper	
	Large Ocean Management Areas (LOMAs)	LOMAs are established to advance collaborative management. For each LOMA, all levels of government, Aboriginal groups, industry organizations, environmental and community groups and academia work together to develop a strategic, long-term plan for sustainable management of resources within its boundaries (DFO, 2015b).
	Marine Protected Areas (MPAs)	To protect and conserve: commercial and non-commercial fishery resources and their habitats; endangered marine species and their habitats; unique habitats; marine areas of high biodiversity or biological productivity; any other marine resource or habitat necessary to fulfill the Minister's mandate

Transport Canada	Canada Transportation Act (2014)	The government of Canada's commitment to meeting the transportation challenges and opportunities of the next decade in a sustainable manner
	Canada Shipping Act (2001)	To protect the health and well-being of individuals, vessels; promote safety in marine transportation; protect the marine environment from damage due to navigation and shipping activities…
	Marine Environmental Protection	The environmental protection division is responsible for the development and management of regulations, guidelines, various official Transport Canada Publications (TPs), programs and initiatives that focus on the prevention of pollution in maritime operations.
	National Environmental Management System (NEMS)	The NEMS includes everything TC do to manage the environmental obligations. By determining and understanding how TC's operations, services and products impact the environment, objectives and targets to be set to reduce those impacts.
	Marine Pollution Prevention in the Atlantic Region	
	Canadian Ballast Water Program	
	Marine Pollution Sources and Regulations	Air pollution; anti-fouling systems; ballast water; garbage; marine pollutants in package form; noxious liquid substances and dangerous chemicals; oil; sewage
	Canadian Marine Advisory Council (CMAC) – a member of the Canadian delegation at the IMO Marine Environmental Protection Committee.	Transport Canada's national consultative body for marine matters. Meetings are normally held twice a year in the spring and fall, nationally in Ottawa.
Canadian Coast Guard	Marine Spills Contingency Plan	The Canadian Coast Guard is responsible for ensuring the clean-up of all oil, and other noxious substance spills in Canadian waters.
	Tank truck to marine vessel oil transfer manual	
	CCG Environmental Response Program	
Natural Resources Canada	Natural Resources Canada's (NRCan) Adaptation Platform	Brings together Canada's institutional, financial and knowledge resources to enable development and widespread use of adaptation information and tools.
Canadian Council of Ministers of the Environment (CCME)	Canadian Environmental Guidelines	
	Federal Contaminated Sited Action Plan (FCSAP)	

Health Canada (Jardine et al., 2003, P.581-582)	Decision-Making Framework for Identifying, Assessing and Managing Health Risks (Health Canada, 2000)	Based on the Framework for Risk Management (US), replacing the 1990 framework
	Health Risk Determination: The Challenge of Health Protection (Health and Welfare Canada, 1990)	Used as the model for health risk assessment and management by the federal government until 2000
	CSA-Q850 Risk Management: Guidelines for Decision-Makers (Canadian Standards Association, 1997)	Provides generic guidance to government and industry for many types of risk
	CSA-Z763 Introduction to Environmental Risk Assessment Studies (Canadian Standards Association, 1996)	Published as a companion to CSA-Q850, and based on CSA-Q634-91; stresses that environmental risk assessment is part of good corporate environmental policy
	CSA-Q634-91 Risk Analysis Requirements and Guidelines (Canadian Standards Association, 1991)	Developed primarily to address the occupational risk from exposure to hazardous materials or processes
	Integrated Risk Management Framework (Treasury board of Canada Secretariat, 2001)	Designed to provide guidance to advance the use of a more corporate and systematic approach to risk management, and to assist public service employees in their decision making

Different countries have developed their own management processes for sediment quality. Good examples can be learned from the U.S., Hong Kong, the Netherlands, Australia and New Zealand among others. Though there are differences between the methods adopted by different agencies, Hong Kong, the Netherlands, Australia and New Zealand are all using the “hazard region” and multiple environmental assessment tools instead of a simple hazard guideline. In the U.S., the US Environmental Protection Agency (USEPA), National Oceanographic and Atmospheric Administration (NOAA), US Army Corps of Engineers (USACE), US Geological Survey (USGS) and the Federal Government are now working together to regulate activities in order to ensure sediment quality. The strong multi-governmental management method offers sediment related services in a high efficient way. San Francisco Public Utilities Commission for example, has developed intergovernmental regulation networks to achieve high standard performances on “Customers, Environment & Natural Resource, Infrastructure, Community, Governance & Management, Workplace” levels.

4.2 Provincial, regional and local framework

In 2010, the Government of Nova Scotia published the document Water for Life: Nova Scotia’s water resource management which aims to integrate different levels of government work. According to the document, the provincial government intends for Nova Scotia to have one of the most environmentally and economically sustainable ways of life in the world by 2020. Water resources in the province are managed by different levels of government including municipal, provincial, or federal governments what results into a sometimes complex scenario with overlapping responsibilities. The water strategy aims to integrate the water management and Nova Scotia Environment (NSE) is proposed as the leading agency on pollution prevention. Currently, the legislation and regulations related to contaminants governance in Nova Scotia include: Environment Act (amendments), Contaminated Sites Regulations, Petroleum Management Regulations and Environmental Emergency Regulations; at regional level: The Capital Regional District Liquid Waste Management Plan and the DRD Regional Source Control Program (RSCP).

Halifax Regional Municipality (HRM), the department of Halifax Water in particular, is the leading agency for the sewage treatment project launched in 2000s. The department is now playing a role in regulating water quality, “to provide our customers with high quality water, wastewater, and stormwater services” (“Mission Statement | Halifax.ca,” 2015.). Under the regulation of Halifax Water, two programs are launched to improve the system performance: a) the Stormwater Inflow Reduction (SIR) Program for infiltration reduction and b) the Pollution Prevention Program for pollution prevention. Related legislation and regulations include Halifax Regional Water Commission Act, Halifax Regional Municipality Charter and Halifax Water Rules and Regulations.

5. GAP ANALYSIS AND RECOMMENDATIONS FOR IMPROVED ENVIRONMENTAL MONITORING AND MANAGEMENT FOR HALIFAX HARBOUR

The environmental management in the Halifax Harbour can be seen as a multicomponent framework including: environmental management, regulations, stakeholders, source control and environmental monitoring (Figure 5). To succeed into an effective management approach these components (which sometimes overlap) need to be aligned and feed each other through communication and actions. In this section gaps and recommendations have been identified for each of these components.

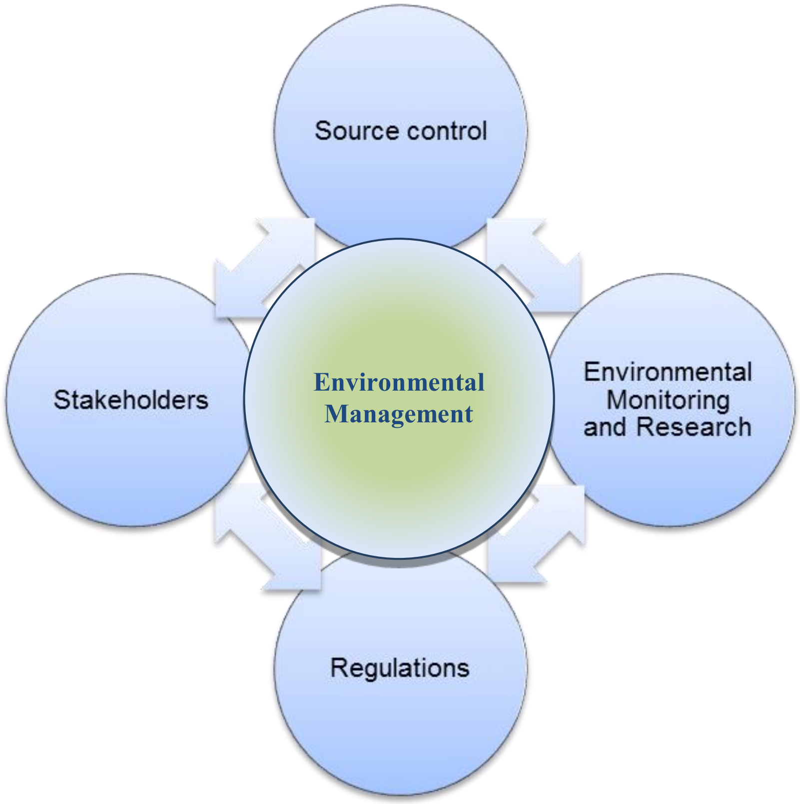

Figure 5. Key interconnected components for an effective management in Halifax Harbour.

5.1 Regulations

Generally, the Environmental Quality Guidelines (EQGs) are based on toxicological experiments in which animals were exposed to the contaminant in question at various concentrations until a toxic effect was observed. Then, scaling and safety factors are applied in accounting for difference in body weight and uncertainty. In Canada, EQGs (CCME, 2015) support various legislative acts, such as the Canadian Environmental Protection Act (CEPA, 1999) and have been widely endorsed internationally by the United Nations and the World Health Organization. Canadian EQGs also support international conventions such as the Great Lakes Water Quality Agreement and the London Convention, plus Canada is one of the few jurisdictions in the world with 'tissue residue guidelines' for fish-eating wildlife (e.g. marine mammals, seabirds). In terms of EQGs a lot can be learnt from the experience of Canada, however, complex mixtures and biomagnification are rarely addressed in any strategy.

Some of the existing initiatives, including the Stockholm Convention on POPs, have led to the ban in the production of many contaminants. Nevertheless, their persistence in the environment, even though they are not newly generated, disrupts the food chain by accumulating in the body fat of organisms (bioaccumulation) becoming more concentrated when transferred from one individual to another in the food web (biomagnification). Unfortunately, most sediment quality guidelines and regulations were not designed to protect against bioaccumulation, and do not consider upper trophic levels (Lachmuth et al., 2011). In addition, according to Burton (2002) "Chemical data (e.g., Sediment Quality Guidelines) have been the primary decision-making tool, with little or no site validation of biological effects". In the US, studies show that the current Sediment Quality Guidelines (SQGs) have errors of 25% or greater (Burton, 2002). Arblaster et al. (2015) showed that if the PCB concentration is equal to the SQGs, then PCB concentrations in most wildlife species can be expected to exceed the tissue residue guideline for the consumption of fish and shellfish by wildlife species and by humans, as well as toxicity reference concentrations for marine mammals. This means that the current SQGs are very limited as they do not include accumulative effects nor effectively protect organisms. In addition there are many chemicals of concern in Canadian harbours that have not been addressed in quality guidelines.

Studies in British Colombia show that "A simple comparison of the results suggests that the risks of consuming contaminated shellfish from the study areas in 1990 are comparable to (and may even be somewhat greater than) those associated with diet substitution. Hence the fishery closures and consumption advisories may have resulted in the substitution of one health risk with another that is at least as great. The results highlight the need for government agencies to conduct risk assessments and make decisions that are culturally sensitive, requiring a full analysis of the potential exposed populations and how they may be impacted by different management options." (Wiseman and Gobas, 2002, P.338). In terms of guidelines designed to protect human health, thresholds are based on the diet in average Canadians, disregarding specific consumer such as indigenous people whose lives and foods rely on the aquatic system.

Despite the efforts and achievements of the Stockholm Convention and other international and national plans, there is an additional major concern: how climate change will affect the impacts of pollutants. Significant climate-induced changes are foreseen in relation to future releases of POPs into the environment, their long-range transport and environmental fate, and to human and environmental exposure (UNEP/AMP, 2011). This could lead to higher health risks in both human populations and the environment and confirms the need to understand how trophic structure and POPs processes within organisms are likely to change as a result of climate change in order to understand how biomagnification of POPs in food webs may change (UNEP/AMP, 2011).

In the particular case of the Halifax Harbour, regardless of the fact that all of the sectors involved in activities in the harbour are under the regulation at different levels, they are not connected. Currently, there is a lack of either a regulatory network or influential information exchanges among multiple government departments and other stakeholders. In some aspects, the overlap of environmental capabilities and government affairs are diminishing the efficiency of the system, making problem-solving a challenge. This fact can also lead to other problems, such as government departments evading responsibility to each other when it comes to environmental issues.

5.2 Source Control

To effectively manage and mitigate pollution in the marine environment, it is critical to identify the point and nonpoint sources of these chemicals of concern and their pathway to the marine environment. Therefore, source control and regulations are crucial for a comprehensive management of deleterious substances in harbours. Currently, other than historical contaminants, pollutants present in harbours might come from land or water activities. In the case of contaminants being introduced by land activities, most management efforts have focused on industrial and urban sewage water treatments, which is a key component for regulatory approaches. The questions arise in terms of the effectiveness of the sewage treatment plans. In Halifax for instance, the Waste Water Treatment Facilities (WWTF) processes are currently limited to advanced primary treatment method (Dabbous and Scott, 2012), during which only the solids are removed, dewatered and transported, whereas other chemical components are dissolved. Pollutants such as pharmaceuticals and agrochemicals are still not properly addressed in these facilities. Other land sources of contaminants include agriculture related contaminants, ground water and upstream water pollutions, urban run-offs and stormwater issues, which are still poorly managed. Similarly, Victoria Capital Regional District conducts a very basic treatment of their wasterwater, however upgrades in WWTF are being currently discussed after report presented by SETAC experts (Stubblefield et al., 2006) and increased of public concern.

5.3 Stakeholder involvement and public awareness

Currently there is lack of general awareness on the importance of the sediments in terms of environmental health. Most of the efforts or concerns are limited to the water quality and less attention is paid to the status of the sediments. Efforts from all involved stakeholders are in need to achieve the goal of sustainable development. No single government department or organization can do it alone. Best practice, outreach and education are essential in order to look for solutions for the environmental health of the harbour.

Increasing public awareness of the problem is crucial to developing an effective solution (USEPA, 2012). According to McKenzie-Mohr (2000), changing individual behavior is central to achieving a sustainable future. In today's society, the general public plays an important role in achieving an sustainable urban environment together with legislation, regulation and scientific approaches. Unlike policy and legislation approaches, which are in need of complex processes and government approvals, outreach activities can be achieved in multiple ways.

In Halifax region, the education organizations that have ocean education programs include universities, the Discovery Centre, and other NGOs. However, as a coastal city and one of the most important port harbours in Canada, Halifax lacks of a leadership on environmental quality education. Water is recognized as a vital element for a healthy and prosperous community, however the public awareness is not aware of the role of sediment quality and its important link to the ecosystem. Ongoing and past work has been limited to academia or isolated research with no translation into the public.

During a recent multi-stakeholders workshop on Solutions to Ocean Pollution to protect SARA-listed marine mammals organized by the Vancouver Aquarium (May 2015), ten guiding principles were appointed: 1) Every problem has a solution; 2) A healthy ocean is valuable; 3) Data, research & monitoring inform problem identification and solution design; 4) Ocean pollution is complex (>100,000 chemicals) yet simple ('bad' for marine mammals); 5) The ocean is a sink that is unable to treat all chemicals; 6) Toxicity testing should be carried out in the lab, not in the ocean; 7) The new tripartite: best practice, regulations and engagement; 8) Land-sea connections are integral: e.g. 'killer whale support streams'; 9) Every person is connected to the ocean (e.g. my home is ocean habitat); 10) The commons needs a governance model.

Traditional education programs, such as school programs and NGO outreach events are the most popular ways to increase the public awareness, and to influence individual decisions. However, it is argued that educators should be more creative in order to find out the best way to pass out information. This can be practiced by using multiple modern tools such as marketing based instruments and social media outreach.

One successful approach, also discussed in the Solutions to Ocean Pollution workshop, is using marketing based instruments as environmental-friendly certifications for consumer products (i.e. sustainable seafood, sustainable domestic or personal care products, etc.). In addition to using environmental labeling, smart phone Apps are also very valuable these days for public outreach, especially for youth and teenagers. "Think Dirty" for example, is one smart phone App that can simply show customers the harmful chemicals in personal care products by scanning the QR code. Think Dirty will pull up a "dirty meter," which gives users a health impact rating between zero (harmless) and 10 (serious health impact) on each rated category. From there, users can check out the ingredient list on a particular product, their individual characteristics and risks. With the increasing users of the App, more customers tend to purchase "safe" products plus companies also tend to environmentally improve their products as per market pressure.

Figure 6. Slogan of the Solutions to Ocean Pollution Workshop (Vancouver Aquarium, 2015)

5.4 Environmental Monitoring and Research

Despite an abundance of literature on some of the 'legacy' contaminants (i.e. those considered to be regulated under the terms of national laws and international treaties), much remains unclear about their partitioning between abiotic (sediments, water, and air) and biotic (food webs) matrices and their toxicity to biota. Chemical analyses performed alone in bulk sediment do not always reflect the toxic fraction since they vary depending on the bioavailability and bioreactivity of the toxic compounds (Morales-Caselles et al., 2008). Research and monitoring are crucial to better understand the complexity of sources, fate and behaviour of contaminants in the environment. Three factors have been considered as primarily responsible for the difficulties in accurately predicting the exposure and bioavailability of organic contaminants in sediment to aquatic biota: (1) the complex geochemistry of sediment makes understanding chemical speciation and kinetics difficult; (2) aquatic organisms interact with the sediment in a myriad of ways, influencing contaminant fate and their own exposure to the pollutants; (3) biological variability is substantial due to numerous biochemical responses that occur once the contaminant has entered the organism, making simple assumptions based on sediment contaminant analysis difficult (Munawar et al. 1999). In Halifax Harbour, the large volume of daily water exchanges and the pattern of turbulent flow brings fresh water into the harbour every day. These characteristics can also affect bioaccumulation rates, which might variate depending on the flow, making environmental risk assessments more challenging.

Notwithstanding the growing concern about contaminants such as PBDEs, there remain unanswered questions about their fate in coastal ecosystems, and a virtually complete lack of established models to predict their fate in the environment to inform the design of Environmental Quality Guidelines (EQGs) (Lachmuth et al., 2010).

Currently, there is a wide range of sources of contaminants to the Halifax Harbour, and the quantification of contaminant loadings to the environment from a number of identified sources is lacking. A broad harmonized and comprehensive monitoring in the area that informs stakeholders and general public is completely absence; in addition, the deficiency in accessibility to data from institutions and organizations makes it difficult to understand what is being monitored, how is being assessed and what are the results.

Regardless of the scientific research done by independent programs, there exists today a distinct lack of information on contaminant trends or concerns in Halifax Harbour. Regulated discharges are typically constrained to point source releases ('end of pipe' discharges) of a limited suite of basic pollutants (e.g. suspended solids, nutrients) and/or localized receiving environments. Generalized research or monitoring efforts suffer from a lack of agreed upon parameters, contaminant types, Quality Assurance protocols, periodicity, matrices and study sites. There is no consolidated, durable and meaningful monitoring framework in the area. The recent spill of Bunker fuel from the *MV Marathassa* in Vancouver (April, 2015) highlighted the distinct lack of baseline (pre-spill) contaminant data for coastal British Columbia. Such baseline data for a wide range of contaminants, including hydrocarbons, would inform source identification, emerging risks to sea life, trend analysis, and the effectiveness of regulations or best practices. In the case of an oil spill, such information would help discern the origin of the petroleum hydrocarbons and distinguish a spill from historical (cumulative) background. Similarly, the lack of appropriate baseline data and monitoring in the Halifax Harbour reduces the options for an effective environmental management.

The importance of building a database is well accepted. According to Tay et al. (1992), without collection of baseline data, including biological response studies, it is impossible to monitor the results of any population control programs designed to clean up the marine environment. The situation of Halifax Harbour is changing in a dramatic way. During the past decade, the population has doubled, shipping activities is becoming more active, and economic is increasing with the urban development. All these changes have the potential to affect the sediment quality. Without a harmonized database, it is difficult to analyze the impacts of human activities on the marine environment. It is recommended that either Environment Canada or DFO take the lead on environmental monitoring and data collection as well as the establishment of a systematic open database.

5.5 Environmental Management

Despite the two environmental programs that have been conducted in the harbour (Halifax Harbour Task Force and Halifax Solutions Project) and that the inner harbour presented environmental improvements during the treatment period, other harbour areas show little significant environmental change (Dabbous and Scott, 2012).

For an integrated coastal management network, top-down approaches should combine with bottom-up approaches to achieve the best result. From the governance perspective, federal, regional and provincial, and municipal government departments share responsibilities on environmental issues. Related departments include, but are not limited, Halifax Regional Municipality, Halifax Port Authority, Nova Scotia Environment, Industrial Canada, Environmental Canada, Transport Canada, Department of Fisheries and Oceans, Department of National Defence, Health Canada, and US Coast Guard. Other non-governmental stakeholders include universities, Non-Governmental Organizations, as well as industrial companies that are using the coastal resources. It is crucial that all these stakeholders collaborate in an integrated way to achieve a common goal for the harbour. San Francisco Public Utilities Commission (SFPUC) has developed a state-of-the-art multi-governmental management approach that could be an example to apply in Halifax Harbour. Even though the legislation and political setting is different in Canada, a lot can be learned from SFPUC's successful cases.

SFPUC is a multi-governmental agency responsible for all water related activities at multiple levels. At the governmental level, it launches programs to improve the quality of drinking water and the health of urban watersheds, monitors ocean and beaches, supports clean energy developments, regulates San Francisco shipyards, and manages sewage treatment facilities. At the community level, it works closely with local groups to engage the public for pollution prevention projects such as Pollution Prevention Calendar, Only Rain Down the Drain, Cooking Oil Recycling, To Flush or Not to Flush?, Expired Medications, Less-Toxic Products, Garden Workshops, Classroom Presentations, Proper Copper. The active media team and outreach programs make the society work efficiently for the bottom-up approaches.

The SFPUC also publishes annual reports to analyze its sustainability performance. It uses six major categories to frame its Strategic Sustainability platform, which includes customers, community, environment and natural resources, governance and management, infrastructure and assets, and workplace. Each year, the Committee examines its performances by analyzing data and doing surveys, and summarize them by using scoring scale of 1 to 5 (best). By comparing with former years' performances and the target goals, the Committee is able to understand how well it worked in the past year and where improvement is needed in the coming years. All the data and reports are accessible to the public. By using this method, the overall performance of SFPUC is showing a positive trend in the past five years.

SFPUC is a successful case that could work as a regulation framework in Halifax Harbour which is much in need of an effective management to ensure a healthy status. As a start point, Nova Scotia Environment or Halifax Water is potentially suitable for acting as a leading agency to form the multi-governmental framework. A multi-agency workshop is suggested a starting point towards an effective environmental management of the Harbour.

6. CONCLUSIONS

In summary, sediment quality is crucial for a healthy harbour environment. Sediments support the coastal ecosystem, acting as a source and sink of contaminants, and being used by scientists and managers internationally. Sediment quality is strongly connected to biota and humans. Harmful contaminants can enter the food web and accumulate in the body of coastal organisms where long term and chronic effects can occur. Indigenous people might have a higher risk of exposure to the contaminants due to their particular diet, and this should be considered in risk assessments. Contaminants bound to sediments can also affect human health through other different pathways i.e. water uses, territory and atmosphere related activities.

From the perspective of Canadian legislation, CEPA 1999 and CCME guidelines are out dated and need an update in terms of contaminants and approaches. Scientific research show that a simple guideline that does not consider bioaccumulation factors, geographic differences, diverse diet behaviour and long-term effects is not accurate enough to make conclusions on sediment quality. In terms of source control, the effectiveness of sewage treatment facilities for Halifax is questionable. The lack of a harmonized contaminants baseline in the harbour as well as the absence of a monitoring program weakens the options of a healthy well managed harbour. From the management perspective, Halifax Harbour is lacking an efficient network that integrates multiple government departments, non-governmental organizations, academia and other stakeholders. At the community level, the education and outreach approaches are weak or completely nonexistent in some aspects, making difficult to raise awareness on the impacts of contaminants in the harbour.

After analyzing the roles of science and environmental monitoring, the ongoing legislation and source control efforts and the stakeholder's involvement, several ways to improve the environmental management of Halifax Harbour have been suggested. These include an update on CCME guidelines, their design as well as related documents to the environmental assessments and decision making processes. In order to improve the management and regulation approaches, a multi-governmental network with effective communication should be established. An active management system can be referenced from the case of San Francisco Public Utilities Commission (SFPUC). In terms of technology developments to support source control, the sewage treatment facilities may need to be upgraded; a comprehensive baseline and database is urgently in need to be established as well as a strong monitoring program including sediment quality. Last but not least, it is crucial to increase the public awareness in the issue of environmental health with a particular focus on Halifax Harbour. The public should know more about the importance of environmental quality, and understand the ways in which each on can contribute. Such cultural changes can be achieved by using multiple and creative outreach methods.

The sustainable development of Halifax Harbour and a healthy marine environment involves stakeholders from multiple levels and perspectives. It is important to realize that active participation is the key for a well-balanced coastal management system. The proposed management evolution will translate into a priceless improvement of the environmental quality of Halifax Harbour and all the stakeholders connected to it.

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