TOXIC CHEMICAL CONTAMINANTS

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine
Council on the
Marine Environment

May 2013

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Gulf of Maine Council on the Marine Environment

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The Gulf of Maine Council on the Marine Environment was established in 1989 by the Governments of Nova Scotia, New Brunswick, Maine, New Hampshire and Massachusetts to foster cooperative actions within the Gulf watershed. Its mission is to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations.

The *State of the Gulf of Maine Report*, of which this document is a part, is available at www.gulfofmaine.org/stateofthegulf.

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1. Issue in Brief

This paper provides an overview of known toxic chemical contaminants in the Gulf of Maine. A contaminant is any element or natural substance (e.g., trace metal or organic compound) whose concentration locally exceeds the background concentration, or any substance that does not naturally occur within the environment (e.g., synthetic chemicals such as DDT) (DFO 2009). This paper describes the prevalence and implications of key contaminants in the Gulf of Maine including metals, synthetic organic compounds, and polycyclic aromatic hydrocarbons (PAHs) using the driving forces, pressures, state, impacts and responses (DPSIR) framework (Figure 1). For information on nutrients, carbon dioxide, and pathogens, see Eutrophication, Climate Change and its Effects on Humans, Climate Change and its Effects on Ecosystems, Habitats and Biota, and Microbial Pathogens and Toxins.

The driving forces and pressures influencing toxic contaminants in the Gulf of Maine include changes in the human environment (i.e., population growth, industrial development, human activities) and the natural environment (i.e., oceanographic, atmospheric, and biotic conditions and their variation). The main

LINKAGES

This theme paper also links to the following theme papers:

- Microbial pathogens and toxins
- Eutrophication
- Climate change and its effects on ecosystems, habitats and biota
- Climate change and its effects on humans
- Emerging Issues
- Land Use and Coastal Development
- Watershed Status
- Aquaculture

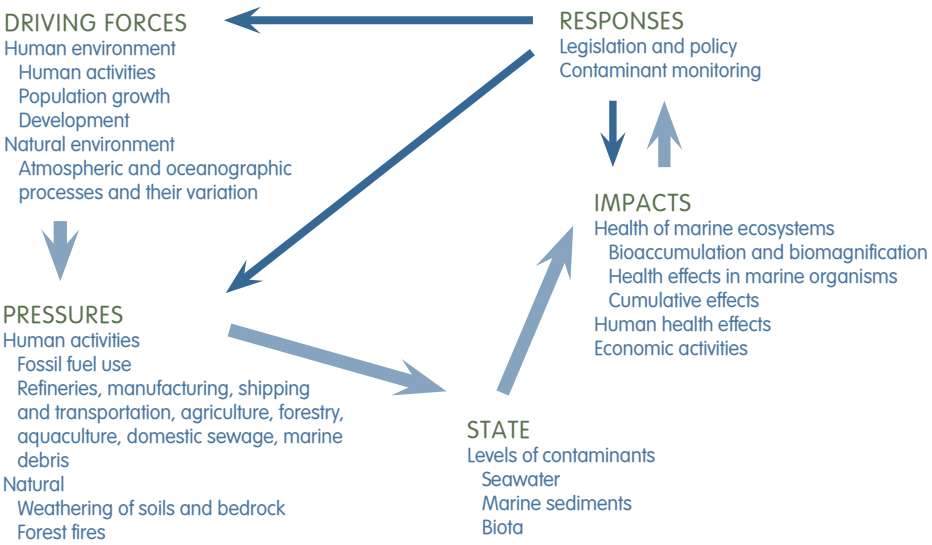

Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to toxic contaminants in the Gulf of Maine. In general, the DPSIR framework provides an overview of the relation between different aspects of the environment, including humans and their activities. According to this reporting framework, social and economic developments and natural conditions (driving forces) exert pressures on the environment and, as a consequence, the state of the environment changes. This leads to impacts on human health, ecosystems, and materials, which may lead to societal or government responses that feed back on all the other elements.

Garrett Coakley

human sources of toxic contaminants in the Gulf of Maine include industrial harbors, economic activities, coastal development, atmospheric deposition, shipping and transportation, agriculture and forestry, aquaculture, and marine debris. The main natural sources of toxic contaminants include the weathering of soils and bedrock, and forest fires.

Available information on contaminants in the region indicates that the offshore portion of the Gulf of Maine is relatively uncontaminated relative to other marine waters around the world (Pesch and Wells 2004). A 2012 report from the United States Environmental Protection Agency (EPA) rated the overall condition of coastal waters in the Gulf of Maine as "fair" and concluded that good water quality conditions predominate in the well-mixed, open estuaries of the Gulf (US EPA 2012). A variety of toxic contaminants have been measured in the sediments, seawater, and biota of the Gulf of Maine. In general, levels of contaminants in the Gulf, and more broadly, the northwest Atlantic Ocean are relatively low—at or near background levels. Industrialized harbours and estuaries in the Gulf located near large population centres (e.g., Boston, Saint John) have much higher levels of contamination than more rural or offshore areas. Data from the Gulfwatch monitoring program in coastal areas of the Gulf of Maine suggest a southwest to northeast trend of decreasing contamination, with Massachusetts being the most contaminated in the region and Nova Scotia being the least contaminated. Contaminant monitoring data also suggest that there have been substantial declines in a number of key contaminants in the marine environment since the 1970s and 1980s, including polychlorinated biphenyls (PCBs), DDT, and tributyl-

tin (TBT), while levels of other contaminants such as brominated flame retardants (i.e., polybrominated diphenyl ethers or PBDEs) in the marine environment have increased exponentially since their introduction in the 1970s. In addition, there are many "emerging" contaminants in coastal waters of the Gulf of Maine such as pharmaceuticals, steroids, and antibiotics. However, little is known about their effects in the marine environment. A variety of management actions have been implemented by Canada and the United States to regulate the release of toxic contaminants into the marine environment including a range of legislation and policies, and contaminant monitoring programs. The use and production of many toxic substances in Canada and the United States is strictly regulated or banned altogether. Additional information about toxic contaminants in the Gulf of Maine is available in the Toxic Chemical Contaminants Review.

2. Driving Forces and Pressures

The driving forces influencing marine toxic contaminants in the Gulf of Maine include changes in the human environment such as population growth, development, and human activities; and the natural environment (i.e., oceanographic, atmospheric, and biotic conditions and their variability)(Figure 1). Together, these driving forces have resulted in a multitude of chemical contaminants, both natural and synthetic, being introduced into the Gulf of Maine. Some of these contaminants are released locally within the Gulf of Maine and its watershed, but many are transported in the atmosphere from distant industrial, urban, and agricultural centres. While certain potentially harmful substances and chemicals occur naturally in the marine environment, human activities are the primary source of toxic contaminants in the Gulf of Maine.

2.1 HUMAN

Human activities can accelerate the natural processes that introduce chemicals into the marine environment (e.g., weathering of soils and bedrock) and also introduce new, man-made contaminants. The main human sources of toxic contaminants in the Gulf of Maine include industrial harbours, economic activities, coastal development, atmospheric deposition, shipping and transportation, agriculture and forestry, aquaculture, and marine debris (see Land Use and Coastal Development, Watershed Status, and Aquaculture theme papers). Many of these sources have management measures in place to limit the introduction of toxic chemicals into the environment (see Section 5 and Toxic Chemical Contaminants Review).

Many coastal areas of the Gulf of Maine are moderately or highly developed with residential, agricultural and forestry, and industrial land uses. Approximately 80 percent of all pollutants entering the Gulf of Maine's waters come from urbanized, land-based, point and non-point sources (NOAA 1997; Pesch and Wells 2004). In 2004, there were over 2000 point sources of pollution in the Gulf including 1000 industrial facilities and eight power stations in the United States alone, and a concentration of heavy industries around Saint John, New Brunswick (NOAA 1997; Pesch and Wells 2004). Manufactured and produced chemical contaminants are released into coastal waters during agricultural, industrial, and domestic activities through surface runoff, effluent and sewage outfalls, surface spills, and atmospheric fallout (Wells and Rolston 1991; Brandon and Yeats 1994; Muir and Howard 2006). Sewage and wastewater discharged into the marine environment can deplete oxygen levels and also introduce a variety of contaminants such as antibiotics, pesticides, flame retardants, and metals (Halling-Sorensen et al. 1998; Kidd and Mercer 2012; Marklund et al. 2005; Meyer and Bester 2004; Weinstein and Moran 2004). Runoff from agriculture can contain pesticides, metals, antibiotics, pharmaceuticals, and steroidal compounds.

Atmospheric deposition is one of the primary pathways by which contaminants such as mercury enter the Gulf of Maine (Pesch and Wells 2004; Sunderland et al. 2012). Important atmospheric inputs include industrial stacks, domestic furnaces, and transportation, particularly motor vehicles. In addition to these contaminants from local domestic and industrial sources, a substantial amount of the contaminants in the Gulf of Maine comes from distant industrial sources. These contaminants are transported through the atmosphere and subsequently deposited into the Gulf. Roughly 60 percent of the atmospheric sources lie within the Gulf of Maine region, with the balance coming from other states and provinces (NESCAUM 1998; Pesch and Wells 2004).

Marine sources, largely shipping, aquaculture, and debris from marine activities, make up a much smaller proportion of contaminants entering Gulf of Maine waters. There are a number of important cargo ports located in the Gulf of Maine including Saint John, New Brunswick; Portland, Maine; Portsmouth, New Hampshire; and Boston, Massachusetts (Figure 2). Vessels travelling to and from these ports are permitted to discharge an oily mixture from cargo tank cleaning and engine room bilge operations, following strict regulations. Accidental discharges from vessels are another, rare, source of hydrocarbon discharges. Finfish aquaculture is confined to relatively sheltered areas in the cooler northern waters of the Gulf of Maine. Following strict controls, chemicals such as vaccines, antibiotics, and pesticides may be used in aquaculture operations to maintain the health of the farmed fish and control pests such as "sea lice."

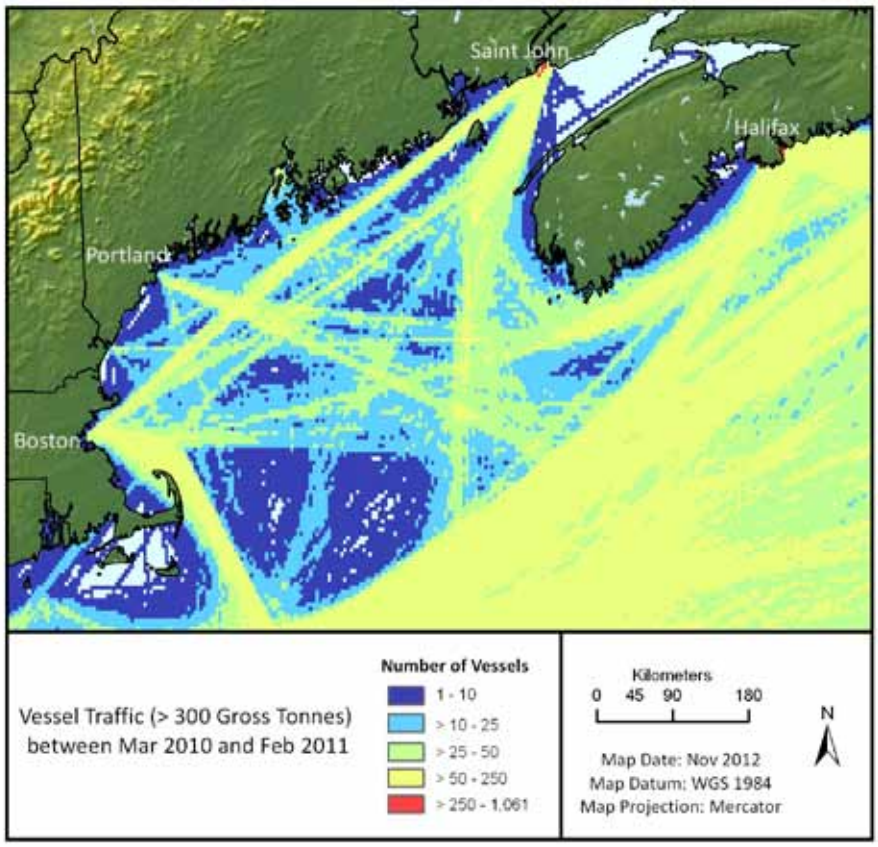

Figure 2: Vessel traffic in the Gulf of Maine from the Long Range Identification and Tracking (LRIT) system, March 2010-February 2011. This figure underestimates the total ship traffic in the Gulf as only vessels over 300 gross tonnage on international voyages are included. However, it does provide an indication of general traffic patterns crossing the Gulf of Maine. Data were provided by the Canadian Coast Guard's Long Range Identification and Tracking System National Data Centre for purposes of safety, security and environmental protection/response (adapted from Koropatnick et al. 2012).

Plastic debris released into the Gulf of Maine from both land-based and marine activities can accumulate a variety of contaminants including PCBs, DDT, and PAHs to high levels (Mato et al. 2001; Rios et al. 2007). For example, PCBs can accumulate in marine debris to levels one hundred thousand to one million times the levels typically found in seawater (Mato et al. 2001).

2.2 NATURAL

Natural conditions and processes play an important role in the transport and distribution of toxic contaminants in the marine environment and therefore have a strong influence on local contaminant concentrations. The natural conditions of the Gulf of Maine are described in detail in The Gulf of Maine in Context. Oceanographic conditions (such as currents, mixing, advection, and turbulence) transport and distribute contaminants vertically and horizontally in the water column and deposit them on the ocean bottom. The atmosphere is another important pathway for the transport of natural and human contaminants from the continents to the ocean (Duce et al. 1991). Some contaminants can be transported long distances in the atmosphere before being deposited in the marine environment (Brandon and Yeats 1984). The dominant storm tracks in the Northwest Atlantic Ocean pass through highly industrialized regions of North America, and subsequent precipitation from these storms introduces contaminants into the Gulf of Maine region (Brandon and Yeats 1984). Contaminants such as organochlorine and organobromine compounds and mercury are known to gradually drift towards the poles by atmospheric transport through a repeated process of evaporation and precipitation (Wania and Mackay 1993).

A number of chemical elements and compounds are introduced into the Gulf of Maine through natural processes. Coastal erosion and the weathering of continental crust generates material containing metals (e.g., mercury), which then is transported by wave action, groundwater, streams, and rivers to marine waters. Disturbances by humans, such as the removal of vegetation and soil during agriculture or forestry operations, construction projects, or mining can expose underlying soil and rock and accelerate these processes.

Natural processes can sometimes cause the concentration of chemicals in a localized area to be significantly higher than surrounding areas. For example, natural hydrocarbon seeps occurring over deposits of petroleum and organic matter can elevate levels of hydrocarbons in the vicinity. Natural petroleum seeps are not known for the Gulf of Maine, although hydrocarbon seeps are expected to occur frequently in the biologically productive estuarine habitats of the Gulf of Maine. Forest and field fires and volcanic activity result in the production and atmospheric transport of PAHs, and dioxins and furans, and also metals such as mercury.

3. Status and Trends

Available information on contaminants in the Gulf of Maine indicate that most of the Gulf is relatively uncontaminated compared to other marine waters around the world, with the exception of the Boston Harbor area (Jones et al. in prep; Pesch and Wells 2004). While there are a number of monitoring programs and studies that have focused on levels of contaminants in the Gulf of Maine, scientific data on certain toxic contaminant levels are limited. Data on some emerging contaminants such as PBDE flame retardants are limited and the true extent of these contaminants in the marine environment is uncertain. The Gulfwatch, Mussel Watch, and National Coastal Assessment monitoring programs are a key source of data regarding toxic contaminants in the Gulf of Maine, as they provide information about a number of important contaminants across the Gulf over time.

Data collected from the Gulfwatch program since 1993 provides information about a variety of contaminants (i.e., various pesticides, PCBs, and PAHs) in blue mussels at 38 sites around the Gulf of Maine (Gulfwatch 2012). Figure 3 shows the location of Gulfwatch monitoring sites in the Gulf of Maine. The following is a summary of the levels of organic contaminants and trace metals measured in mussels from sites in each of the states and provinces bordering the Gulf of Maine. Contaminants were grouped into three categories—low, medium and high—using cluster analysis, so that "low" and "high" mean low and high relative to the other values.

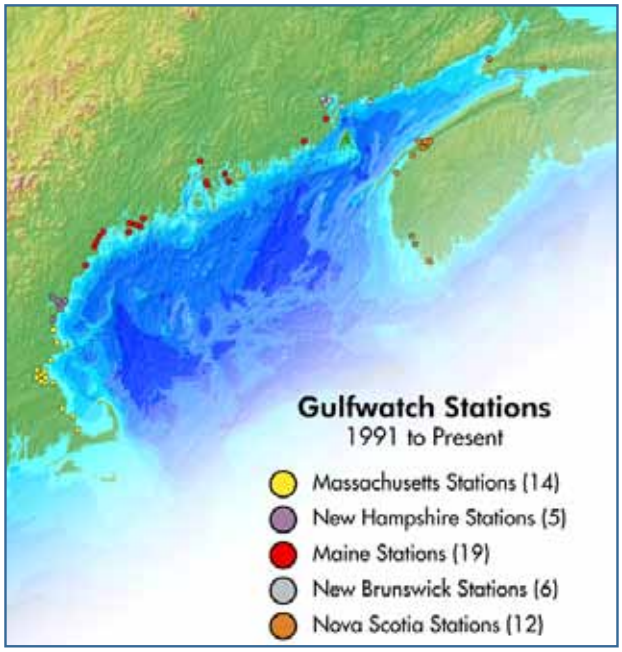

Figure 3: Location of Gulfwatch monitoring sites in the Gulf of Maine (Gulfwatch 2012).

- **Massachusetts:** The majority of monitoring sites have high levels of pesticides (DDT, chlordane, dieldrin), PCBs, silver and lead, and medium levels of PAHs, mercury, cadmium, nickel, zinc, and chromium.
- **New Hampshire:** The majority of monitoring sites have high levels of mercury, cadmium, nickel, and chromium, and medium levels of pesticides, PCBs, PAHs, lead, zinc, and copper.
- **Maine:** The majority of monitoring sites have medium levels of pesticides, PCBs, mercury, silver, nickel, chromium, and copper, and low levels of zinc. There is no apparent trend in levels of PAHs, with some sites having low levels, some medium, and some high.
- **New Brunswick:** The majority of monitoring sites have medium levels of pesticides, PCBs, cadmium, and zinc, and low levels of PAHs, mercury, and lead.
- **Nova Scotia:** The majority of monitoring sites have low levels of pesticides (DDT and chlordane), PCBs, mercury, and copper; and medium levels of the pesticide dieldrin, lead, nickel, and chromium. There is no apparent trend in levels of PAHs, with some sites having low levels, some medium, and some high.

Using data collected from multiple National Coastal Assessment (NCA) sampling stations between 2003 and 2006, the National Coastal Condition Report IV (US EPA 2012) rated the overall condition of coastal waters in the U.S. Northeast (from the Bay of Fundy to Cape Hatteras, North Carolina) as fair and concluded that good water quality conditions predominate in the well-mixed, open estuaries of the Gulf of Maine. The report also found that 76% of coastal areas in the U.S. Northeast had clean sediments with low levels of chemical contamination, an absence of acute toxicity, and moderate-to-low levels in sediment. Benthic conditions were considered to be poor in 31% of coastal areas in the region due to elevated levels of contaminants, often in the vicinity of high human population density. The report states that more than 80% of coastal and estuarine areas in the U.S. Northeast were under fish consumption advisories in 2006, including areas in Maine, New Hampshire, and Massachusetts. Over 90% of these advisories were issued for PCB contamination, either alone or in combination with one or more other contaminants. The NCA sampling stations in the Gulf of Maine are shown in Figure 4. Jones et al. (2010) compared the Gulfwatch mussel monitoring and the NCA sediment contamination programs for mercury and found them to be complimentary in identifying contaminant "hot spots."

A variety of toxic contaminants have been measured in the marine sediments, seawater, and biota of the Gulf of Maine including: PAHs, PCBs, dioxins and furans, DDT, chlordane, PBDEs, butyltin compounds, mercury and methylmercury, and a variety of trace metals (see Table 1 for a summary of status and trends; a more comprehensive review of the status and trends of contaminants in the Gulf of Maine is available in the Toxic Chemical Contaminants Review).

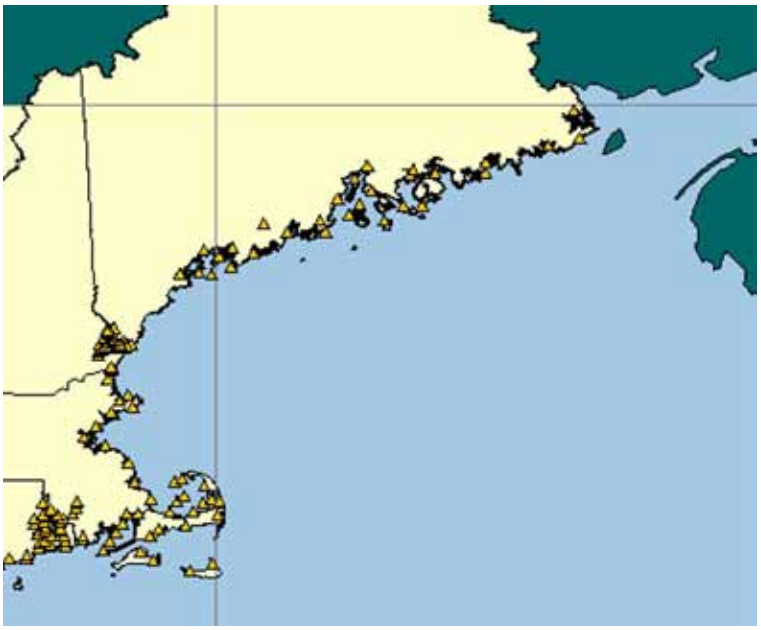

Figure 4: Location of NCA sampling stations in the Gulf of Maine in 2000 (US EPA 2010).

In general, levels of contaminants in the Gulf of Maine—other than high density urban areas—and more broadly, the northwest Atlantic Ocean are relatively low, meaning they are at or near background levels (Addison 1984; Wells and Rolston 1991; Yeats 2000; Pesch and Wells 2004; Yeats et al. 2008). Industrialized harbours and estuaries in the Gulf located near large population centres have higher levels of contamination than more rural or offshore areas (see Table 1). However, high levels of PBDEs and DDT have been measured in a number of top predators in the Gulf of Maine including bald eagles, harbour seals, white-sided dolphins, and pilot whales (Shaw 2003; Shaw et al. 2008, 2009; Weisbrod et al. 2001). This indicates the biomagnification of these contaminants in the Gulf food web. Data from the Gulfwatch monitoring program indicate that coastal areas of Massachusetts are the most contaminated in the Gulf of Maine region, and coastal areas of Nova Scotia are the least contaminated. Contaminant monitoring data also suggest that there have been substantial declines in a number of key contaminants in the marine environment since the 1970s and 1980s including PCBs, DDT, and TBT. In contrast, levels of PBDEs in the marine environment have increased exponentially since their introduction in the 1970s and have surpassed PCBs and DDT as the number one persistent organic contaminant in the marine environment (Ross et al. 2007; Shaw and Kannan 2009). Levels of other contaminants in the Gulf of Maine, such as PAHs, chlordanes, mercury and methylmercury, and trace metals, have remained stable or do not show a clear trend. In recent years, there has been growing concern over the prevalence of mercury in the Gulf of Maine ecosystem due to its tendency to bioaccumulate and biomagnify in organisms and its high toxicity (Pesch and Wells 2004).

Table 1: Status and trends of select key contaminants in the Gulf of Maine.

CONTAMINANT	DESCRIPTION/USE	STATUS AND TRENDS	REFERENCES
Polycyclic aromatic hydrocarbons (PAHs)			
PAHs	• Organic compounds found in many fossil fuels and produced as by-products during the combustion of fossil fuels and other organic materials. Some PAHs are synthesized by marine plants and zooplankton or derive from natural products and processes.	• Found in sediments and mussels in coastal bays throughout the Gulf of Maine. • Concentrations in deep basins are 10 times lower than coastal regions. • Concentrations in fish in Cape Cod Bay and Georges Bank are 100 times lower than in mussels in coastal areas. • Highest concentrations are found in mussels off Mass., decreasing northwards towards N.B. and N.S. • No Gulf-wide temporal trend in PAH levels in mussels observed between 1993 and 2008; increasing trend in N.H. during the same period attributed to several spills.	Boehm and Hirtzer 1982, Brun et al. 2004, Chase et al. 2001, Johnson and Larsen 1985, Larsen et al. 1986, Gustafson et al. 1998, Kennicutt et al. 1994, Pruell et al. 1986; Windsor and Hites 1979
Organochlorine and organobromine compounds			
PCBs	• Organochlorine compounds that were used for many years as insulation in electrical equipment and were found in a variety of common consumer products for which disposal was not controlled. • PCB production was banned in the United States and Canada in the 1970s due to its harmful environmental effects.	• Widespread contamination in marine sediments in the Gulf of Maine, particularly in estuaries. • Concentrations decline with distance from Boston Harbor to deep basins offshore. • Concentrations decrease by about 10 times from the southwest in Mass. to the northeast in N.S. • Highest PCB concentration in mussels measured in Boston Harbor in a 2007 global bivalve survey. • Most frequent contaminant detected in demersal or bottom–living fishes in the north-east United States in 1999-2001 assessment surveys (detected at 44% of the sites). • Levels in biota have declined in the atmosphere and biota since the 1970s. • Levels in inner Casco Bay, Maine declined slightly between 1991 and 2001, while levels in the outer bay declined two-fold. • No temporal trend in PCB concentrations observed between 1940s canned mussel samples and 1988-2007 mussel samples. • Levels in harbour porpoises from the Bay of Fundy and Jeffrey's Ledges declined four fold between 1971-77 and 1989-91. • Levels in harbour seals declined approximately seven fold between the 1970s and 1990s before stabilizing. • Elevated levels were detected in seven sea-run Atlantic salmon collected from three rivers in ME between 2008 and 2010. • Elevated levels were detected in a single Atlantic sturgeon collected from a beach in Cape Cod, MA in 2007. • Low levels detected in common tern eggs and chicks collected from five islands along the Maine coast in 2004 and 2005. • Low levels detected in common tern and roseate tern eggs collected from National Wildlife Refuges in MA and ME in 2005. • Low levels detected in the eggs of four species of seabirds nesting in the Bay of Fundy in the 1970s.	Addison and Smith 1998, Apeti et al. 2010, Braune et al. 2007, Gaskin et al. 1973, Gaskin et al. 1983, GoM Council 2012, Kennicutt et al. 1994, Lake et al. 1995, Larsen et al. 1985, Mierzykowski et al. 2008, Mierzykowski 2008, Mierzykowski 2010, Mierzykowski 2011, Park et al. 2009, Pearce et al. 1979, Rapaport and Eisenreich 1988, Shaw et al. 2005, Simcik et al. 2000, Vorkamp et al. 2010, Wade et al. 2008, Westgate et al. 1997

Table 1 (continued): Status and trends of select key contaminants in the Gulf of Maine.

CONTAMINANT	DESCRIPTION/USE	STATUS AND TRENDS	REFERENCES
Dioxins and Furans	• Organochlorine compounds present as trace contaminants in a variety of industrial chemicals and are produced as by-products from municipal waste incinerators, pulp and paper mills, petroleum refineries, wood burning, automotive emissions, electric power generation, and the combustion of PCBs.	• Found in sediments of Casco Bay and Portland Harbor, Maine in the 2000s. • Low levels were measured in farmed Atlantic salmon raised in Maine and N.B. in the 2000s. • Trace amounts found in harbour seals from the coast of Mass. in the early 1990s. • Extremely low concentrations were detected in female and pup harbour seals in the Gulf of Maine in the 2000s. • Low levels detected in a few samples taken from bottle-nosed dolphins off the U.S. east coast in 1987/88. • Low levels of dioxins were detected in seven sea-run Atlantic salmon collected from three rivers in Maine between 2008 and 2010. • Low levels of dioxins were detected in a single Atlantic sturgeon collected from a beach in Cape Cod, Mass. in 2007.	Kuehl et al. 1991, Lake et al. 1995, Mierzykowski 2010, Mierzykowski 2011, Shaw et al. 2006, Shaw et al. 2007, Wade et al. 2008
DDT and its metabolites, DDD and DDE (collectively referred to as ΣDDT)	• Organochlorine compound that was used as a commercial pesticide before it was banned in the United States in the 1970s and Canada in the 1980s due to its harmful environmental effects.	• High levels measured in mussels in Small Point, Maine between 1968 and 1970. • Elevated levels of ΣDDT measured in mussels in the late 1980s to early 1990s. • Present concentrations in mussels decrease from the southwest to northeast regions of the Gulf of Maine. • Concentrations in mussel samples from the Gulf of Maine suggest an exponential decline has occurred since the early 1970s, with the greatest decline from the 1970s to the 1990s. • Levels of ΣDDT in mussels from the Gulf of Maine declined in the 1990s before stabilizing in the 2000s. • Similar declines measured in harbour porpoises in Gulf of Maine since 1970s, slowing through the 1990s. • Concentrations of DDT in harbour seals decreased by 96% between 1971 and 2001-01. • Low levels detected in a single Atlantic sturgeon collected from a beach in Cape Cod, Mass. in 2007. • Low levels detected in common tern eggs and chicks collected from five islands along the Maine coast in 2004 and 2005. • Low levels detected in common tern and roseate tern eggs collected from National Wildlife Refuges in Mass. and Me. in 2005. • Low levels measured in seabird eggs in the Bay of Fundy, with fish-eating cormorants having greater concentrations than benthic-foraging eiders.	Apetir et al. 2010, Butler 1973, Dimond and Owen 1996, Gaskin et al. 1971, 1973, 1982, Jones et al. in prep, Mierzykowski et al. 2008, Mierzykowski 2008, Mierzykowski 2010, Pearce et al. 1979, Shaw et al. 2005, Westgate et al. 1997
Chlordane	• Organochlorine compound that was used as a commercial pesticide before it was banned in the United States and Canada in the 1980s due to its harmful environmental effects.	• Low concentrations detected in sediments and polychaete worms from Boston Harbor and Merrimack River, Mass., and Kennebec River and Portland Harbor, Maine in the 1980s. • Low concentrations measured in mussels from around the Gulf of Maine between 1993 and 2008. • Detected in white-sided dolphins and pilot whales from the Cape Cod, Mass. area in the early to mid-1990s, with lower levels found in mackerel, herring and squid.	Apeti et al. 2010, Elfes et al. 2010, Gaskin et al. 1983, Hauge 1988, Jones et al. in prep, Kennicutt et al. 1994, Lake et al. 1995, Lauenstein 1995, O'Connor and Lauenstein 2006, Mierzykowski et al. 2008, Mierzykowski 2010, Ray et al. 1983, Shaw et al. 2005, 2006, Westgate et al. 1997

Table 1 (continued): Status and trends of select key contaminants in the Gulf of Maine.

CONTAMINANT	DESCRIPTION/USE	STATUS AND TRENDS	REFERENCES
Chlordane (continued)		• Found in farmed Atlantic salmon from Maine, N.B. and N.S. • Low levels measured in harbour seals between 2001 and 2002 and in humpback whales, dolphins, and pilot whales in 2005-06. • Sediment concentrations in Casco Bay, Maine unchanged between early 1980s and 1990. • Levels in mussels were found to be increasing over the 1993-2008 period at Merrimac River, Mass., and Limekiln Bay, N.B. • 46 of 51 sampling sites in the Gulf of Maine had decreased levels between 1972 and 1992. • 35 of 47 sampling sites along the U.S. east coast had decreasing trends between 1986 and 2003, with the remaining sites indeterminate. • Concentration in mussels from Birch Cove, Maine declined between the late 1980s and mid 1990s, with no further decline up to 2007. • No change observed in concentrations in harbour porpoise samples from the Bay of Fundy and approaches between the 1970s and those sampled between 1989 and 1991. • Concentrations in harbour seals decreased by a factor of two between 1980 to 1990-92. • Low levels detected in a single Atlantic sturgeon collected from a beach in Cape Cod, Mass. in 2007. • Low levels detected in common tern eggs and chicks collected from five islands along the Maine coast in 2004 and 2005.	
PDBEs	• Organic compounds used as flame retardants in a wide variety of industrial and consumer products.	• Found in sediments sampled off Mass. • Recent studies in the Gulf of Maine found PBDEs in a variety of marine organisms including (in order of lowest to highest concentration): mussels, herring, herring gull eggs, harbour seals, white-sided porpoises, and bald eagle eggs. • Exponential increases in marine life and humans since their introduction in the 1970s. • Low levels were detected in seven sea-run Atlantic salmon collected from three rivers in Maine between 2008 and 2010. • Detected in a single Atlantic sturgeon collected from a beach in Cape Cod, Mass. in 2007.	Chen et al. 2012 Goodale et al. 2008, Kimbrough et al. 2009, Mierzykowski 2010, Mierzykowski 2011, Shaw et al. 2008, 2009, Shaw and Kannan 2009, Tuerk et al. 2005
Organometals			
Organotins	• Organic compounds used as wood preservatives, biocides, and anti-fouling agents applied to vessels (e.g., tributyltin or TBT).	• Found in seawater in survey sites between Portland Harbor and Boothbay Harbor, Maine in the early 1990s, with the parent compound TBT dominating and highest concentrations near shipyards • TBT concentrations in Casco Bay, Maine sediments declined dramatically over a ten-year period between 1991 and 2001.	Larson et al. 1997, Wade et al. 2008

Table 1 (continued): Status and trends of select key contaminants in the Gulf of Maine.

CONTAMINANT	DESCRIPTION/USE	STATUS AND TRENDS	REFERENCES
Mercury and methylmercury	• Methylmercury is the organic form of the chemical element mercury. • Methylmercury is formed by aquatic organisms from inorganic mercury through anaerobic and aerobic processes, and is also produced in some industrial processes.	• Mercury found in fine-grained sediments in the Bay of Fundy, with highest values in St. John Harbour, N.B. • Found in sediments in Passamaquoddy Bay, N.B. • Found in mussels collected from 51 locations around the Gulf of Maine between 2003 and 2008; harbour seals near Grand Manan and Deer Island, N.B. in 1971; harbour seals collected off Mass. in 1980; 146 porpoises from the Bay of Fundy and adjacent waters in the 1970s; seabirds (guillemots, eiders, herring gulls, and cormorants) in the Bay of Fundy during the 1980s. • Methylmercury was found in a variety of fish species from Bay of Fundy and approaches in the early 1970s. • Similar levels of mercury were measured in porpoises from the Gulf of Maine in 1969-1977 and 1991. • A 2003 study assessed mercury levels in the livers of Gulf harbor seals and found high concentrations that exceeded international action levels for liver injury in mammals, with the highest levels detected in seals in Penobscot Bay, Maine. • A United States EPA study that measured mercury in sediments at 179 sites in Mass., N.H. and Maine during 2000-2001 found the highest concentrations in Boston Inner Harbor. • A summary of 55 Gulfwatch sites spanning the years 1993-2001 revealed that average mercury concentrations were elevated, with the highest concentrations at sites in Great Bay, N.H.; Casco Bay, Maine; and coastal N.S. • Low levels of mercury were detected in seven sea-run Atlantic salmon collected from three rivers in Maine between 2008 and 2010. • Elevated levels of mercury were detected in a single Atlantic sturgeon collected from a beach in Cape Cod, MA in 2007. • Low levels of mercury were detected in common tern eggs and chicks collected from five islands along the Maine coast in 2004 and 2005. • Low levels of mercury were detected in common tern and roseate tern eggs collected from National Wildlife Refuges in MA and ME in 2005. • Mercury was detected in seven species of seabirds collected from 13 islands in the Gulf of Maine in 2004 and 2005.	Braune 1987, Gaskin et al. 1973, 1979, Jones et al. 2010, Lake et al. 1995, Loring 1979, Loring et al.1996, Pesch and Wells 2004, Ray and MacKnight 1984, Mierzykowski et al. 2006, Mierzykowski et al. 2008, Mierzykowski 2008, Mierzykowski 2010, Mierzykowski 2011, Shaw 2003, Stein et al. 1992, Sunderland et al. 2004, Zitko et al. 1971
Trace metals			
Trace metals (e.g. iron, magnesium, zinc, copper, chromium, nickel, vanadium, arsenic, manganese, and selenium)	• Trace metals occur naturally in terrestrial and marine ecosystems with large variations in concentration; also introduced into the environment from human activities (e.g. industrial activities). • Some trace metals are needed for biological functions (e.g. copper, manganese) while others are toxic (e.g. mercury, lead, arsenic).	• Consistently high values of lead, cadmium, copper, chromium, nickel and zinc measured in sediments from Boston Harbor and Salem Harbor, Mass. in the late 1980s. • Moderate levels of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc measured in coastal embayments in Mass. in the 1980s. • Studies of trace metals in St. Croix Estuary and Passamaquoddy Bay, N.B. in the 1990s suggest that only cadmium, lead and zinc may be above natural levels. • Seven metals analyzed in mussels from the Gulf of Maine between 1993 and 2008 were present at a wide range of concentrations, with elevated levels of silver and lead in Mass. and elevated levels of mercury, cadmium, nickel, and chromium in N.H.	Elliott et al. 1992, Gottholm and Turgeon 1992, Larson 1992, Larsen and Gaudette 2010, Loring 1979, Loring et al. 1998, Mierzykowski 2008, Mierzykowski 2010, Wade et al. 2008

Table 1 (continued): Status and trends of select key contaminants in the Gulf of Maine.

CONTAMINANT	DESCRIPTION/USE	STATUS AND TRENDS	REFERENCES
Trace metals (continued)		• Mercury and lead concentrations measured in mussels between 1993 and 2008 were higher in the Gulf of Maine compared to those of other areas in the United States • Little change in trace metal concentrations at 38 sample sites in the Gulf of Maine between 1993 and 2008. • Elevated levels of chromium, copper, and selenium, and low levels of zinc were detected in a single Atlantic sturgeon collected from a beach in Cape Cod, MA in 2007. • Low levels of arsenic, copper, iron, magnesium, manganese, selenium, strontium, and zinc were detected in common tern and roseate tern eggs collected from National Wildlife Refuges in MA and ME in 2005. • In the late 1980s, elevated levels of selenium and and cadmium were measured in Leach's storm-petrels and elevated levels of lead were measured in herring gulls.	

4. Impacts

Toxic contaminants in the Gulf of Maine have the potential to impact marine biodiversity and ecosystem function, human health, and economic activities (Table 2). Each of these elements is discussed in greater detail below.

Table 2: Potential biophysical and socio-economic impacts of toxic contaminants in the Gulf of Maine.

ELEMENT	POTENTIAL IMPACTS
Biophysical	
Biodiversity and Ecosystem Function	• Contaminants can cause a variety of lethal and sublethal effects in marine organisms including invertebrates, fish, seabirds, marine mammals, and marine species at risk. • Direct exposure to some contaminants can be lethal to some organisms (e.g., loss of flight, buoyancy, and thermal insulation during an oil spill). • Some contaminants have a tendency to bioaccumulate in marine organisms and biomagnifiy in marine food webs (e.g., PCBs, DDT, PBDEs, methylmercury), resulting in particularly high concentrations of these contaminants in higher trophic level organisms. • Some contaminants such as organochlorine compounds persist in the marine environment for long periods and will cycle through marine food webs for decades and even centuries. • Environmental impacts may occur as a result of the combined effects of multiple contaminants and other stressors in the Gulf of Maine ecosystem (cumulative impacts). • Vulnerability of keystone species to contaminants could alter ecosystem structure and function.
Socio-economic	
Human Health	• Contaminated fish and fish products can pose a serious health risk to humans if consumed.
Economic Activities	• Economic losses to the fishing industry associated with market restrictions or consumption advisories for fish and fishery products. • Contaminants may impact the health and productivity of commercially valuable fish stocks.

4.1 BIODIVERSITY AND ECOSYSTEM IMPACTS

Elevated levels of contaminants in the marine environment could affect marine biodiversity and impair ecosystem function (see Coastal Ecosystems and Habitats and Offshore Ecosystems and Habitats). The health of marine organisms can be affected as a result of (1) chronic exposure to contaminants; (2) toxic effects of contaminants on prey species; and (3) direct contaminant exposure (e.g., oil spills) (Ross et al. 2007). Fish and invertebrates may be exposed to contaminants through both diet and respiration, while marine mammals and birds are exposed to environmental contaminants almost exclusively through dietary uptake (with the exception of acute exposures such as oil spills) (Ross et al. 2007). The effects of exposure to a chemical can be manifested at the cellular, organ, organism, population or community level. The toxicity of a particular contaminant; the duration, magnitude, and means of exposure; and the tolerance level of marine species are key factors that determine the effects of contaminants on marine organisms. Exposure to toxic contaminants may rapidly harm or kill an organism, or may cause chronic sub-lethal health effects over time. More detailed information about

the known effects of specific contaminants on marine organisms in the Gulf of Maine is available in the Toxic Chemical Contaminants Review.

Some organic chemicals degrade slowly and are able to persist in the marine environment for long periods of time, and will therefore cycle through marine food webs for decades and even centuries. These chemicals are commonly known as persistent organic pollutants (POPs) and include dioxins and furans, PCBs, DDT, chlordane, and PBDEs. For example, PCBs and DDT have recently been detected in a variety of marine organisms in the Gulf of Maine such as mussels, seals, and porpoises (albeit at declining levels), despite the fact that the use of these chemicals has been banned for decades in the United States and Canada (Gaskin et al. 1973; Shaw et al. 2005; Park et al. 2009; Apeti et al. 2010; Jones et al. in prep). POPs have a tendency to accumulate in the fatty tissue of organisms, be transported long distances, and cause adverse effects on human health and/or the environment.

Some contaminants may not cause adverse effects until they reach higher concentrations in an organism through bioaccumulation and biomagnification. Bioaccumulation is the process by which a chemical or substance accumulates in an organism over time through the uptake of food and water. Some common contaminants that bioaccumulate in marine organisms include PCBs, DDT, PBDEs, and TBT. TBT bioaccumulates 2000-11 000 fold in invertebrates, fish and marine mammals (Tanabe 1999; Murata et al. 2008). PAHs are known to bioaccumulate in benthic organisms (Pruell et al. 1986; Jones et al. in prep).

Biomagnification is the process by which a chemical or substance increases in concentration at each trophic level in the food web. Higher concentrations of chemicals and substances will therefore be observed in organisms at higher levels of the food web (i.e., top predators such as large pelagic fish and marine mammals). For example, a study of white-sided dolphins and pilot whales with a presumed diet of herring and mackerel in the Gulf of Maine suggested that DDT is biomagnified 1000 fold between predator and prey (Weisbrod et al. 2001). The biomagnification of chlordane in the Gulf of Maine food web is illustrated in Figure 5. Other contaminants that have a tendency to biomagnify in marine food webs include PCBs and methylmercury. PCBs are known to biomagnify to five orders-of-magnitude in marine food chains (Oehme et al. 1996; Harding et al. 1997; Skarphedinsdottir et al. 2010; Sobek et al. 2010). Certain perfluorinated compounds are known to bioaccumulate in marine food chains (Tomy et al. 2004; Houde et al. 2006). A study of mercury in organisms at different trophic levels in the Bay of Fundy found that methylmercury concentrations were 2200 times greater in bluefin tuna than phytoplankton (Harding et al. 2003; Pesch and Wells 2004). Organisms at intermediate trophic levels, including zooplankton, macrozooplankton, krill and herring, had intermediate and increasing methylmercury concentrations. PAHs are not known to biomagnify in aquatic food webs, but rather have reduced concentrations further up the food chain due to the more

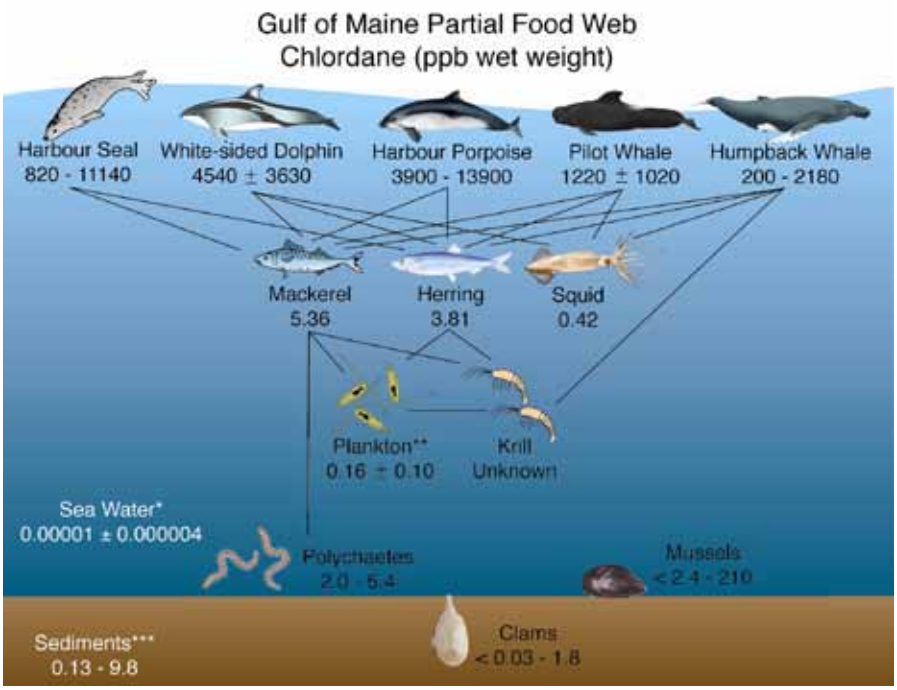

Figure 5. Biomagnification of chlordane in the Gulf of Maine food web. The concentration of chlordane increases at each trophic level in the food web. Sea water values are from the western Arctic Ocean, 1998-2001 (Hoekstra et al. 2003); plankton values are from the southern Gulf of St. Lawrence, 1993 (Harding et al. in prep). Sediments are in ng/g dry weight.

efficient metabolic degradation in higher trophic organisms (Kayal and Connell 1995; Nakata et al. 2003; Wan et al. 2007).

4.2 Human Health

The potential for acute or chronic health effects resulting from the consumption of contaminated seafood is the primary impact of toxic contaminants from the Gulf of Maine on human health. Seafood contaminated with mercury is a major public health concern because exposure to elevated levels of mercury may result in serious health problems and even death in cases of extreme poisoning (Health Canada 2009). Regulatory agencies in Canada and the United States have issued consumption advisories to the public advising certain individuals to limit their consumption of predatory fish such as shark, swordfish, and fresh and frozen tuna due to elevated levels of mercury in these products (US EPA 2012; US FDA and US EPA 2004; Health Canada 2009).

Contaminants such as PCBs, DDT, and dioxins and furans can trigger a range of subtle effects on human health, even at the generally low concentrations found in the environment. A growing body of scientific evidence associates human exposure to POPs with cancer, diabetes, neurological disorders, reproductive

disorders, immune system dysfunction, and other health effects. For most people, about 90% of overall exposure to POPs is through foods rich in animal fat, such as meats, fish, and dairy products. People are exposed to multiple POPs during their lifetime and most people today carry detectable background levels of a number of POPs in their bodies.

Regulatory agencies such as the Canadian Food Inspection Agency (CFIA) and the United States Food and Drug Agency (US FDA) monitor contaminant levels in seafood products on a regular basis and take action to remove products from the market if action or tolerance levels are exceeded. The action and tolerance levels for various contaminants in fish and fish products in Canada and the United States are shown in Table 3 and the regulatory limits for hazardous metals in fish and fish products are shown in Table 4.

Table 3: Action or tolerance levels for select toxic substances in fish and fish products in Canada and the United States (µg/g, ppm). Source: CFIA (2005) and US FDA (2011).

CONTAMINANT	CANADA	UNITED STATES
Chlordane	>0.1	>0.3
DDT and its metabolites	>5.0	>5.0
Polychlorinated biphenyls (PCBs)	>2.0	>2.0
Dioxins and furans	>0.00002	-
Polycyclic aromatic hydrocarbons (PAHs)	>0.003	-
Methylmercury	>0.5	>1.0

Table 4: Regulatory limits and guidance levels for hazardous metals in fish and fish products in Canada and the United States (µg/g). Values for bivalve molluscs (e.g., mussels) and decapod crustaceans (e.g., lobster) are shown in brackets. Source: CFIA (2005) and US FDA (2011).

CONTAMINANT	CANADA	UNITED STATES
Arsenic	>3.5	>76 (86)
Cadmium	-	>3 (4)
Chromium	-	>12 (13)
Lead	>0.5	>1.5 (1.7)
Nickel	-	>70 (80)

4.3 Economic Impacts

The main economic impact of toxic contaminants in the Gulf of Maine is the potential for contaminated seafood to affect the commercial fishing industry. Market restrictions and consumption advisories associated with contaminated fish and fishery products may lead to decreased public demand for the affected products and economic losses for the fishing industry. For example, in the early 1970s, the sale of swordfish for human consumption was banned in Canada until 1979 after levels of mercury in the species exceeded the regulatory limits for total mercury at the time (Freeman et al.1974; Stewart and White 2001). In addition to direct economic impacts, high levels of contaminants may lead to lethal and/or sublethal health effects in commercial fish stocks, adversely affecting the productivity of commercially valuable fish stocks and leading to reduced landings and revenues.

5. Actions and Responses

5.1 LEGISLATION AND POLICY

Key pieces of legislation that regulate the release of toxic contaminants into United States and Canadian waters include the U.S. *Toxic Substances Control Act* (TSCA, 1976), the *Canadian Environmental Protection Act* (CEPA, 1999) and the Canadian *Fisheries Act* (1972). The United States Environmental Protection Agency (EPA) and Environment Canada use the TSCA and *Fisheries Act*, respectively, to impose restrictions, testing requirements, and reporting and recording requirements for chemical substances to protect human health and the environment. These laws are enforced both by monitoring for select deleterious substances and by standardized biological toxicity testing. Pesticide use in Canada is overseen by the *Pest Control Products Act* and the *Food and Drug Act*, both administered by Health Canada. The *Food and Drug Act* also regulates the use of veterinary drugs in Canada. In the United States, the EPA and individual states register pesticides under the *Federal Insecticide, Fungicide and Rodenticide Act*. The EPA regulates veterinary drug use and establishes tolerances for pesticides in food under the *Federal Food, Drug and Cosmetic Act*. The EPA also establishes standards for wastewater release in surface waters under the *Clean Water Act*. The U.S. *Pollution Prevention Act* establishes a policy of pollution prevention, wherever possible, at source. In addition to the legislation and regulations described here, which focus on the contaminants themselves, a vast array of legislation and regulations govern the management of activities that may use contaminants (see also Toxic Chemical Contaminants Review). For example, Canadian and U.S. legislation require that vessels follow strict operational conditions when making discharges. Discharges from cargo tank cleaning and engine room bilge operations must pass through oil filtering equipment and must not have an oil content greater than 15 ppm. Large oil tankers must have ballast tanks separate from their cargo tanks to prevent oil being released to the marine environment during ballast exchange.

The proliferation of synthetic chemicals and their often inadvertent introduction to the environment has caused rising concern among the public, medical profession, and scientific community about the impact of these chemicals on human and the ecosystem health. This concern has led to the regulation of organic contaminants by the Governments of Canada and the United States as well as international agencies (see Table 5). In 2001, the UN Environmental Programme Governing Council banned the use of 12 POPs. The so-called "dirty dozen" include aldrin, chlordane DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, PCBs, dioxins and furans, and polychlorinated bornanes. It has been suggested that carcinogenic PAHs, brominated flame retardants (e.g., PBDEs), and butyltin be added to this list of banned substances.

Table 5: Actions and responses related to key toxic contaminants in Canada and the United States

CONTAMINANT	RESPONSE
PAHs	• Regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL) ratified by Canada and the United States. Regulated by the *Oil Pollution Act* (U.S.) and the *Canada Shipping Act* within the Exclusive Economic Zones. • Regulated under section 36 of the Canadian *Fisheries Act* and Canadian interim sediment quality guidelines and probable effects levels (CCME 1999).
PCBs	• PCBs voluntarily restricted in North America in the 1970s, followed by legislative restrictions in the United States and Canada in 1976-77. • Banned globally at the *Stockholm International Convention on Persistent Organic Pollutants* in 2004.
Dioxins and furans	• Pulp and paper regulations introduced by Canada in 1992 to reduce release into the environment. • Banned globally at the *Stockholm International Convention on Persistent Organic Pollutants* in 2004. • The Canadian tissue residue guidelines for the protection of mammalian and avian consumers of aquatic food were established in 2001 (CCME 2001).
ΣDDT	• Banned in Canada in 1970 and in the United States in 1972. • Banned globally at the *Stockholm International Convention on Persistent Organic Pollutants* in 2004.
Chlordane	• Use in the United States discontinued in 1986 except for treatment of fire ants which was terminated in 1995. • Use for crops in Canada discontinued in 1976 and registration discontinued in 1985. • Banned globally at the *Stockholm International Convention on Persistent Organic Pollutants* in 2004.
Organobromines (e.g. PBDEs)	• In 2007, use of penta-BDE and octa-BDE in the United States and other industrially developed nations was discontinued. • Penta-BDE and octa-BDE will soon be added to the list of banned chemicals included in the *Stockholm International Convention on Persistent Organic Pollutants*.
Organotin compounds (e.g. TBT)	• The U.S. *Organotin Anti-fouling Paint Act* of 1988 and similar Canadian legislation in 1989 regulated TBT application to boats less than 25 m in length. • Organotin antifouling paints such as TBT were banned globally in 2008 under the International Maritime Organization's *Antifouling System Convention*.
Methylmercury	• Canada has established permissible limits for total mercury in seafood for human consumption. For swordfish, tuna (fresh or frozen), marlin, escolar, shark and orange roughy, the limit is 1 ug/g wet weight). For all other species, the limit is 0.5 ug/g wet weight. The United States has established an action level of 1 ug/g wet weight for methylmercury. • Both Canada and the United States have issued seafood consumption advisories regarding elevated levels of mercury in some fish species (e.g., tuna and swordfish).

5.2 CONTAMINANT MONITORING

The main contaminant monitoring programs in the Gulf of Maine region are described here.

- **Gulfwatch:** Gulfwatch is a contaminant monitoring program developed and run by the Gulf of Maine Council on the Marine Environment. Since 1993, Gulfwatch has measured contaminants in blue mussels at various locations to assess the types and concentration of contaminants in coastal waters of the Gulf of Maine. Gulfwatch is coordinated and conducted by scientists and managers from government agencies and universities around the Gulf of Maine and it is the only monitoring

program in the Gulf to be coordinated across international borders. The program operates under the guidance of the Gulf of Maine Council's Gulfwatch Contaminants Monitoring Subcommittee and has been supported variously with funding from the Gulf of Maine Council on the Marine Environment, the United States EPA and Environment Canada. Gulfwatch measures 40 different PAHs, 22 PCBs, 16 chlorinated pesticides, and 9 metals at 38 sites along the coast of Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia. For more information visit: http://www.gulfofmaine.org/gulfwatch/.

- **Mussel Watch:** Mussel Watch is the longest running, continuous contaminant monitoring program in U.S. coastal and Great Lakes waters. The project was developed to analyze chemical and biological contaminant trends in sediments and bivalve tissues collected at over 300 coastal sites from 1986 to present. Attributes or variables monitored include sediment and bivalve tissue chemistry for over 100 organic and inorganic contaminants, bivalve histology, and pathogen concentrations. This project regularly quantifies PAHs, PCBs, DDTs and its metabolites, chlordane compounds and other chlorinated pesticides, TBT and its metabolites, and toxic trace elements at a total of 12 locations within the Gulf of Maine, of which three are located close to Gulfwatch sampling sites. For more information visit: http://ccma.nos.noaa.gov/about/coast/nsandt/musselwatch.aspx.

- **Marine Environmental Research Institute (MERI) Seals as Sentinels Research Program:** In 2000, MERI launched a long-term research project known as Seals as Sentinels: Assessing the Impacts of Toxic Contaminants in Northwest Atlantic Seals. The research program examines levels, effects, and trends of toxic environmental contaminants in pinnipeds (primarily harbor seals) and their prey fishes. For more information visit: http://www.meriresearch.org/RESEARCH/SealsasSentinels/tabid/85/Default.aspx.

- **United States EPA's National Coastal Conditions Assessment (NCCA):** The EPA's National Coastal Assessment surveys the condition of coastal resources in the United States by creating an integrated, comprehensive monitoring program among the coastal states. The most recent National Coastal Condition Report (US EPA 2012) contains data for the U.S. Northeast region from 2003-2006. For more information visit: http://www.epa.gov/emap/nca/.

- **Environment Canada Seabird Monitoring Program:** Environment Canada has been measuring contaminants in eggs of nesting seabirds in the Bay of Fundy region since 1972 (Environment Canada 2003; Burgess et al. 2013). Monitoring includes Atlantic puffin, double-crested

cormorant, herring gull and Leach's storm-petrel, which each feed in different food webs in the marine environment.

- **U.S. Fish and Wildlife Service's Environmental Contaminants Program:** The U.S. Fish and Wildlife Service has established an Environmental Contaminants Program in Maine that aims to prevent pollution from harming fish and wildlife and their habitats, identify and investigate contaminant problems, respond to oil and hazardous chemical spills, and assist in natural resource damage assessments (U.S. Fish and Wildlife Service 2012). As part of this program, the U.S. Fish and Wildlife Service monitors contaminant levels in a variety of marine and terrestrial fish and wildlife species including seabirds, sea-run Atlantic salmon, and Atlantic sturgeon. For more information visit: http://www.fws.gov/northeast/mainecontaminants/index.html.

6. Indicator Summary

INDICATOR	DPSIR FRAMEWORK	STATUS	TREND
Quantity of toxic contaminants released into the Gulf of Maine	Pressure	Unknown – Many sources of toxic contaminants are not tracked.	Unknown – Cannot determine trend with existing information.
Number of contaminants	Pressure	Poor – Number of contaminants is in the thousands, a challenge for monitoring and responding to impacts.	Worsening – The number of contaminants is increasing, which will likely result in further impacts on the environment.
Concentration of toxic contaminants in marine waters and sediments of the Gulf of Maine relative to more remote (pristine) locations, and where available, national standards and guidelines	State	Fair – In most areas, except for industrialized harbours, concentrations are similar to more remote locations. There are few national standards and guidelines for toxic contaminants in marine waters.	Unknown – There is limited information on temporal trends of contaminants in sediments and no temporal data on contaminants in seawater.
Concentration of toxic contaminants in marine organisms of the Gulf of Maine relative to more remote (pristine) locations, and where available, national standards and guidelines	State	Fair – Some marine organisms have concentrations higher than background levels. Concentrations generally do not exceed national food guidelines. There are limited national standards and guidelines for toxic contaminants.	No trend (limited information) – Available information on a limited number of species shows no clear overall trend.
Presence of contaminants in the marine environment whose use has been banned	State	Fair – Presence of banned contaminants in marine sediments and organisms remains a concern, largely due to their ability to persist in the marine environment for many years.	Improving – Levels of banned contaminants such as PCBs, DDTs, HCHs, CHLs and Dieldrin in the marine environment have stabilized or decreased.
Presence of emerging contaminants (e.g., pharmaceuticals, flame retardants)	State	Poor – Emerging contaminants have been detected near urban centres of the Gulf of Maine. Limited effort is being made to monitor emerging contaminants in the marine environment and there are few management measures in place to control their release.	Worsening – More emerging contaminants are being detected in the marine environment; treatment plants are ineffective at removing most pharmaceuticals.
Sub-lethal and/or lethal health effects in marine organisms directly attributed to toxic contaminants	Impacts	Unknown – Lethal and sub-lethal impacts have been observed in some species. There is a lack of information about the health effects of contaminants on marine organisms. The cumulative effects of toxic contaminants on marine ecosystems are unknown.	Unknown – The health effects of contaminants on marine organisms and the ecosystem as a whole are largely unknown; skin lesions and sex changes in fish detected in polluted harbours.
Number of seafood consumption advisories or market restrictions due to toxic contaminants	Impacts	Fair – In recent years, areas of the U.S. northeast have been under fish consumption advisories due to elevated levels of toxic contaminants. Canada has also issued seafood consumption advisories for areas of the Gulf of Maine.	No trend – No clear trend in the number of seafood consumption advisories.
Number of banned or regulated chemicals and substances	Response	Fair – There is an extensive management regime to deal with major toxic contaminants.	Worsening – The number and variety of toxic contaminants is increasing more quickly than monitoring and management efforts can accommodate.

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

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