Gulf of Maine Association
In support of the Gulf of Maine Council on the Marine Environment

Welcome to the State of the Gulf of Maine

The Gulf of Maine is a dynamic, changing ecosystem. Bordered by the northeastern United States and the Canadian Maritime Provinces, the Gulf of Maine is one of the largest semi-enclosed coastal seas in North America. It is recognized as one of the world's richest marine ecosystems with various marine and estuarine habitats, such as salt marshes, seagrass beds, tidal mud flats, underwater rocky outcrops, and kelp beds. Over 10 million people live in the Gulf of Maine watershed. Along its western and northern shores lie the cities and towns of coastal Massachusetts, New Hampshire, Maine, New Brunswick, and Nova Scotia. The Gulf has supported a long tradition of fishing, marine transportation, coastal development, and recreation, and continues to be a valuable resource for the people who live and work in the region.

Contents

The State of the Gulf of Maine Report is a modular, living document made up of a context document and a series of theme or issue papers. The project is not currently active.

Eutrophication

- Eutrophication (PDF, 1.85 mb)

Aquatic Habitats

- Coastal Ecosystems and Habitats (PDF, 1.6 mb)
- Offshore Ecosystems and Habitats (PDF, 1.9 mb)
- Watershed Status (PDF, 2 mb – hi-res version, 21 mb, is here) NEW!

Biodiversity

- Marine Invasive Species (PDF, 1.5 mb)
- Species at Risk (PDF, 1.4 mb)

Emerging Issues

- Emerging Issues (PDF, 1.3 mb)

Fisheries and Aquaculture

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Actions and Responses

Each State of the Gulf theme paper has an "Actions and Responses" section that briefly discusses how the issues highlighted in the paper are being addressed. This section doesn't list every possible action that is or could be taken. Many other documents—such as guidelines, best management practices, and codes of conduct—have been developed for carrying out activities. Some of these guidelines can be found here.

These links are provided for information purposes and are not endorsed by the Gulf of Maine Council. The linked documents may recommend techniques that do not meet the requirements of Gulf of Maine Council member agencies. They may also contravene regulations in readers' jurisdictions. Before undertaking activities, readers should check laws, regulations and guidelines in their home jurisdiction. The supporting agencies do not make any warranty or representation, expressed or

Quick Links

- **State of the Gulf of Maine – Overview**
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THE GULF OF MAINE IN CONTEXT

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2010

1. Introduction

The Gulf of Maine Council on the Marine Environment was established in 1989 by the region's Premiers and Governors as a regional entity with the mission to "maintain and enhance environmental quality in the Gulf of Maine and to allow for sustainable resource use by existing and future generations" (GOMC 2007). The Gulf of Maine Council is a US/Canada public-private partnership that works to protect and conserve the Gulf's renewable and non-renewable resources for the use and benefit of all citizens, including future generations. The GOMC is made up of environmental planners and resource managers from the Provinces of Nova Scotia and New Brunswick and the States of Maine, Massachusetts and New Hampshire. Six Canadian and US federal agencies are also members of the Council as well as ten non-profit and for-profit representatives. The Council and its members have supported numerous initiatives, ranging from bi-national actions to local projects, to improve water quality, conserve land, restore coastal habitats, and enable citizens to be better stewards of the environment around them (see www.gulfofmaine.org).

Special emphasis should be placed on the transformation of existing information into forms more useful for decision-making and on targeting information at different user groups. Mechanisms should be strengthened or established for transforming scientific and socio-economic assessments into information suitable for both planning and public information.
Agenda 21, 1992

The Council has recognized the importance of state-of-the-environment reporting as a management tool. It has adopted the strategy for indicator development and state-of-the-environment reporting through the Gulf of Maine Ecosystem Indicator Partnership (ESIP), as outlined in the document *A Strategy for Gulf of Maine Ecosystem Indicators and State of the Environment Reporting* (Mills 2006). The *Gulf of Maine Council on the Marine Environment Action Plan 2007-2012* (GOMC 2007) recognises that the Council needs to "respond to managers' needs for state-of-the-environment reporting and ecosystem indicators" (GOMC 2007).

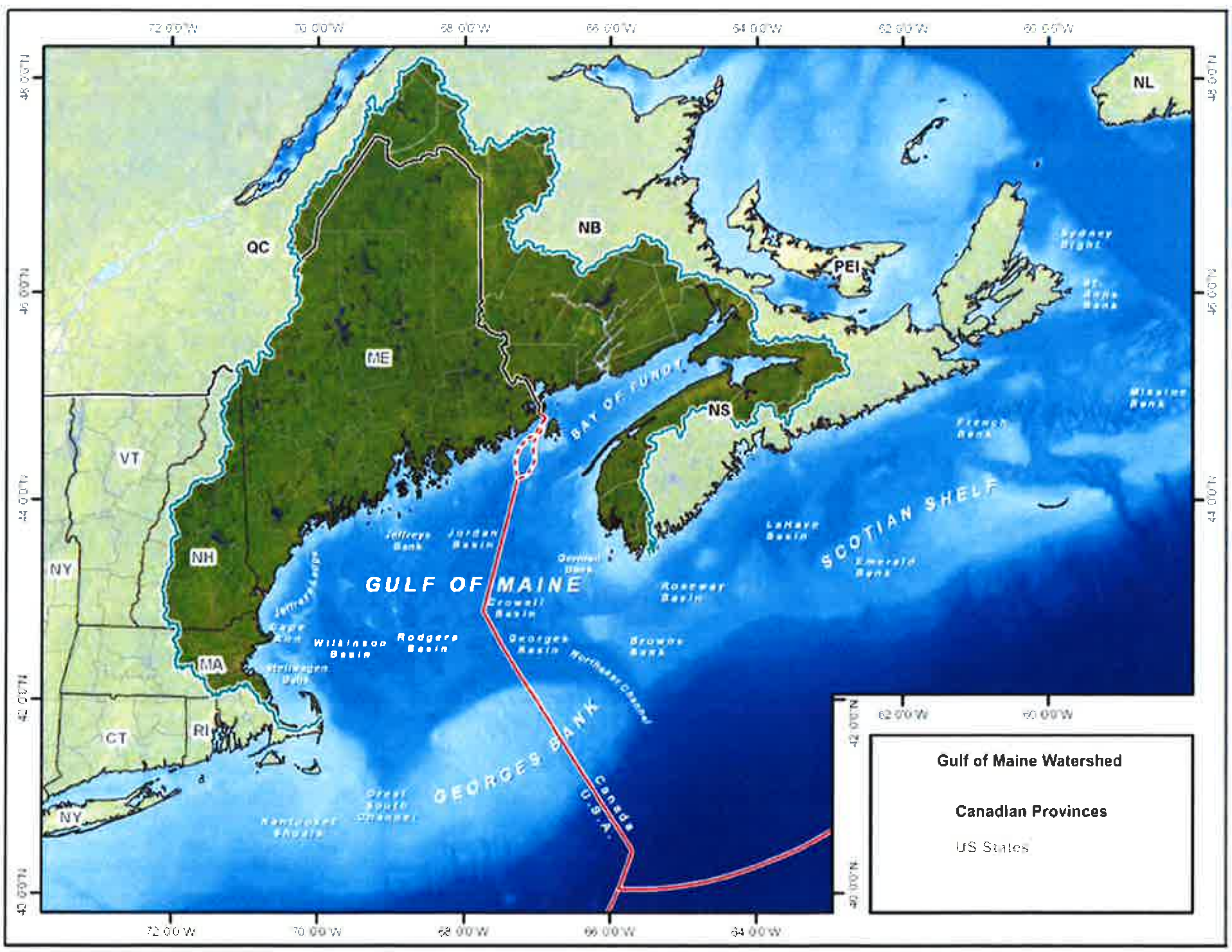
Over the years, participating members have individually taken steps to catalogue the collective understanding of the Gulf of Maine (e.g., Ecosystem Overview Report, Northwest Atlantic Bioregional Assessment, ESIP, etc.), and there are many fine examples of reports that address aspects of a state-of-the-environment report (e.g., Pesch and Wells 2004; ACZISC Secretariat and Dalhousie University 2006; New Hampshire Estuaries Project 2006; Wake et al. 2006; Taylor 2008). However, the State of the Gulf of Maine Report, of which this document is a part, is the first Gulf-wide synthesis of pressures on the environment, biophysical and socio-economic status and trends, and responses to identified issues.

The *State of the Gulf of Maine Report* is a modular, living document that consists of several parts, including this context document and a series of theme or issue papers. *The Gulf of Maine in Context* is intended to provide an introduction to the natural and socio-economic environment of the Gulf of Maine. The aim is to provide the information in a form that is easily accessible and readable, and that immerses the reader in the region. It is complementary to the theme papers, which provide a more in-depth look at important issues within the Gulf (Table 1), based on the six priority areas recognised by the Council under ESIP. The inten-

2. The Natural Conditions in the Gulf of Maine

THE GULF OF MAINE IS A SEMI-ENCLOSED SEA, TERRESTRIALLY BOUNDED BY the north-eastern American states of Maine, New Hampshire, Massachusetts and the Canadian provinces of Nova Scotia and New Brunswick. The watershed also includes a small portion of Quebec. The total land area of this watershed is 179,008 km^2 (69,115 square miles). Only one of the six jurisdictions, Quebec, does not have a Gulf of Maine shoreline and only Maine is located entirely in the watershed (Census of Marine Life 2009). Frequently described as a "sea within a sea", the Gulf of Maine area includes the Bay of Fundy, the Northeast Channel and Georges Bank. It is bounded to the northeast by the Scotian Shelf and is separated from the waters to the southwest (i.e., southern New England) by a boundary that extends to the tip of Cape Cod. The overall watershed may be sub-divided into 25 major watersheds (13 in the United States and 12 in Canada) and 11 minor coastal drainage areas. Major river drainages in the watershed include the Merrimack, Saco, Androscoggin, Kennebec, Penobscot, St Croix and Saint John rivers.

Figure 1: The Gulf of Maine and its watershed (dark green area).



channels of marine waters to the Gulf. The Gulf of Maine banks, which include Georges Bank, Stillwater Bank and Jeffrey's Bank, are relatively shallow offshore areas and attract a unique variety of living organisms.

Much of the geological influence on marine habitats of the offshore Gulf of Maine has to do with sediment particle size. In contrast to the complex processes that have occurred, a large proportion of the offshore is overlain with sediments that form a relatively smooth, homogenous sea floor. The grain size of the sediments is perhaps the most influential geological parameter affecting the distribution of marine biota. This geological occurrence strongly influences the composition and distribution of benthic and demersal communities that live on, in, or near the sea floor (Conservation Law Foundation, WWF 2006).

Geomorphology

The southern and western Gulf of Maine is characterized by relatively gentle bathymetric relief that is covered by a thick layer of sediments and glacial deposits. In contrast, the northern and eastern Gulf has areas of exposed Paleozoic rocks (250+ million years old) that are formed into a series of irregular ridges, pinnacles, and channels. The geomorphology of the Gulf of Maine marine ecosystem further consists of: a 90,000 km^2 inner lowland area with an average depth of 150 m; the 28,000 km^2 Georges Bank, whose offshore crest is less than 40 m below the ocean surface; and the Bay of Fundy, a narrow funnel-shaped body of water with an average width of 56 km and a length of 190 km. On the seaward side of Georges Bank is the continental slope, deeply cut by numerous canyons. Two large channels, the Northeast and Great South Channels, lie east and west of Georges Bank, providing passageways from the Gulf of Maine to the open sea (Backus and Bourne 1987).

Erosion and sedimentation processes within the Gulf of Maine are complex. The area has likely been covered by ice several times, and has been both above and below sea level at different stages. Multiple glaciations over the past 2 million years probably smoothed the landscape and seafloor without altering the overall bedrock influence on major morphology (Kelley 1987). As the ice receded, tonnes of glacial till would have been left across what is now the Gulf of Maine. The most important influence of the last glaciation on the Gulf of Maine was to introduce significant quantities of sediment to the area. The sand, gravel, and other unconsolidated sediments that currently cover much of Maine, Nova Scotia, and the Gulf are largely the products of glaciation and continue to be eroded into the Gulf.

Smaller features such as canyons, pinnacles, and shoals add further complexity to the regions bathymetry. There are several deep basins within the Gulf of Maine that drop below the 200 m isobath. Georges Basin, Wilkinson Basin and Jordan Basin are the three most frequently noted basins. In total, basins make up about 30% of the floor area of the Gulf of Maine (Backus and Bourne 1987). There are

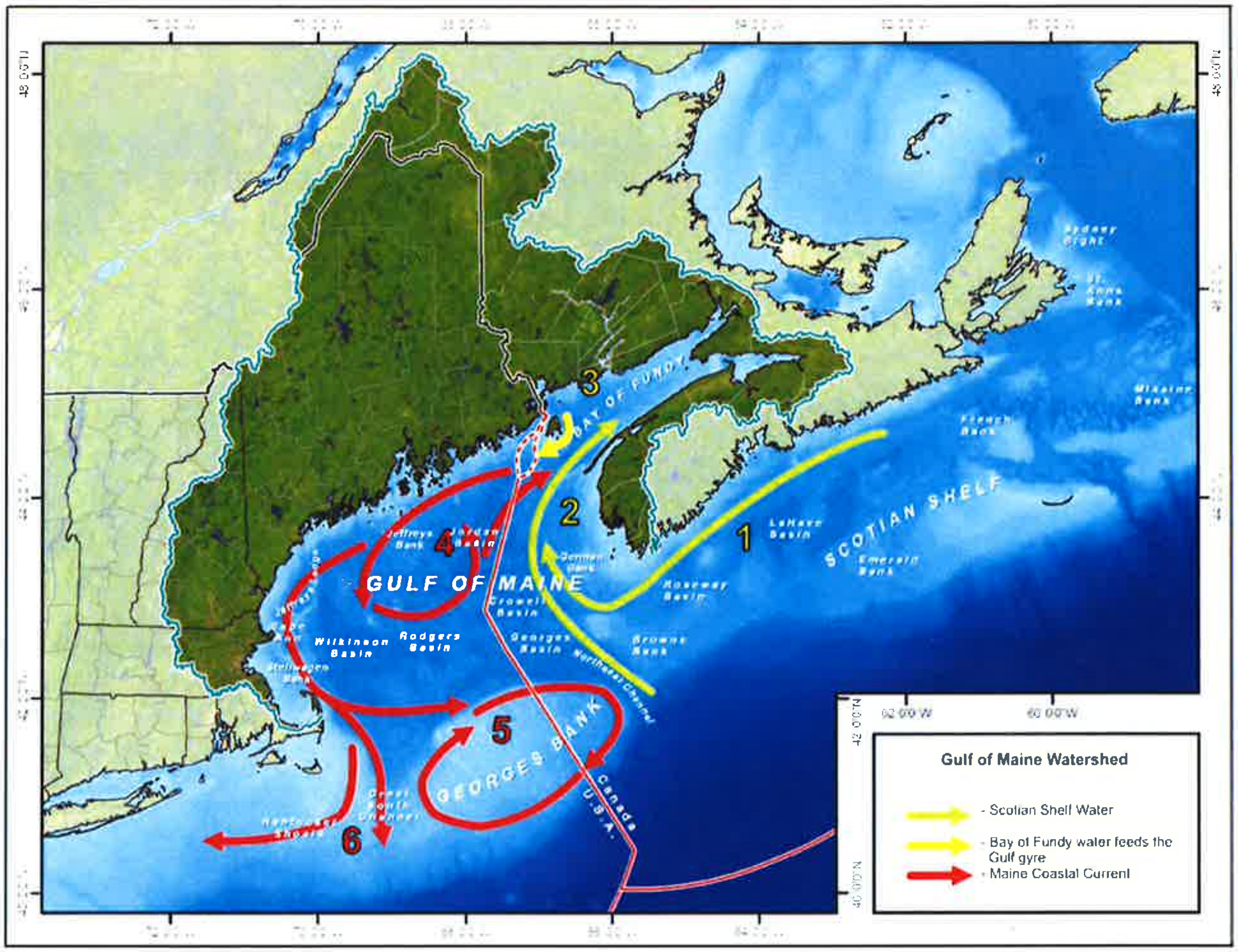


Figure 2: Currents in the Gulf of Maine. 1) Cold water enters the gulf over the Scotian Shelf, Browns Bank and through the Northeast Channel. 2) Once in the Gulf, water flows around Nova Scotia and into the Bay of Fundy. 3) The coast then deflects currents southwestward. 4) The Gulf of Maine Gyre is formed. 5) Tidal fluctuations and shallow water over Georges Bank form a secondary, clockwise-spinning gyre. 6) Water leaves the gulf through the Great South Channel and over the eastern portion of Georges Bank. Source: GoMOOS 2010.

The Gulf of Maine near-surface circulation is generally characterized as a cyclonic (counter-clockwise) movement. The Northeast Channel and Great South Channel provide pathways for sub-surface flow into and out of the Gulf of Maine respectively. As offshore water sources enter the Gulf of Maine along the Northeast Channel, they appear to drive the eastern portion of the counter-clockwise Gulf of Maine gyre and initiate the overall counter-clockwise direction of flow around the Gulf of Maine. Some of the water enters the Bay of Fundy along the Nova Scotian coastline (Xue et al. 2000); another portion of this current turns west to feed the Maine Coastal Current.

The exception to this circulation is a clockwise pattern around Georges Bank (Van Dusen and Hayden 1989). The Georges Bank gyre picks up incoming slope circulation both directly from the Northeast Channel and from circulation of the Maine Coastal Current that gets pushed towards Georges Bank by the projection of the Cape Cod land mass. The shallower coastal shelf with its diverse morphology drives much of the detail we see regarding gyres and localized currents within tic and tropical monthly cycles, all peak simultaneously. The closest match occurs at intervals of 18.03 years, a time known as the Saros (Desplanque and Mossman 1999). With the approach of the 18-year Saros tidal cycle in 2012-2013, the risks of storm surge and coastal flooding will increase throughout the Gulf of Maine.

Chemical Oceanography

The temperature, salinity, density and nutrient content of the water across the Gulf of Maine vary enormously depending on the location, time of year and water depth. The water temperature of the North Atlantic ranges from -1.7 °C in the Labrador Current to 20 °C in the Gulf Stream (International Ice Patrol 2009). Both of these large-scale currents influence seasonal and interannual temperature, salinity, density, and nutrient characteristics in the Gulf of Maine.

There are two primary mechanisms that create water temperature variability in the Gulf of Maine. One is the exchange of heat between the water and the atmosphere; the second is the exchange of different temperature waters through currents and circulation. Ocean temperatures are measured within the upper 1 m of the water column, known as the sea surface temperature (SST). The mean annual SST in the Gulf of Maine, has mirrored global patterns, and are actually less than during the mid 20th-century warming period. However, there has been a recent increase in SST range. Mean annual SST range has increased on the continental shelf to the highest levels seen from 1875 to 2005. A change in temperature range can have significant implications on how quickly seasonal change occurs and seasonal changes have significant biological implications.

The primary source waters into the Gulf of Maine have great influence on salinity, just as they do on temperature. The continental slope water that enters through the Northeast Channel is warm and saline, whereas the water that comes off the Scotian Shelf is cool and relatively fresh. These waters mix with the existing Gulf of Maine water at various intensities and depths depending on location in the Gulf, and provide a range of salinities around the Gulf of Maine.

The same processes that bring variable salinities to different areas in the Gulf of Maine also tend to drive nutrients. In locations where mixing brings highly saline water to the surface, it also brings marine nutrients from deep within the water column. Where relatively fresh, low salinity occurs, fewer nutrients are generally observed. Freshening can impede nutrient exchange between surface and deep waters, which reduces the overall spring productivity throughout the region. The Maine Coastal Current system and its rich load of inorganic nutrients increase the biological productivity of the Gulf of Maine.

The Gulf of Maine has peculiar vulnerabilities to the world's changing climate well beyond rising sea levels. As physical characteristics in the Gulf change, so too will chemical and biological attributes. Oceanographic research and analysis of nutridiving ducks and other birds). Lumpfish, rockfish, cunner, Acadian redfish, and sculpin are some of the predatory fish that feed in rocky intertidal and subtidal habitats. Mammal predation can be significant (Carlton and Hodder 2003); musk-rats, mink, and other small mammals forage in the Gulf of Maine's rocky inter-tidal zone. The primary productivity of seaweed-dominated rocky shorelines is nearly ten times greater than that of the adjacent open ocean (Harvey et al. 1995) and helps fuel the marine ecosystem. Seaweeds sustain animals in other habi-tats, as fragments break off, drift away, and enter the food web. Both the physical structure provided by rock itself and the biogenic structure created by seaweeds, mussels and other attached species offer important habitat for many organisms. Spawning fish such as herring and capelin use the rocky habitats to shield their eggs from currents and predators. Rock crevices protect algae and small animals such as snails, crabs, isopods and amphipods from predators.

Sandy Habitats. Sandy environments tend to have comparatively low biologi-cal productivity and species diversity, but they have unique species assemblages. Some filter and deposit feeding invertebrates thrive in sandy habitats and fish hide among the ripples and ridges of subtidal sandy bottoms. Dunes provide nest-ing habitat for some imperilled birds, such as the roseate tern, northern harrier, piping plover, least tern and for the threatened diamondback terrapin.

Muddy Habitats. Muddy bottoms are areas of fine sediments that may be unveg-etated or patchily covered with green algae and benthic diatoms. These habitats occur in calm, wave-sheltered, depositional environments in both the subtidal and intertidal zone, where they are commonly referred to as tidal flats. Mud habi-tats exist in many wave-protected areas along the Gulf of Maine coast, particularly at the heads of bays. The Bay of Fundy is well known for its highly productive tidal flats. In the subtidal zone, large areas of mud occur in deep waters off the coast of Massachusetts, including Cape Cod Bay and north of Georges Bank. Grain size can range from pure silt to mixtures containing clay and sand. The sediments of muddy habitats boast a higher proportion of nutrient-rich, organic-mineral aggregates (detritus) than the sediments in sandy habitats (Whitlatch 1982). The cohesive nature of muddy sediments facilitates burrow construction by many types of invertebrates. Watling (1998) estimates that a thousand species of macroinvertebrates live in muddy habitats of the Gulf of Maine. Mussels, clams and other filter feeders provide a vital link between water column and seabed habitats by feeding on plankton and other waterborne particles. These consumers, in turn, are prey for animals higher in the food web. Tidal flats are noteworthy for their value as shorebird feeding grounds. The high densities of crustacean and molluscan prey in tidal flats support vast numbers of shorebirds during migration.

The Water Column

The liquid realm between the seafloor and the sea surface is referred to generically as the water column. All of the estuarine and marine waters in the Gulf of Maine are part of the water column. The water column is a dynamic, three-dimensional some young fish, shellfish, crabs and shrimp because the physical structure of the grasses offers hiding places from predators. As they grow, salt marsh plants absorb atmospheric carbon dioxide, which is a major greenhouse gas. The carbon can be stored in the soil for thousands of years as the vegetation dies and is transformed into peat. The roots and stems of marsh plants improve water clarity by slowing water flow and trapping waterborne sediments, which block sunlight penetration, clog filter-feeding animals and fish gills, and may contain toxins or heavy metals. In addition, the grasses absorb excess nutrients that enter groundwater and surface water from fertilizers and sewage discharge. This reduces the risk of eutrophication and oxygen depletion in estuaries and nearby coastal waters.

Seagrass Beds. Seagrass is a general term for flowering plants that live in low intertidal and subtidal marine environments. Roots anchor seagrass to the sediment, but unlike terrestrial plants, seagrass also absorbs nutrients from the water along the entire length of its blades, which can reach ten feet. Two species of seagrass live along the Gulf of Maine coast. Eelgrass (*Zostera marina*) is the dominant seagrass throughout the region, while widgeon grass (*Ruppia maritima*) is limited to low-salinity waters. Seagrass usually lives in shallow (to a depth of 11 m), clear waters where it receives ample sunlight. The beds often lie next to salt marshes or in harbours and inlets where they are protected from storms. Seagrass is critical habitat in the Gulf of Maine. It improves water quality by filtering suspended sediment and excess nutrients; seagrass blades act as refuges for small animals and slow the water, providing inhabitants a respite from currents; seagrass produces oxygen through photosynthesis, which benefits the animals that inhabit the beds; they are also notable for their role as nurseries. Commercially valuable species such as bay scallop, cod, blue mussel and winter flounder use seagrass habitats as juveniles, although not exclusively. Many algal and invertebrate species attach themselves to seagrass blades, including encrusting and upright bryozoans, tunicates, hydroids, and red and green epiphytic algae. Atlantic silversides and other species spawn in eelgrass beds. Other species that occur commonly in seagrass beds are lobster, pipefish, tomcod, American brant, and European green crab.

Kelp Beds. While many different types of seaweed live on rocky substrates in the Gulf of Maine, kelps are noteworthy because they are large and create underwater forests with physical structure and layering similar to that of a terrestrial forest. Kelps are brown algae that use root-like holdfasts to attach to hard substrates. Although their general morphology resembles terrestrial plants, kelps are quite different. For example, nutrient absorption occurs throughout the whole organism, not just through the holdfast. Kelp beds resemble forests on land in that the kelp blades form a canopy layer, fleshy algae such as Irish moss form an understory layer, and the crustose red algae that live on rocks are comparable to a forest's herb layer. This complex structure creates homes for many different species. Invertebrates and fish, especially juvenile fish, find protection from predators and harsh environmental conditions, including ultraviolet radiation and strong currents, by the Gulf of Maine. This section gives a broad overview of some of the key species and communities found within the Gulf of Maine (see also *Gulf of Maine Ecosystem Overview Report*, Parker 2009).

Planktonic Communities

Phytoplankton consist of microscopic plants that form the base of the marine food chain. Though they are small, the energy they capture from the sun through photosynthesis helps to sustain almost all life in the ocean. A phytoplankton bloom has been defined as a "high concentration of phytoplankton in an area, caused by increased reproduction; which often produces discoloration of the water" (Garrison 2005). Blooms occur when sunlight and nutrients are readily available to the plants, and they grow and reproduce to a point where they are so dense that their presence changes the colour of the water in which they live. Blooms can be quick events that begin and end within a few days or they may last several weeks. They can occur on a relatively small scale or cover hundreds of square kilometres of the ocean's surface. In the Gulf of Maine, spring and fall blooms occur on an annual basis. Other planktonic community members include the ichthyoplankton (developing fish with limited mobility) and bacterioplankton (bacterial component of plankton important in fixing carbon dioxide and nitrogen).

Benthic Communities

Macrobenthos, excluding groundfish, dominates the intermediate trophic-level biomass, production and consumption in the Gulf of Maine. It is the macrobenthos such as sea grasses, star fish and shellfish that transfer the greatest proportion of energy through the ecosystem. Human activities, including overfishing and species introductions, have had a dramatic impact on benthic communities in the Gulf of Maine within the past two decades. In addition to changes in relative abundance, many of these introduced species have greatly expanded their distribution and habitat selection. The habitats and roles of introduced and established species and the interactions between species within communities are changing in unpredictable ways in the Gulf of Maine. The factors that will determine the future direction of shallow water benthic community development are not well known. The present observations indicate that the changes underway are increasing in magnitude and spreading to affect other communities (Harris and Tyrrell 2001).

Macrophytes. There have been 271 species of macrophytes (marine algae large enough to be seen with the naked eye) identified in the Gulf of Maine. Important coastal species include eelgrasses, brown algae and the commercially important Irish moss. Kelps (brown algae) are also found in the Gulf of Maine. The most common species in this region are sugar kelp, oarweed, edible kelp and shotgun kelp.

Invertebrates: Infaunal communities. There are about 1,410 species of invertebrates making up approximately 60% of the known marine species of plants and animals within the Gulf of Maine. Infauna comprises those species that live within the bottom substrates of the Gulf. Relatively common infaunal invertebrate

Table 2: Deepwater and shelf/slope fish assemblages found in the Gulf of Maine.

DEPTH CLASS	DEMERSAL FISH ASSEMBLAGE	BOUNDARY RELEVANCE TO THE GULF OF MAINE	PRIMARY ASSEMBLAGE SPECIES	
> 200 m	Temperate deepwater	From the Gulf of Maine northwards; the Gulf of Maine is approximately southern in extent.	Marlin – spike Black dogfish Atlantic argentine	Longfin hake Barracudinas Roughnose grenadier
> 200 m	Southern deepwater	From the Gulf of Maine southwards; the Gulf of Maine is approximately northern in extent.	Blackbelly rosefish Offshore hake Shortnose greeneye Shortfin squid	Buckler dory Beardfish Slatjaw cutthroat eel Armoured searobin
< 200 m	North-temperate bank/slope	From Georges Bank northward; the Gulf of Maine is approximately southern in extent.	Northern wolffish Spotted wolffish Atlantic sea poacher Arctic cod Greenland halibut Polar sculpin	Greenland cod Fourline snake blenny Threebeard rockling Atlantic spiny lumpsucker Atlantic hookear sculpin
< 200 m	South-temperate bank/slope	Extends to both north and south of the Gulf of Maine.	Red hake Goosefish (angler) Spiny dogfish Silver hake White hake Pollock Cusk Yellowtail flounder Winter flounder Ocean pout	Longhorn sculpin Winter skate Northern sand lance Atlantic hagfish Fourbeard rockling Haddock Atlantic soft pout Wrymouth Threespine stickleback Sea raven
< 200 m	Southern bank/ slope	From the Gulf of Maine southwards; the Gulf of Maine is approximately northern in extent.	Fourspot flounder Butterfish Spotted hake Fawn cusk-eel Gulf Stream flounder Summer flounder Scup Black sea bass Northern (common) searobin	Smooth dogfish Windowpane flounder Little skate Bigeye scad Rough scad Round scad Plainhead filefish Smallmouth flounder

—the longfin inshore squid (*Loligo paeleii*) and the highly migratory northern shortfin squid (*Illex illecebrosus*). A number of other pelagic invertebrates are found within the Gulf of Maine, and several are important as prey items to fish communities. Echinoderm (star fish and sea urchins), barnacle larvae, and krill are observed during spring and summer in the Bay of Fundy. Jellyfish commonly encountered include ctenophores (comb jellies), medusae, salps (tunicate), and Chaetognatha (predatory worm). Leatherback turtles feed almost exclusively on jellyfish while in the Gulf of Maine.

Marine Turtles. Three sea turtles, loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*) and leatherback (*Dermochelys coriacea*) are documented as regularly occurring in the Gulf of Maine (Census of Marine Life 2009). The green sea turtle (*Chelonia mydas*) have also been reported around Cape Cod, MA. All sea turtles in the Gulf of Maine are considered migrants, coming to forage in northerly areas on or along the shelf (Shoop 1987).

Small Cetaceans. Related to the whales, this group includes species of dolphin and porpoise. In the Gulf of Maine, the main species sighted (in descending order) are harbour porpoise (*Phocoena phocoena*), white-sided dolphin (*Lagenorhynchus acutus*), and two species of pilot whales (long-finned - *Globicephala melas*; and short-finned - *Globicephala macrorhynchus*) and the common dolphin (*Delphinus delphinus*). Two other dolphin species, Atlantic bottlenose dolphin (*Tursiops truncates*) and white-beaked dolphin (*Lagenorhynchus albirostris*) are occasionally seen. Significant numbers of (~40,000) of both white-sided dolphin and harbour porpoise reside in the US Gulf of Maine year round, with virtually 100% of the northeast shelf population being located in the Gulf. The Gulf of Maine-Bay of Fundy population of harbour porpoise is one of four in the western North Atlantic (NOAA 2006). Harbour porpoise is listed as threatened under the US Endangered Species Act and under the Canadian Species at Risk Act, and is the only member of this group of small cetaceans that is currently a federally listed species.

Seals. Harbour, harp, hooded and grey seals are listed on the Gulf of Maine species census. In general, there is evidence that the seal populations in the Gulf of Maine have increased over the last 20 years (Parker 2009).

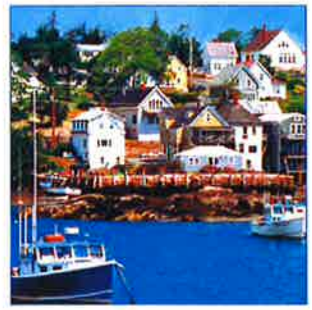
Seabirds

The Gulf of Maine is rich in avian diversity and abundance. There are more than 184 species of Marine birds that have been documented within the Gulf of Maine. The Gulf of Maine has several attractive features for pelagic birds, including ice-free winters and areas of high marine productivity that ultimately produce food supplies at the top of the food chain. The Gulf of Maine ecosystem components support breeding, migrating/staging and non-breeding populations of waterfowl, seabirds and shorebirds (Table 3).

Table 3: Important marine areas within the Gulf of Maine for select seabirds.

SPECIES	STATUS OF BIRD	TIME OF YEAR/LOCATION	ENVIRONMENTAL CHARACTERISTICS
Northern Gannet	Immature	Winter: Cape Cod Breeding: Grand Manan Post-breeding: Grand Manan and Cape Cod	Shallow and mixing regime Strong tidal currents Strong tidal currents
Greater Shearwater	Moulting	June: Georges Bank	Shallow waters
Black Legged Kittiwake	Immature	Post-breeding: Grand Manan Small breeding colony in Bay of Fundy	Shallow and mixing regime
Herring Gull	Immature	Winter: Cape Cod Breeding: Cape Cod Post-breeding: Cape Cod, Grand Manan and Georges Bank	Mixing regime Strong tidal currents Strong tidal currents and shallow waters
Great Black-backed Gull	Immature	Winter: Cape Cod and Georges Bank Breeding: Cape Cod Post Breeding: Georges Bank	Shallow and mixing regime Currents and shallow waters Shallow waters

After 1880, farms declined in size and number and urban areas expanded. Electrification brought more dams, many of which still remain today. By 1920, there was still approximately 2 million acres (0.8 million hectares) of "virgin" forest in New England, but harvesting was occurring 3.5 times faster than replacement. By the 1940s, 38% of the forests were less than 20 years old and many states were forced to import wood. In Canada, much of the abandoned farm and forest land reverted to the Crown (McInnis Leek 2004) and over-harvesting was limited to areas near water transportation.



The population grew moderately in the 20th century. By 1940, two-thirds of the population lived in coastal counties of the Gulf in a limited number of centres, fuelled by industrialization of its shores. Population continued to migrate from rural to urban areas, following employment opportunities and services. Settlement patterns began to change after World War II, spurred by federal housing policies and construction of the US Interstate and Trans-Canada highways. Housing rates increased dramatically and changes in household size and structure prompted demand for new housing types. Increased prosperity led to construction of vacation and retirement homes in settings near recreational amenities. Dispersal of development into rural lands, commonly known as "sprawl," is now a defining feature of the Gulf's landscape (Pesch and Wells 2004).

3.2 DEMOGRAPHY

As of 2007, nearly 10.8 million people live within the Gulf of Maine region, which includes: New Brunswick (NB, 0.75 million), Nova Scotia (NS, 0.94 million), and in the US, the New England states of Massachusetts (MA, 6.45 million), Maine (ME, 1.32 million) and New Hampshire (NH, 1.32 million) (US Census Bureau 2007, Statistics Canada 2007). Distribution of population by county is shown in Figure 3. The current population growth in the region is just over 1%, as compared to the US and Canadian averages of less than 1%. This population trend and the migration of human settlement toward the coast will continue to impact the Gulf of Maine ecosystem for decades to come. By 2025, the population of the Gulf is expected to increase by approximately 0.6 million people. While growth trends in the Canadian provinces are mixed (population is projected to decrease in Nova Scotia), the US states are growing and likely to continue to do so. Most of that growth (95%) is residential. The fastest growing towns within expanding metropolitan areas are the low density new suburbs, 16 to 40 kilometres (10 to 25 miles) distant from traditional metropolitan centers. Two major trends for the Gulf of Maine region are out-migration from rural to metropolitan centres and ageing population. Growth projections for the coast of Maine categorise nearly all of it as "suburban" by year 2050. Nova Scotia has the highest median age in the region at 41.8, followed by New Brunswick at 41.5. Both provinces are higher than Canada's median age of 39.5. Maine has the highest median age (41.2) of any state in the US (36.4) and the proportion of elderly residents is projected to almost double by 2030. New Hampshire and Massachsuetts are experiencing simi-

3.3 ECONOMIC OVERVIEW

The Gulf of Maine economy had a gross domestic product (GDP) of over US$500 billion[1] in 2008, which comprised: Massachusetts $365 billion, New Hampshire $60 billion, Maine 49.7 billion, Nova Scotia $32 billion and New Brunswick $ 25.6 billion (Bureau of Economic Analysis 2009; Statistics Canada 2009). Between 2004 and 2008 the region's economy grew by approximately 17%. The economy is largely serviced-based, with 80% of its GDP generated by service industries and only a small 2.5% arising from natural resource based industries, i.e., agriculture, forestry, fishing, hunting, mining, and oil and gas extraction (Figure 4).

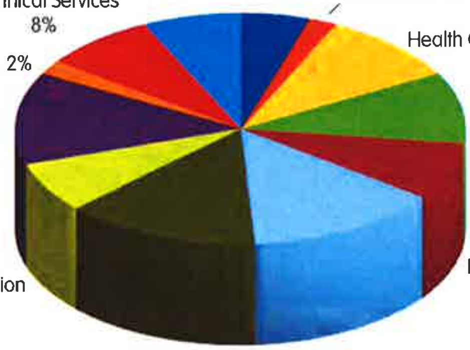


Figure 4: Relative contribution to GDP by major industry sectors in the Gulf of Maine region for 2007. Sources: Bureau of Economic Analysis 2009; Statistics Canada 2009.

The Gulf of Maine Marine Economy

The marine economy of a region comprises commercial activities related to and/or having inputs from the sea. The marine economy in the Gulf of Maine region is constantly evolving as it adapts to changing demands for products and services and supply of natural resources. Over two-thirds of the population in the region lives along the coastline and this serves as a driver that is exerting pressure on coastal and ocean ecosystem health. An economic valuation of the marine environment is based on the marine services it provides. Marine ecosystem services refer to benefits that people obtain from marine ecosystems, including the open ocean, coastal seas and estuaries (Daly 1997). Ecosystem services are critical to the functioning of coastal systems and contribute significantly to human well-

[1] All currency quoted in US dollars unless specified in Canadian dollars (C$). Canadian dollar conversions are based on market rates and yearly exchange averages.

Table 4: Some key economic statistics for the marine economic sector in the Gulf of Maine.

NOVA SCOTIA	Major marine sectors:	Military defense, offshore oil & gas, fishing
	Percentage of GDP:	15.5%
	Percentage of household income:	10.2%
	Employment:	>30,000 direct full-time jobs
	Annual output:	C$2.6 billion
NEW BRUNSWICK	Major marine sectors:	Fish processing, ship/boat building, transportation & ports
	Percentage of GDP:	4.3%
	Percentage of household income:	4.1%
	Total direct impact (1995–97):	C$610 million
MAINE	Major marine sectors:	Tourism/recreation, ship/boat building
	Employment:	45,685
	Annual wages:	$1.2 billion
NEW HAMPSHIRE	Major marine sectors:	Tourism/recreation, transportation
	Employment:	14,005
MASSACHUSETTS	Major marine sectors:	Commercial seafood, transportation, tourism/recreation, science/technology, construction/infrastructure
	Estimated total marine payroll:	$4.3 billion
	Annual output:	$14 billion

Data were compiled from different sources that varied in their methods and the years analyzed.
Sources: Gardner et al. 2009; Mandale et al. 2000; Colgan 2004; University of Massachusetts/Donahue Institute 2006.

schooners that plied its waters, and the resulting maritime culture that developed on its shores, the Gulf of Maine has inherited one of the greatest maritime histories. Multiple factors, however, have led to reduced commercial fishing in this region over the past 20 years including stock depletion and changes in fishing regulation.

All of these factors are changing the face and nature of fishing communities within the Gulf of Maine. Ground fish stocks in the Gulf of Maine have become severely depleted (although several fish stocks are recovering and their status is improving, e.g., monkfish and haddock) and traditional maritime-oriented ways of life are in decline, changing the structure of many coastal communities. In particular, established fishing communities are forced to adapt to new social, economic, and environmental conditions in part because of a lack of marine resources from over-fishing and increased fishery management regulations. These communities are also being supplemented with new technology-based industries and tourism and gentrification are factors in some communities (e.g., Chatham, Marblehead and Scituate, MA and Vinalhaven, ME). Many processors and fish

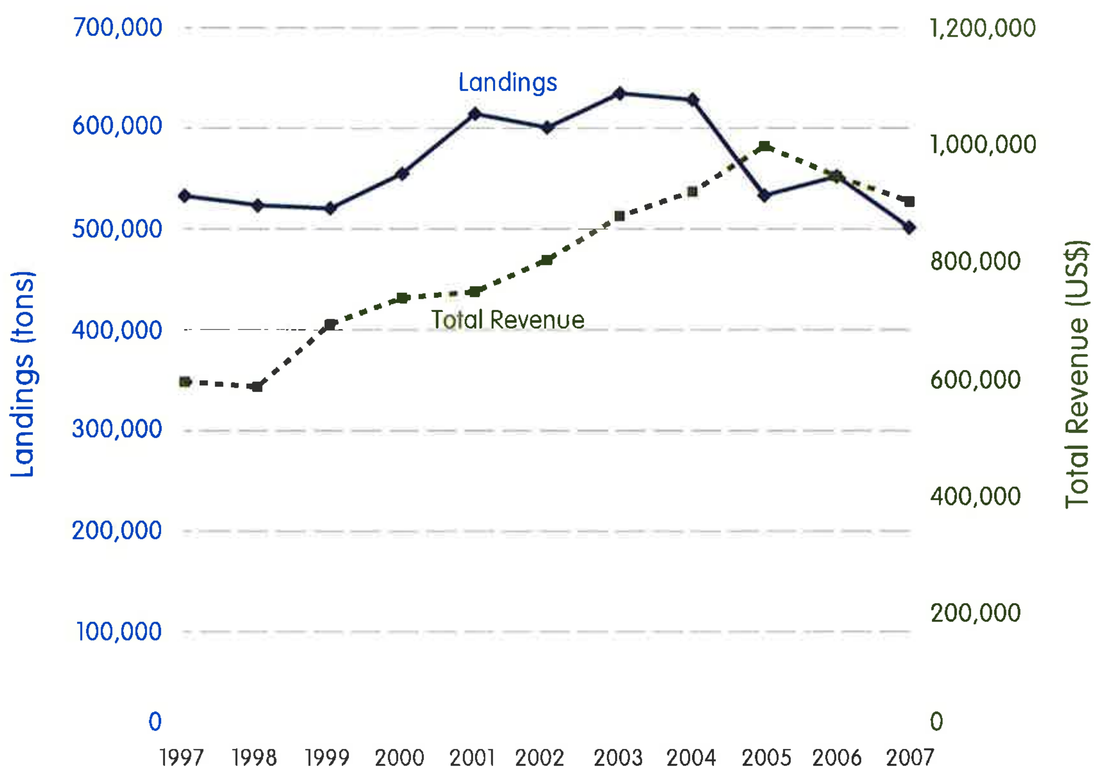


Figure 5: Fisheries landings, by revenue and weight (tons) 1997-2007.
Sources: NOAA 2009; DFO 2009.

Figure 5 shows fish landing by revenue and weight for all four regions combined. Over the period 1997-2007, total landings averaged 563 million tons, ranging from a high of 635 million tons in (2003) to a low of 502 million tons in 2007. Overall Massachusetts had the largest increase in landings (136%), with Gloucester and New Bedford having the highest landed value from commercial fishing among all ports in the entire US from 2000-2006. This was largely due to an increase in Atlantic mackerel landings. Shellfish landings for 2007 were 175 million tons.

Overall, revenue increased 54% from 1997 to 2007, largely due to the increase in revenue from shellfish (76% in real terms). Revenues from finfish and other fishery products declined 9%. Massachusetts and New Hampshire experienced the largest growth in ex-vessel revenue during this period, increasing 136% and 57% respectively.

The ten key species represented on average 84% of the ex-vessel value in the Gulf of Maine, with American lobster accounting for 42% of total landings revenue. American lobster and sea scallops accounted for 71% of the average annual revenue for all key species combined. Scallops in particular, have allowed the port of New Bedford to prosper in comparison to other Massachusetts ports. The largest annual increase during the period 1997-2007 was 764% for Atlantic mackerel (2001-2002). This species also had the largest annual decrease in revenue, declining 69% from 2004-2005.

Despite being a lower value species ($0.11 per pound in 2007), Atlantic herring contributes more to the harvest tonnage than any other species or group. The landings in 2007 contributed 162 million tons, approximately 32% of total landings for the region. The Scotia/Fundy region's contribution to the Atlantic herring harvest is the highest in the region, at 92,704 tons. Scallop landings from Georges Bank are currently at an historic high while those from the Gulf of Maine are among the lowest on record.

Coastal Tourism and Recreation

Tourism and recreation are an important aspect of the coastal economy in the Gulf of Maine region. Tourism offers communities both economic promise and environmental concern. In Maine, the tourism industry and its affiliated support services employ more than fishing, farming, forestry, and aquaculture combined. The region's fame as a coastal destination generated over $40 billion in tourism revenue in 2006 and created over 300,000 jobs. The term "coastal tourism and recreation" embraces the full range of tourism, leisure, and recreational activities that take place in the coastal zone and the offshore coastal waters. These include coastal tourism development (hotels, resorts, restaurants, food industry, vacation homes, second homes, etc.), and the infrastructure supporting tourism development (retail businesses, marinas, fishing tackle stores, dive shops, fishing piers, recreational boating harbours, beaches and recreational fishing facilities). Also included is ecotourism and recreational activities such as recreational boating, cruises, swimming, recreational fishing, snorkelling, and diving.

Of all the activities taking place in coastal zones and the near-shore coastal ocean within the Gulf of Maine, none is increasing in both volume and diversity more than coastal tourism and recreation. Virtually all coastal and ocean issue areas affect coastal tourism and recreation either directly or indirectly. Clean water, healthy coastal habitats, and a safe, secure, and enjoyable environment are clearly fundamental to successful coastal tourism. Similarly, healthy living marine resources (fish, shellfish, wetlands, coral reefs, etc.) are important to most recreational experiences. Security from risks associated with natural coastal hazards such as storms, hurricanes, flooding, and the like is a requisite for coastal tourism to be sustainable over the long term.

It is not within the scope of this document to address all aspects of tourism and recreation, but merely to provide an overview of general tourism by province/ state (not only marine tourism) as well as some of the activities occurring in the

Nova Scotia. In 'Canada's Ocean Playground', tourism contributed C$1.31 billion in 2006 to the province's economy. Tourism revenues increased 1% from 2005 generating 510.5 million in tax dollars and 32,800 direct and indirect jobs (Tourism Industry Association of Nova Scotia 2009).

Coastal Activities

Whale Watching. The Gulf of Maine region supports a very active whale watching industry. Approximately 1.5 million people took part in whale watching cruises throughout the region in 2007, generating approximately $30 million in direct ticket revenue, with another $30 million in indirect expenditures. The season generally begins in April, peaks in August and ends in October. Whale-watching companies are based in many ports in the Gulf of Maine, ranging from Provincetown MA to Digby NS. Currently there are eight operators in New Brunswick (St Andrews, Grand Manan Island), seven in Nova Scotia (Digby, Brier Island); six in Maine (Bar Harbor), three in New Hampshire and fourteen in Massachusetts (Gloucester 4; Boston 5; Plymouth 1; Barnstable 1; Provincetown 4). In Nova Scotia and New Brunswick whale watching is concentrated in the Bay of Fundy. In addition to the commercial boats, a large fleet of smaller private craft, dubbed by operators "the mosquito fleet," follow commercial whale-watching boats, or otherwise seek out whales independently.

Birding. Sustainable tourism niche markets, such as birding, have been increasing in the region over the last few years. Several birding festivals take place each year like the Down East Spring Birding Festival, headquartered in Whiting, ME, and the Warblers and Wildflowers Festival in Bar Harbor, ME. There are also several state and federal wildlife preserves. Acadia National Park, the Grand Lake Stream area, Northeastern Coastal Maine, the waters around Machias Seal Island (Puffin Breeding Colony) as well as Cape Sable Island, NS, have all been recognised as Globally Important Bird Areas by the American Bird Conservancy.

Recreational Fishing. Recreational salt-water fishing directly contributes over $1 billion to the Gulf of Maine economy, and involves as many as 1.9 million residents and visitors. Anglers took approximately 6 million recreational trips in 2006 in one of three fishing modes: party/

SUSTAINABLE TOURISM

With tourism generating such large revenues, employment numbers, and visitor statistics, it is important that the tourism industry preserves and improves the natural and cultural resources that draw people to the Gulf of Maine region. The Gulf of Maine Council's 2001-2006 Action Plan sets out a goal of developing "a nature-based tourism strategy that sustains the environment and the wellbeing of local people" and several studies and proposals have pointed to the need for university based extension in the area of sustainable tourism development.

The University of Maine has heeded this call by creating a new Center for Tourism Research and Outreach and the state recently unveiled its new nature-based tourism initiative. The premise of many of these proposals is that, if carefully planned and managed, tourism can contribute to the economic development of the regions rural and urban areas. State agencies and the University of Maine co-sponsored a Symposium on Nature-based Tourism in April 2002. In 2003, the Governor's Conference on Tourism highlighted sustainability challenges and the synergies between agriculture and tourism. The Bureau of Parks and Lands and the Maine Island Trail Association are framing a ten-year management plan for public islands. The Downeast Resource and Conservation District's Vacationland Resources Committee is one of eight regional bodies working on a sustainable tourism strategy. The Maine Tourism Commission has created a Natural Resources Committee to investigate problems and opportunities in managing Maine's natural attractions. Operators and stakeholders in the Nova Scotia tourism industry created the Nova Scotia Strategy for Sustainable Coastal Tourism Development in 2007 and released a comprehensive inventory of success stories on Nova Scotia sustainable tourism.

Natural resources will continue to be the region's primary tourism draw. Research indicates that the 140 million Americans interested in nature tourism and/or historical/cultural travel spend twice the average amount tourists typically spend (Fermata 2005). It is this class of visitor who most appreciates and will pay extra for sustainable tourism.

ucts. This cargo is associated with some 2,000 port calls by self-propelled vessels (mostly foreign flag) and 1,500 barges (mostly domestic) per year and represents about 4% of total US oceangoing cargoes (US Army Corps of Engineers 2009).

The largest port, based on cargo tonnage in the Gulf of Maine region, is the Port of Portland ME, with an average of 27.5 million tons for the past five years (see Figure 6). It also ranked as: the largest foreign inbound tonnage transit port in the US; the largest tonnage port in New England; the 25th largest port in the United States, and the largest oil port on the US East Coast. Ships destined for the Portland-Montreal Pipe Line, a crude oil pipeline that stretches from South Portland to Montreal, was a major contributing factor in these rankings.

The second largest US port in the region is Boston, MA with an average of 23.4 million metric tons and 478 vessels making use of the port in 2007. The Port of Boston handles more than 1.3 million tons of general cargo, 1.5 million tons of

Figure 6: Cargo ports in the Gulf of Maine. Sources: US Army Corps of Engineers/Navigation Data Center 2007; St John Port Authority 2009.

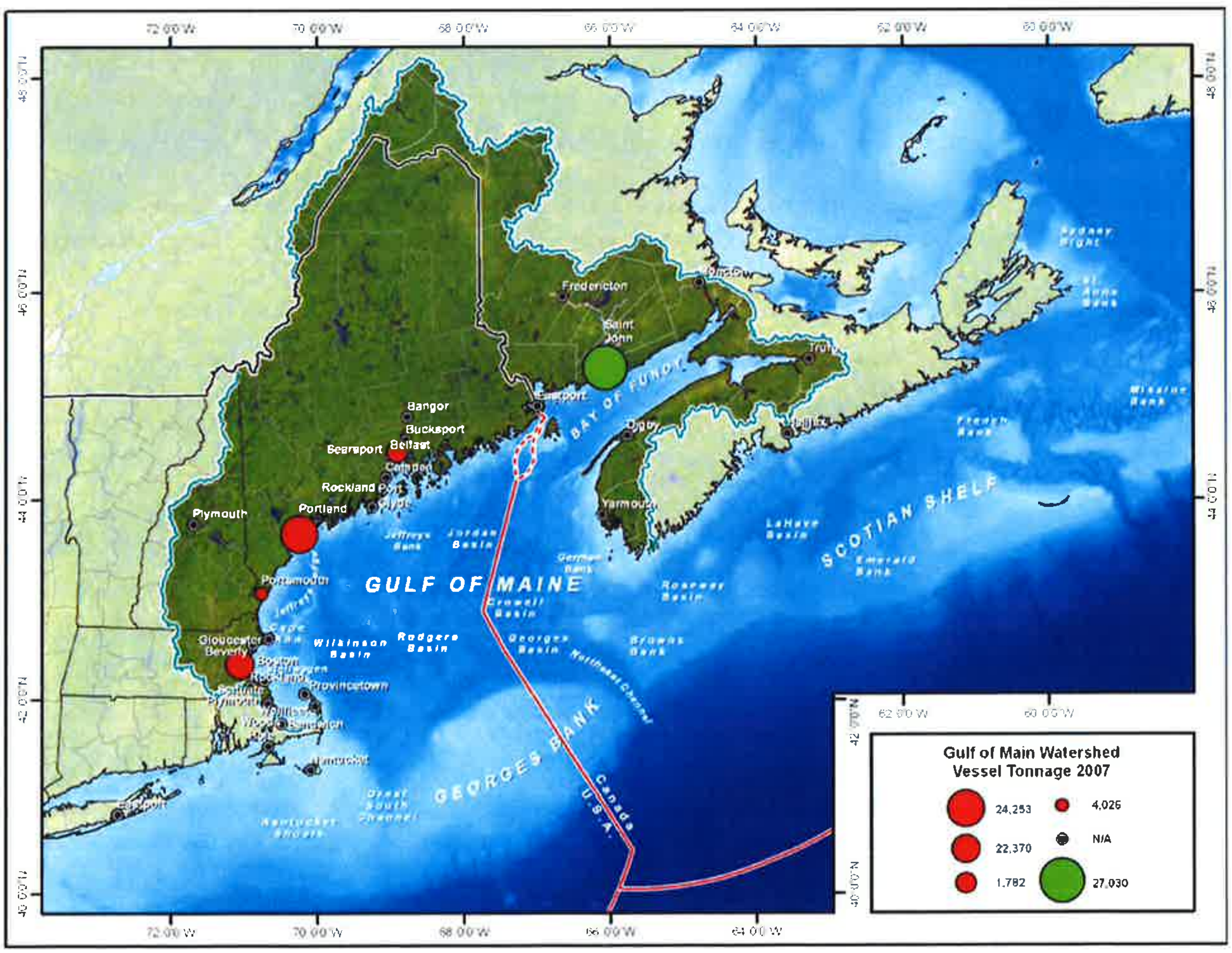
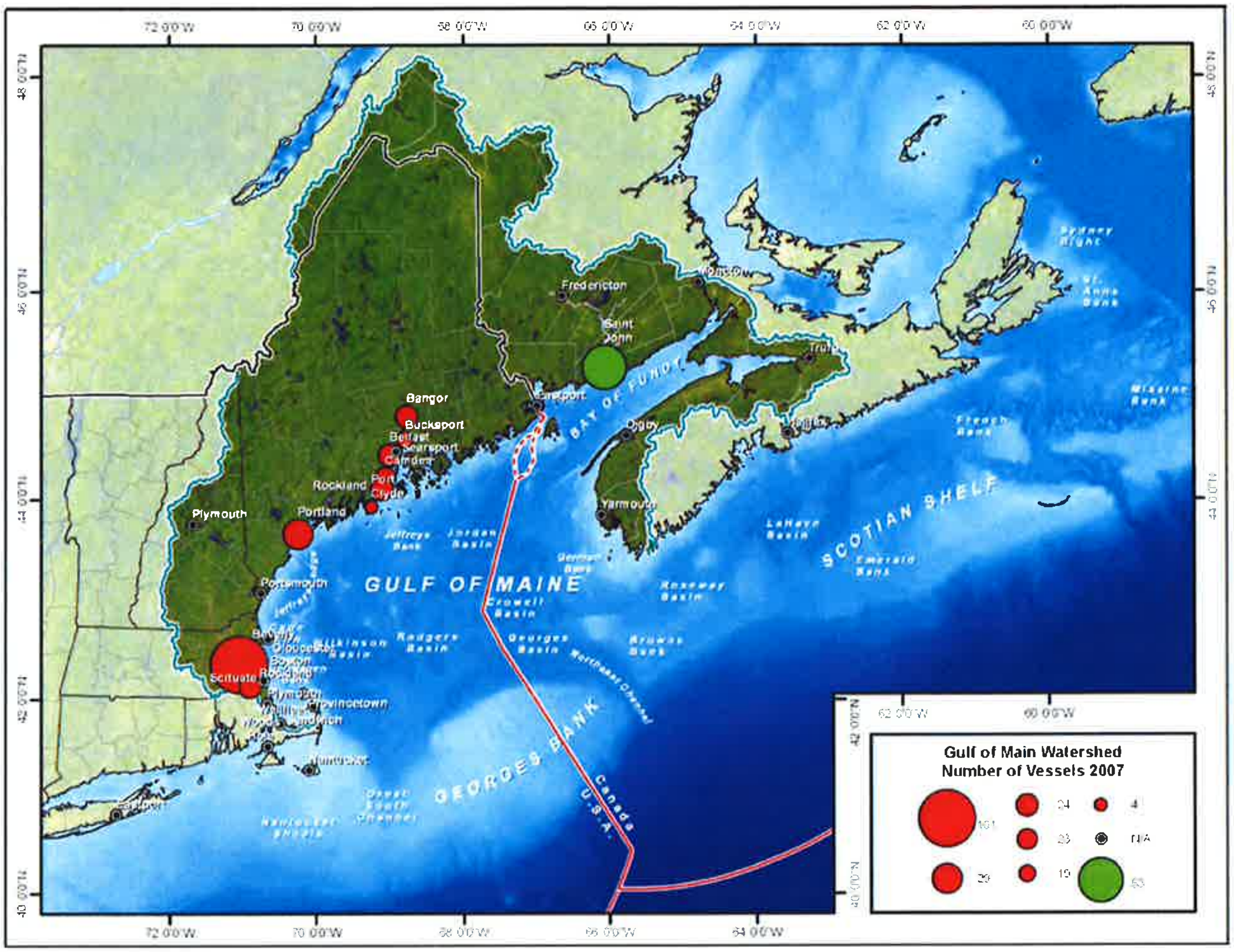


Figure 7: Cruise ship ports and number of vessels docking in the Gulf of Maine in 2008.
Sources: US Army Corps of Engineers/Navigation Data Center 2007; St John Port Authority 2009.



2007. The state ranks eleventh nationally for economic impact from the cruise industry in North America.

In 2008, Maine accounted for more than $29 million in cruise industry direct spending, a 20% increase over 2007 (Maine Port Authority 2009). Maine cruise ship traffic is heaviest in Bar Harbor ME, which experienced 91 ship calls in 2007 and 97 in 2008 (see Table 8 and Figure 7), carrying more than 200,000 passengers. Given its rural charm and close proximity to the Acadia National Park, it has emerged as one of the most popular ports of call along the Maine coast. The port of Portland has seen the most growth in cruise ship passengers. The city hosted an estimated 47,841 cruise ship passengers in 2008, a 45% increase above passengers who visited in 2003 (Gabe and McConnon 2009). Bangor, Belfast, Boothbay Harbor, Bucksport, Camden, and Rockland received a total of 144 ships calls combined.

Energy

From tidal power turbines in Nova Scotia and New Brunswick to proposed offshore wind farms from Maine to Massachusetts, the energy-producing possibilities from the Gulf of Maine have become the focus of state and provincial interest. Three forms of energy have been highlighted in recent years within the Gulf of Maine area. Two of these forms, tidal and wind are renewable and there is great interest in further development. A third, liquefied natural gas, is a traditional use that has the potential for considerable expansion.

Liquified Natural Gas (LNG)

LNG is the liquid form of natural gas, a clear, colourless, non-toxic, liquid composed mainly of methane with small quantities of ethane, propane, and heavier hydrocarbons. Taken out of the ground as natural gas, it is turned into a liquid by being chilled to -162 °C and can be kept at normal atmospheric pressures in specially designed tanks that work on principles similar to a thermos container.

Natural gas is contributing an ever larger share of the energy mix to Gulf of Maine communities for heating homes and generating electricity. There are currently two LNG terminal facilities operating in the region and three have been proposed in the Passamaquoddy Bay area.

Irving Oil and Repsol YPF, SA, an integrated international energy company based in Spain, received approval from the Canadian government in 2006 to jointly construct a terminal in Saint John. Canaport LNG will eventually have a send-out capacity of 30-million cubic metres (one billion cubic feet) of regasified natural gas per day (Canaport 2009). The C$1-billion terminal is the first to be built on the East Coast of North America in 30 years. The first phase of the terminal is operational, and is estimated it will attract double-hull tankers varying in size from 70,000 to 140,000 m3 and vessel traffic into the port will increase by approximately 100 vessels per year (Williams 2007).

Distrigas of Massachusetts LLC owns and operates the only other LNG import and regasification facility in the region, located along the Mystic River in Everett MA (the Everett Marine Terminal). This terminal has been operating longer than any other LNG import terminal in the United States. Between 1971 and 2003, it received approximately half of the LNG imported into the United States. Currently, the Everett Marine Terminal meets approximately 20% of New England's annual gas demand. Also in MA, the Northeast Gateway LNG project is operational and the Neptune LNG project has been constructed and will have received shipments by the time this document is published.

Washington DC-based Downeast LNG plans to develop a terminal in Robbinston, ME. Robbinston residents voted 227 to 83 in favour of the project (Downeast LNG 2009). The proposed terminal is currently going through environmental

New Brunswick. The province of New Brunswick has committed to increasing its generation capacity from renewable resources and as such has required, under the Electricity from Renewable Resources regulation, that NB Power purchase 10% of its sales from new renewable sources by 2016. The provincial government has accelerated this time frame by asking NB Power to move immediately with the addition of an extra 300 MW of wind power in New Brunswick, which would bring the wind power generation capacity to over 400 MW once all projects are completed. There are currently no marine wind farms.

Massachusetts. Energy Management Inc., a Boston-based company, announced its plans in 2001 to construct a wind farm called Cape Wind comprised of 130 turbines located between four and 11 miles off the Cape Cod coast in federal waters. The towers will be 78.6 metres from the water surface to the center of the blades. The blades will reach 146.6 metres above the water. The company says the proposed wind farm would produce an average of 170 MW of electricity. The power would be transported through 12.8 kilometres of transmission cable coming ashore at West Yarmouth, MA. The Cape Wind project was approved by the US Department of the Interior in 2010.

Tidal Power

During the past two decades, tidal energy devices have advanced considerably in design and efficiency. The technology of the moment uses tidal stream generators (in-stream turbines), which do not require damming of rivers or inlets. The moving tide rotates a series of blades, which then spin a generator to produce electricity. Tidal turbines can be arrayed underwater in rows, similar to turbines in a terrestrial wind farm. The key requirement, however, is a strong coastal current running at least four knots.

Maine, New Brunswick, and Nova Scotia all border the Bay of Fundy, through which more than 115 billion tons of water flows each day. The Bay of Fundy tidal range can reach 15.2 m at its eastern edge since the bay is generally U-shaped and tapers significantly near its northern terminus. The incoming tide gains greater strength at it moves inward, resulting in a renowned tidal bore found in the Minas Basin. This is viewed as a perfect source of clean, reusable, alternative energy.

Nova Scotia. The province has committed to draw nearly 20% of its electricity supply from renewable sources by 2013. In 1984, Nova Scotia opened a small plant that took

THE OCEAN ENERGY INSTITUTE

The Ocean Energy Institute, founded by Matthew Simmons, is advocating developing wind power in the Gulf of Maine. Simmons and his partner, physicist George Hart, are proposing a 5 GW wind farm, with five 64 nmi^2 (220 km^2) sections, each containing 200 5-MW turbines. That would generate sufficient power in winter to replace the state of Maine's consumption of home heating oil. According to Simmons, a proponent of peak oil, "If we don't do this, we're going to have to evacuate most of Maine."

As proposed, the turbines would be built on floating platforms, anchored in waters 100–200 m deep - something that has never been done in the US. It will take several years to test the feasibility of such buoyed turbines. (The Hywind wind turbine became the world's first operating large-capacity (2.3 MW) floating wind turbine in the summer of 2009, operating in the North Sea off Norway.) Angus King, a former governor of Maine, is supportive of the idea, "I see this as a huge economic development opportunity for Maine. This thing could create 20,000 to 30,000 jobs." However, others have challenged the project's projected cost, which could reach $25 billion.

Ocean Renewable Power Company, a Miami, Florida firm, worked with students from the Washington County (Maine) Community College Marine Technology Center, and created a turbine generator unit that hangs 300 feet down into the water column from a stationary barge. The $1.2 million device, which can generate 32 KW in a 6-knot tidal current, was completed and installed in December, 2007. It began producing limited electrical power in 2008 and the company predicts the turbines eventually will send 250 KW into the local power grid.

Aquaculture

Aquaculture continues to be the fastest growing sector of the world's fishery. The Food and Agriculture Organization of the United Nations, reports that global marine-based aquaculture production now represents almost 50% of world fisheries production (FAO 2006). Aquaculture production in Canada and the US has dramatically increased in conjunction with global production. Total US aquaculture production is about $1 billion annually, relatively small when compared to world aquaculture production of about $70 billion. About 20% of US aquaculture production is marine species. The largest single sector of the US marine aquaculture industry is molluscan shellfish culture (oysters, clams, mussels), which accounts for about two-thirds of total US marine aquaculture production, followed by salmon (about 25%) and shrimp (about 10%) (NOAA 2009). In Canada, the industry is dominated by the production of finfish, primarily salmon off the coasts of British Columbia and New Brunswick. Gross output by aquaculture producers in Canada for 2007 was approximately 170 thousand metric tonnes valued at C$845.4 million (DFO 2009).

Aquaculture as has been practiced in the Gulf of Maine region for over a century including both finfish and shellfish culture (Brennan 1991). Marine aquaculture as an industry however, is relatively new and dates to the early 1970s. Within the Gulf of Maine, aquaculture was worth $454.9 million in 2007 up from $72.3 million in 1990. These figures do not include New Hampshire, which has had only minimal marine-based aquaculture production. New Brunswick's had the greatest production in the region in 2007 at 48.7 metric tons and a value of C$295.9 million (NB Fisheries and Aquaculture 2007). This was followed by Maine (13.5 million metric tons; $100 million; Maine DMR 2009), Nova Scotia (10.1 million tons; C$53 million; Government of Nova Scotia 2009), and Massachusetts ($6.2 million).

New Brunswick. Since its initiation in the early 1940s for oysters and late 1970s for Atlantic salmon and mussels, aquaculture in New Brunswick has grown dramatically. In 2008 there were two shellfish aquaculture sites (blue mussels, scallop, soft shell clam) and 96 finfish sites. The total aquaculture development area is 1,780.8 ha (0.025% of the Bay of Fundy). Atlantic salmon is still the dominant species raised, accounting for approximately 89% in terms of volume of

DMF reflects only the producers who self-reported.

Industrial Development

Beginning in the late 1700s, the rivers, estuaries and marine waters of this area were used to transport logs, harvest fish and power sawmills. As the population of the region increased and other industries developed, they were used as waste dumps for a wide range of activities including logging operations, sawmills, fish processing plants, private septic systems, municipal sewage plants, pulp mills, agricultural drainage and more recently, aquaculture operations.

Growth in coastal populations around the Gulf of Maine, increased development, and changes in land use have all contributed towards increased contaminant levels in coastal waters in the region. A contaminant is defined as any foreign, undesirable physical, chemical, or biological substance into the environment (Environment Canada 1991) and could include anything from sawdust to nutrients, suspended solids, pesticides, and industrial chemicals. It has been estimated that 100-500 thousand chemicals are now in regular industrial use and most have the potential to enter the marine environment through a variety of sources (Parrett 1998).

Contaminants enter the Gulf of Maine from point sources such as wastewater treatment plants (WWTP) and industries and from non-point sources such as atmospheric deposition (power plants, incinerators and vehicle emissions) and storm water runoff from urban and agricultural areas. Oil refineries, pulp mills, port activities and manufacturing plants release a complex cocktail of heavy metals, chlorinated hydrocarbons, petroleum products and many other chemicals into the Gulf of Maine/Bay of Fundy waters.

FAST FACTS

- There are 2,024 active point source facilities in the region, 273 are major facilities.
- Major point source dischargers are wastewater treatment plants and paper mills.
- There are 378 wastewater treatment plants.
- There are 93 power plants.
- 40% of facilities are located in 2 watersheds in the US – Massachusetts Bay and Merrimack River.
- The Deer Island wasterwater treatment plant is the largest overall discharger in the Gulf of Maine.

TOP TEN POINT SOURCE DISCHARGERS IN THE GULF OF MAINE

Rank	State	Facility
1	MA	Deer Island WWTP
2	ME	Great Northern Paper, Inc.
3	MA	Greater Lawrence WWTP
4	ME	SAPPI Fine Paper North America
5	MA	South Essex WWTP
6	ME	Mead Oxford Paper
7	NH	Manchester WWTP
8	MA	Lowell WWTP
9	ME	Fraser Paper Limited
10	MA	Lynn Regional WWTP

Source: Hameedi et al. 2002

Generally, five major types of sediment contaminants are recognized. Directly or indirectly they cause a wide range of adverse biological effects in plants, animals, and people, through direct chemical toxicity, genotoxicity, physiological dysfunction, behavioural abnormalities and habitat disruption and destruction. Contaminants include:

- Bulk organics, including organic wastes from sewage treatment plants, oil and grease, other deoxygenating substances, and humic materials.

In the largest urban area, Saint John, only 58% of the population's sewage is treated; the remainder is discharged raw. Smaller communities including St Stephen, St George, Blacks Harbour, and Alma have systems in need of upgrading.

In Nova Scotia, Parrsboro and Amherst are discharging untreated sewage. In rural areas, people utilize on-site septic systems that, if inadequately maintained or poorly designed, also contribute to coastal contamination. The result is that as the density of coastal development increases, there is an increase of contamination in many bays and estuaries that impact shellfish growing areas and opportunities for recreation (Hinch 2002).

Seven hundred square kilometres of the Canadian portion of the Gulf of Maine are closed to shellfish harvesting due to bacteriological contamination. This includes some of the most productive shellfish areas in the region.

New Hampshire has a small Gulf of Maine coastline, however about two-thirds of the state is a watershed that drains into the Gulf of Maine. Discharges of untreated sewage from a straight pipe or municipal outfall are not permitted. All communities have secondary treatment except for Portsmouth, which has a waiver allowing a super primary treatment plant. Fifteen percent of the population is on municipal systems and most treatment plants are government owned. The largest city is Manchester, with just over 100,000 people has a 34 million gal/day treatment plant. There are about 110 small municipal treatment systems (Hinch 2002).

Massachusetts has about 60 major wastewater treatment facilities that are permitted for surface water discharges. Minor discharges are designated more on flow than on impact. Groundwater discharge permits are handled under state authority. Any discharge in excess of 15,000 gal/day requires a permit, whereas anything below 15,000 gal/day can be handled under State Sanitary Code Title 5 Septic System Regulations (Hinch 2002).

Nutrients

Nutrients are substances that organisms require from their environment because they cannot make the substances themselves. Nutrients can become pollutants when they are too abundant. Over-enrichment of water with nutrients, that otherwise limit plant growth, can cause too much plant growth and have deleterious effects on the environment. The nutrients of most

GULF OF MAINE CONTAMINANT MONITORING PROGRAMS

Gulf of Maine-wide programs

- Gulfwatch, Mercury Deposition Network
- Gulf of Maine Ocean Observing System

Canadian programs

- Canadian Shellfish Sanitation Program (CSSP)/Maritime SSP
- Atlantic Coastal Action Program
- Dredged Material Ocean Disposal Site
- Biotoxin Monitoring Program
- Moosehead Maritimes Beach Sweep and Litter Survey
- Toxic Chemicals in Canadian Seabirds

US programs

- National SSP/state SSPs, National Estuary Program
- National Estuarine Research Reserves-System Monitoring
- Disposal Area Monitoring System
- National Marine Debris Monitoring
- NOAA National Benthic Surveillance
- Bioeffects Studies & Mussel Watch projects
- EPA Environmental Monitoring and Assessment Program
- National Coastal Assessment Program, Ambient Air & National Atmospheric Deposition Program
- National Water Quality Assessment Program
- Toxic Contaminants in Tissue of Seals in the Gulf of Maine

Source: RARGOM Symposium 2003

4. Environmental Management in the Gulf of Maine

THIS SECTION FOCUSES ON THE WORK OF THE GULF OF MAINE COUNCIL as well as highlighting some important transboundary initiatives between Canada and the US. A detailed overview of the governance of the area can be found in *Overview of Current Governance in the Bay of Fundy/Gulf of Maine: Transboundary Collaborative Arrangements and Initiatives* (DFO 2006).

4.1 THE GULF OF MAINE COUNCIL ON THE MARINE ENVIRONMENT

By the late 1980s, growing evidence of declining water quality, resource degradation, and user conflicts in the Gulf of Maine emphasised the need for a more cooperative, management approach to address these issues. In December 1989, after the region's Premiers and Governors formed the Gulf of Maine Council on the Marine Environment, planners and resource managers from the region formed the Gulf of Maine Working Group. The Working Group was convened for two primary purposes, to facilitate and improve communication among the jurisdictions on Gulf topics and to compile a set of recommendations for the sustainable management of the Gulf ecosystem.

Gulf of Maine Council on the Marine Environment

In 1989 representatives from numerous provincial, state and federal agencies, along with members from academia, the scientific community, and the public, met to discuss suggestions for an action plan for the Gulf of Maine, which resulted in the region's Premiers and Governors signing an Agreement on the Conservation of the Marine Environment of the Gulf of Maine. Under the terms of the Agreement, the parties pledged to establish the Gulf of Maine Council on the Marine Environment. Among the topics to be addressed by the Council were ecosystem protection, pollution, sustainable resource use and the development of cooperative management programmes. The Council was also tasked with the preparation of an Action Plan, which would set out environmental trends and conditions and provide specific recommendations.

The Gulf of Maine Council functions as a regional forum for exchanging information and engaging in long-term planning. The Gulf of Maine council was established by the Premiers of Nova Scotia, New Brunswick and the Governors of Maine, New Hampshire, and Massachusetts. The Council's mission statement is "to maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations". Councilors meet twice a year to set objectives, convene partnerships, and marshal the resources necessary to implement the Action Plan. To achieve these goals, the Council partners with government agencies, environmental organisations, researchers, businesses and the public to sponsor research, implementation, and education initiatives throughout the Gulf of Maine. Currently, each Governor or Premier appoints two senior level government representatives and two non-profit or business sector representatives to serve on the Council. Since 1992, Canadian and US

Climate Change Program

The Climate Change Committee was one of three regional air initiatives developed by the New England Governors and Eastern Canadian Premiers (NEG/ECP). An action plan was drafted in 2001 that recognised the human influence on climate change and the benefits of reducing emissions. A steering committee was established to oversee the implementation of the plan which identified short, medium and long-term goals for the reduction of GHG emissions in the region:

- Short-term goal: Reduce regional GHG emissions to 1990 emissions by 2010.
- Medium-term goal: Reduce GHG emission by at least 10% below 1990 emissions by 2020.
- Long-term goal: Reduce regional emissions sufficiently to eliminate any dangerous threat to the climate (estimated to require reductions of 75-85% below current levels).

Specific actions were then identified in four general categories to help achieve these goals. Actions identified included standardised emissions inventories and a regional emissions registry; the need to anticipate and avoid negative social, economic and environmental impacts of climate change; education and outreach; and regional plans for reducing green house gas (GHG) emissions and conserving energy. States and provinces have committed to taking measures to reduce GHG emissions. Within the electricity sector, the parties have agreed to reduce CO2 emissions per unit of power by 20% by 2025. In addition, there is a general commitment to reduce energy demand by the year 2025 by 20% through efficiency and conservation.

Fisheries Management

In 1970 Canada and the US extended their respective offshore jurisdictions to 200 nautical miles and the Gulf of Maine became the exclusive domain of Canadian and US fisheries. Problems emerged in the region of Georges Bank when the two countries' claims overlapped. The disputed area was home to several transboundary commercial species such as cod, haddock, and scallops. In 1984 the International Court of Justice established the Hague Line as the international boundary between the two countries in the Gulf of Maine. Following the court's decision, fishing by the two countries was confined to their respective jurisdictions. However, the problem of managing transboundary fisheries resources in the region remained and co-operative management was virtually non-existent. Increased fishing efforts led to the overexploitation of the transboundary groundfish stocks that migrated back and forth between the countries.

In 1984, The Gulf of Maine Advisory Committee (GOMAC) was established by Fisheries and Oceans Canada (DFO) to serve as a government-industry forum for discussing the management of fish stocks in the Gulf of Maine. GOMAC provides shared among DFO, the Canadian Food Inspection Agency, and Environment Canada. The Canada-US Shellfish Agreement of 1948 remains the foundation for the respective shellfish sanitation programs of the two countries.

The Gulf of Maine Council on the Marine Environment administers Gulfwatch, a chemical contaminants monitoring program. Scientists from agencies and universities around the Gulf of Maine analyze tissue from *Mytilus edulis* (blue mussels) to measure the type and concentration of contaminants in the coastal marine environment. Both Canadian and US authorities have used Gulfwatch data in making sanitary survey reports to determine whether it is safe to harvest shellfish from an area. A similar nationwide initiative is the US NOAA's National Status and Trends Mussel Watch program, the longest chemical contaminant monitoring program in US coastal waters.

Species At Risk

Endangered species habitats overlap the Canadian and US borders, which creates several transboundary issues such as commercial fisheries and environmental contamination that may affect species' recoveries. Collaboration, therefore, between Canada and the US in research and recovery is important in order to conserve the species and their habitat. A Species at Risk Working Group was formed in 2003 to address interactions between fisheries and the North Atlantic right whale. In 2006 its mandate was expanded to discuss broader transboundary species at risk issues.

- **The Leatherback Turtle** - is listed as "endangered" by the Species at Risk Act (SARA/Canada) the Endangered Species Act (ESA/US). A number of transboundary issues face turtles, including environmental degradation, contamination, accidental capture and entanglement from fishery operations. Canada and the US work co-operatively to identify and address these threats and both participate in the Annual Symposia on Sea Turtle Conservation and Biology hosted by the National Marine Fisheries Service.
- **The North Atlantic Right Whale** – is listed as "endangered" under SARA and ESA. The Bay of Fundy and Gulf of Maine represent the primary foraging ground for the whales. All threats are, therefore, transboundary issues, and include, collisions with commercial vessels, entanglements with fishing gear, disturbance from human activity, and habitat degradation. The North Atlantic Right Whale is an organization made up of governmental, NGO's and individuals from both countries who work to study and conserve North Atlantic Right Whales.
- **Atlantic Salmon** – is listed as endangered under SARA and ESA. Common marine habitat in Canadian and US waters creates similar concerns over threats to Atlantic salmon survival. Canada and the US are contracting parties to the Convention for the Conservation of Salmon in

- **Gulf of Maine Science Translation Project** facilitates the transfer of scientific findings and techniques.
- **Gulfwatch Monitoring Program,** a bi-national program that assesses the fate and impacts of toxic contaminants in the Gulf of Maine by measuring contaminant concentrations in blue mussels

Scientists from across the region have longstanding collaborative research programs and initiatives in the Gulf of Maine in support of conservation for migratory and resident aquatic birds. Current collaborative scientific initiatives include research on distribution and numbers of phalaropes in the Bay of Fundy and Gulf of Maine with support from the Canadian Wildlife Service (CWS) and US Fish and Wildlife Service (FWS). Collaborative scientific programs on foraging ecology of shorebirds and monitoring of shorebird migrations are also conducted through CWS and FWS and the Manomet Center for Conservation Studies. Other initiatives include the Regional Association for Research in the Gulf of Maine and the Northeast Coastal and Ocean Data Partnership. These collaborative programs throughout the migratory and foraging range of aquatic bird species allow scientists to quantify why certain areas and habitats are important for species and facilitate designation of specific sites for conservation purposes.

5. In Conclusion

The Gulf of Maine in Context gives a brief overview of the region by providing some baseline knowledge of the biophysical, social and economic environment in the Gulf and its watershed. It is intended as a useful resource for a broad-based audience, as well as a providing context for the more in-depth discussion in the theme papers. Readers interested in finding out more about the issues facing us in the Gulf of Maine are encouraged to read the theme papers at: www.gulfofmaine.org/stateofthegulf.

Harvey J, Mann K, Podolsky R and Conkling PW. 1995. The Thin Edge Between Land and Sea. Pages 121-143 In PW Conkling, ed., From Cape Cod to the Bay of Fundy: An Environmental Atlas of the Gulf of Maine. MIT Press, Cambridge, MA.

Heymans J. 2001. "The Gulf of Maine, 1977–1986", in S Guénette, V Christensen and D Pauly (eds) Fisheries Impacts on North Atlantic Ecosystems: Models and analyses, Fisheries Centre Research Reports 9(4), pp 128-150

Hinch PS. 2002. Sewage Management in the Gulf of Maine: Workshop Proceedings. Gulf of Maine Council on the Marine Environment www.gulfofmaine.org.

Huettmann F and Diamond AW. 2000. Seabird migration in the Canadian northwest Atlantic Ocean: Moulting locations and movement patterns of immature birds. Canadian Journal of Zoology 78: 624-647.

Institute for New Hampshire Studies. 2006. New Hampshire Tourism Data. www.plymouth.edu/inhs/index.html (accessed November 2009).

International Ice Patrol. 2009. International Ice Patrol (IIP) Frequently Asked Questions, United States Coast Guard, http://www.uscg-iip.org/FAQ/FAQ_Ocean.shtml (accessed 4 December 2009).

International Oceanographic Commission. 2006. http://ioc-unesco.org/ (accessed December 2009).

Kelley JT. 1987. An inventory of coastal environments and classification of Maine's glaciated shoreline. In: DM Fitzgerald and PPS Rosen (eds), Glaciated Coasts, Academic Press, San Diego, pp 151-175.

Kelley JT and Belknap DF. 1991. Physiography, surficial sediments and Quaternary stratigraphy of the inner Continental Shelf and nearshore region of the Gulf of Maine. Continental Shelf Research, 11:1265-1283.

Longwoods International. 2003. Travel and Tourism in Maine. The 2003 Visitor Study Managment Report .

Mahon R, Brown SK, Zwanenburg KTC, Atkinson DB, Buja KR, Claflin L, Howell GD, Monaco ME, O'Boyle RN and Sinclair M. 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. Can. J. Fish. Aquat. Sci. 55:1704-1738.

Maine Department of Environmental Protection. 2005. Bureau of Air Quality. Air Emissions from Marine Vessels. Report to the Joint Standing Committee on Natural Resource.

Maine Office of Tourism. 2006. Tap Into Tourism. Resource Guide, Workshop March 17 .

Maine Port Authority. 2009. http://maineports.com/key-links.html. Website accessed October 2009.

Mandale M, Foster ME and Chaisson PY. 2000. The Economic Value of Marine-related Resources in New Brunswick. New brunswick Department of Fisheries and Oceans.

Massachusetts Division of Marine Fisheries. 2009. Recreational Fishing. www.mass.gov/dmf/recreationalfishing (accessed October 2009).

Massachusetts Office of Travel and Tourism. 2007. The Economic Impact of Travel on Massachusetts Counties 2006. http://www.massvacation.com/research/ec_imp_hist06.pdf (accessed November 2009).

Massachusetts Port Authority. 2009. Port of Boston. http://www.massport.com/ports (accessed October 2009).

Massvacation. 2009. http://www.massvacation.com/research/ (accessed October 2009).

McInnis Leek, N. 2004. Nova Scotia Department of Natural Resources, July 2004, personal communication.

Mills, KE. 2006. A Strategy for Gulf of Maine Ecosystem Indicators and State of the Environment Reporting. Gulf of Maine Council on the Marine Environment. http://www.gulfofmaine.org/esip/docs/esipstrategy.pdf (accessed February 2009). vi + 56 pp.

New Brunswick Fisheries and Aquaculture. 2007. 2007 Aquaculture Sector Overview. Government of New Brunswick, Fredericton. http://www.gnb.ca/0168/30/ReviewAquaculture2007.pdf (accessed November 2009).

New Brunswick Parks and Tourism. 2006. New Brunswick Tourism Development Guidelines. Government of New Brunswick, Fredericton.

National Oceanic and Atmospheric Administration (NOAA). 2006. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2005, NOAA Technical Memorandum NMFS-NE-194.

National Oceanic and Atmospheric Administration (NOAA). 2009. Fisheries Statistics Division. http://www.st.nmfs.noaa.gov/st1/commercial/index.html (accessed November 2009).

Nova Scotia Department of Fisheries and Aquaculture. Aquaculture Statistics. http://www.gov.ns.ca/fish/aquaculture/stats/index.shtml (accessed November 2009).

Overholtz WJ and Link JS. 2006. Consumption impacts by marine mammals, fish, and seabirds on the Gulf of Maine–Georges Bank Atlantic herring (Clupea harengus) complex during the years 1977–2002. ICES Journal of Marine Science 64: 1-14.

Parker M. 2009. Gulf of Maine Ecosystem Overview Report. Department of Fisheries and Oceans Canada, Dartmouth NS.

Parrett A. 1998. Pollution Impacts on North Sea Fish Stocks. Prepared on behalf of the European Commission DG XIV - Fisheries. World Wildlife Fund–UK, Surrey, England. 122 pp.

Pesch G and Wells P. 2004. Tides of Change Across the Gulf: An Environmental Report on the Gulf of Maine and Bay of Fundy. Gulf of Maine Council on the Marine Environment and Global Programme of Action Coalition for the Gulf of Maine. 81 pp.

Gulf of Maine Association
In support of the Gulf of Maine Council on the Marine Environment

CLIMATE CHANGE

Our Changing Climate

Climate change, or the altering of long-term weather patterns, is already happening and represents one of the greatest environmental threats facing the planet. The Fourth Assessment Report (2007) of the Intergovernmental Panel on Climate Change (IPCC) shows that the Earth's average surface temperature has risen by 0.76 °C since 1850. The northern hemisphere is substantially warmer than at any point during the past 1,000 years. Most of the warming over the past 50 years is very likely to have been caused by emissions of carbon dioxide (CO2) and other 'greenhouse gases' from human activities. Today's atmosphere contains 32 per cent more carbon dioxide than it did at the start of the industrial era. Levels of methane and carbon dioxide are the highest they have been in nearly half a million years.

Global temperatures are predicted to continue rising. Without action to reduce emissions, the global average temperature is likely to rise by a further 1.8 – 4.0 °C this century. This will cause changes in weather patterns, rising sea levels and increased frequency and intensity of extreme weather events such as storms, floods, droughts and heat waves. Such climatic events can have major social and economic impacts including on households, businesses, critical infrastructure (transport, energy and water supply), and vulnerable people (elderly, disabled, poor income households), as well as having an impact on ecosystems and biota.

The Gulf of Maine Council recognizes the importance of climate change to the Gulf of

CLIMATE CHANGE AND ITS EFFECTS ON ECOSYSTEMS, HABITATS AND BIOTA

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2010

1. Issue in Brief

THE EARTH'S CLIMATE IS CHANGING AS A RESULT OF INCREASING ANTHROPOGENIC emissions of greenhouse gases (GHGs; IPCC 2007a,b). Globally, the atmosphere and the oceans are warming. Atmospheric warming and melting of sea ice are altering the physical oceanography of the Gulf of Maine, while higher levels of atmospheric carbon dioxide (CO_2) may alter ocean chemistry, all of which will have effects on the ecosystem. Pressures on the aquatic environment as a result of atmospheric warming include increases in water temperature, decreases in salinity and changes in hydrography (Figure 1). Sea level rise is also an important pressure on coastal habitats and ecosystems. These pressures interact with each other and with additional pressures that are unrelated to climate change. These physical pressures may have negative impacts on some species within the Gulf of Maine, but may enhance the productivity of other species. Because the responses to these pressures will vary by species, the overall ecosystem will likely look profoundly different in the future as compared to the current ecosystem structure and species assemblage of the Gulf of Maine. Our ability to adapt to these changes will depend largely on measures taken to mitigate the ecosystem effects of climate change.

LINKAGES

This theme paper also links to the following theme papers:

- Climate Change and Its Effects on Humans
- Land Use and Coastal Development
- Watershed Status
- Coastal Ecosystems and Habitats

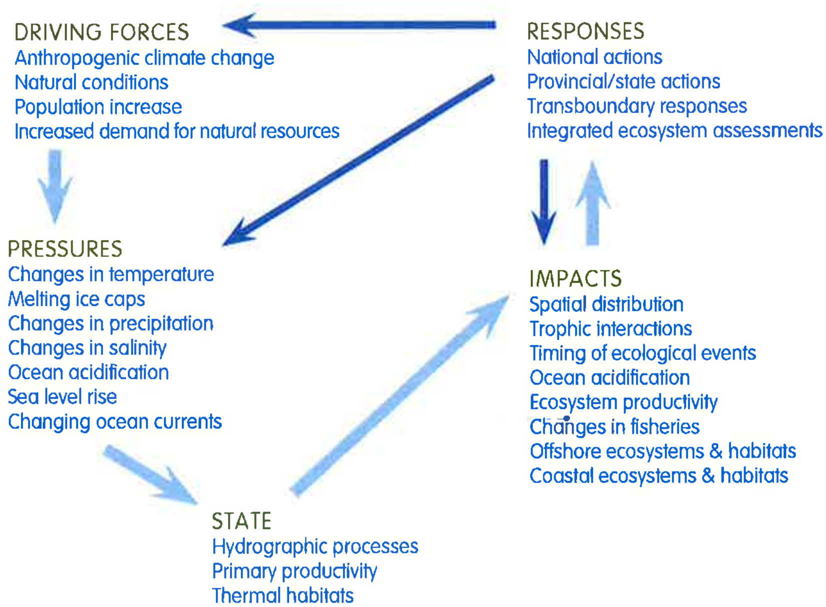


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to climate change and its effects on ecosystems in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments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

of Maine water temperatures decrease and WSW is displaced southward. Water that originates from the cold Labrador Current enters the Gulf of Maine and circulates in a counter-clockwise direction. When the Labrador Current is weak, more warm water from the Gulf Stream enters the Gulf of Maine.

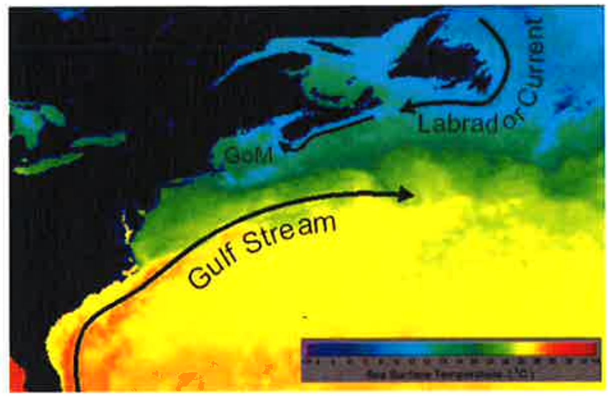


Figure 2: Satellite imagery of sea surface temperature and the location of the Gulf Stream, Labrador Current, and Gulf of Maine (GoM).
Source: SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE, http://oceancolor.gsfc.noaa.gov

Increasing temperatures due to anthropogenic climate change may be exacerbated by natural climate cycles in the Atlantic Multidecadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). The AMO is a natural cycle in North Atlantic sea surface temperature that fluctuates from warm positive phases and cold negative phases every few decades. Currently we are in a positive AMO phase, perhaps exacerbating the warming trend. However, as we enter a negative AMO phase in the next decade, it may offset some of the effects of global warming. The NAO fluctuates on a shorter time scale than the AMO, but in recent years has also been consistently in a positive phase that is synergistic with climate warming trends. Scientists are still studying how natural cycles like the NAO and AMO interact with anthropogenic climate change and how these natural phenomena and hydrography might change with increasing greenhouse gas emissions.

2.4 Sea Temperature

Since the peak of the last ice age, about 20,000 years ago, the global mean air temperature has risen 4°C to 7°C, leading to an increase in sea surface temperatures (SST) in most of the world's oceans (IPCC 2007b). The rate of increase of coastal sea surface temperatures in the Gulf of Maine is similar to the rise in global mean SST of about 0.7°C over the last century (Trenberth et al. 2007; Shearman 2010). However, the rate of increase has accelerated in recent years and regional studies indicate that sea surface temperatures in this region have increased by about 0.23°C from 1982 to 2006 (Belkin 2009). While there is variability in temperatures from year to year, coastal temperatures have increased steadily over the last 40 years, but are not necessarily higher than they were in the 1950s (Figure 3). Climate scenarios examined by the Intergovernmental Panel on Climate Change (IPCC 2007b) project a global mean temperature increase of 1.1°C to 6.4°C by 2100. Global climate models predict an increase in temperature in the Gulf of Maine and surrounding regions by 2°C to 4°C by 2080 (Fogarty et al. 2007a).

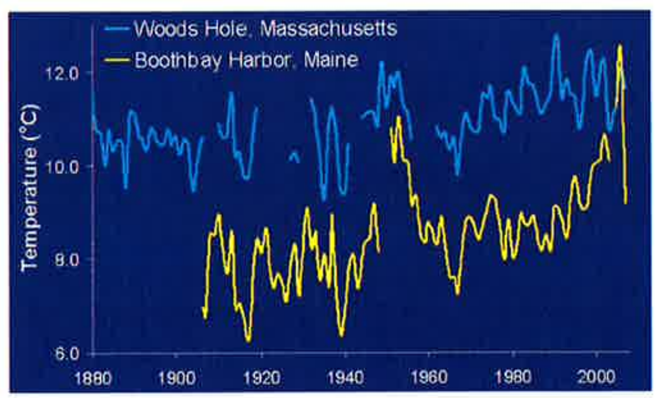


Figure 3: Coastal water temperature taken from two harbors within the Gulf of Maine region.

21st century by IPCC (2007b), excluding future rapid dynamical changes in ice flow, range from 18 cm to 59 cm by 2100. More recent projections (Rhamstorf 2007) estimate that a global mean sea level rise of up to 120 cm by 2100 could occur for strong warming scenarios. Relative sea level rise in the Gulf of Maine is due to the combined effect of an increased global mean sea level, and the additional effect of regional subsidence of the Earth's crust. The subsidence is a manifestation of the crust's long-term response to the end of the last ice age, referred to as 'glacial isostatic adjustment' (Leys 2009). In the Gulf of Maine, subsidence rates are not uniform and are estimated to be from 0 cm to 20 cm/century (Peltier 2004).

The effects of sea level rise are exacerbated by storm surge from storm events. The storm surge is the height difference between the water level due to astronomical tides and the total water level at the peak of the storm. It is due to storm winds piling water onshore, low atmospheric pressure, wave setup, possible resonant effects within a bay and the coastal response to all these factors (Parkes et al. 1997). A rise in sea level would allow storm surges to reach further inland. Climate change could cause an increase in the intensity of storms in the northern hemisphere, as well as a possible northward shift of storm tracks (McCabe et al. 2001; Wang et al. 2006).

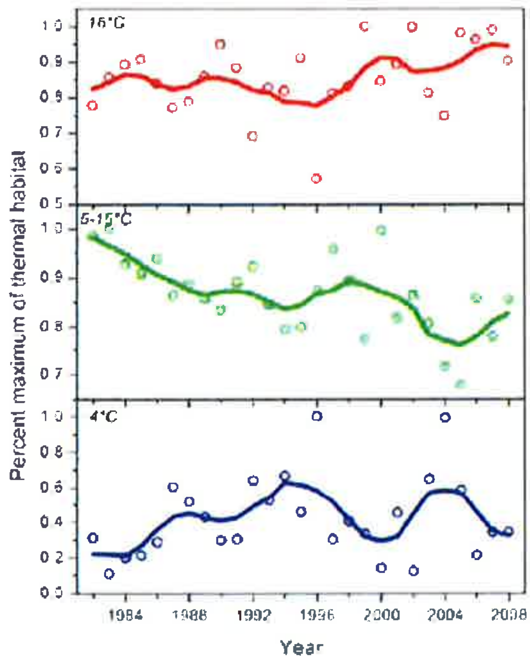


Figure 6: Change in thermal habitat along the US Northeast coast over time.
Source: www.nefsc.noaa.gov/omes/OMES

3.3 Primary Productivity

Phytoplankton form the basis of the Gulf of Maine food web, and any effects of climate change on primary productivity will have effects on all aspects of the food web. The effect of climate change on primary productivity will depend on how temperature, salinity, and hydrography changes in each region. Limited analysis in the Northeast region suggests that there has been an increase in primary productivity in the region from 1958–2002, but there has been a shift in phytoplankton species from large diatoms to small dinoflagellates (Leterme et al. 2005). There may also have been a change in the timing of the occurrence of different phytoplankton species. Diatoms have increased in January and March, but dinoflagellates have increased in spring. Recent analysis has shown that the nutrient regime in the Gulf of Maine has changed since the 1970s. Deep water in the Gulf of Maine has become fresher, cooler, and has lower nitrate and higher silicate concentrations (Townsend et al. 2010). These changes are caused by accelerated rate of melting of the Arctic ice sheet and a freshening of the Labrador Current that enters the Gulf of Maine. How this change will alter the phytoplankton community is uncertain, but in general higher silicate favors diatom production. Diatoms are thought to increase overall ecosystem productivity because of their relatively large size in comparison to small dinoflagellates.

this species is a common and abundant member of the phytoplankton community in the North Atlantic and has extended its range southward. While this species has not reached the Gulf of Maine, southward expansion of cold-water species is expected because of increased flow of the Labrador Current and a lack of obstruction by sea ice. In the Northwest Atlantic boreal plankton have shifted farther south (Johns et al. 2001; Reid and Beaugrand 2002; Reid et al. 2007), but in the Northeast Atlantic subtropical and temperature plankton are shifting further north by as much as 1000 km (Beaugrand et al. 2002). Because the Gulf of Maine is at the edge of boreal and temperate ecosystems, there could be both northward shifts of temperate species and southward shifts of Arctic.

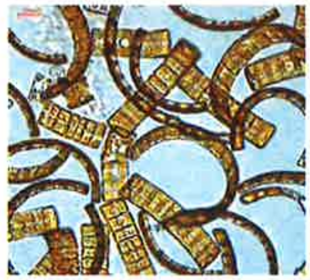


Figure 8: A Pacific Ocean phytoplankton species, *Neodenticula seminae*, now found thriving in North Atlantic waters.

4.2 Changes in Community Assemblages

Changes in salinity have changed phytoplankton and zooplankton assemblages in the Gulf of Maine region in the 1990s. Phytoplankton production increased and was followed by an increase in the number of small zooplankton (Kane and Prezioso 2008; Greene and Pershing 2007). *Calanus finmarchicus* is a relatively large phytoplankton and because it has large stores of energy-rich lipids it is a major food item of many fish species and the primary food source of the endangered right whale. The biomass of small *Calanus finmarchicus* increased in recent years, but larger *Calanus finmarchicus* did not. In general, the zooplankton assemblage has changed from large zooplankton to smaller zooplankton (Kane and Prezioso 2008; Ecosystem Assessment Program 2009). A shift to a smaller zooplankton community structure may have important consequences to animals at higher trophic levels. These animals must now consume greater numbers of phytoplankton and perhaps forage for longer periods of time to meet their energetic demands. Furthermore, the arrival of right whales and their reproductive success is dependent on the abundance and distribution of *Calanus finmarchicus* in the Gulf of Maine (Pershing et al. 2009). Changes in the magnitude and timing of the peak abundance of this species may alter whale migration, behavior, and population abundance.

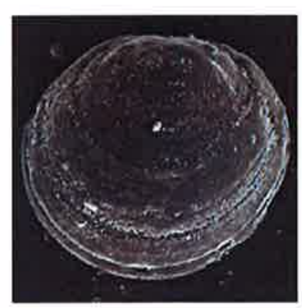
The fish and invertebrate assemblage has changed along the Northeast US coast such that the Gulf of Maine looks more similar to what southern ecoregions looked like in the past. In the Gulf of Maine and along the Northeast US coast, there has been a shift in dominance by more "cold-water" species to more "warm-water" species. Warm-water species are more abundant and/or have shifted their distribution northward into northern ecosystems, including the Gulf of Maine time periods (Parmesan and Yohe 2003). Locally, studies have detected changes in the arrival of some bird species in Maine (Wilson Jr. 2007, 2009) and that Northeast US apples and grapes bloom earlier on average in the time period from 1965-2001 (Wolfe et al. 2004). In the northern shrimp, egg development and hatching times are tightly correlated with local bottom water temperatures such that young shrimp hatch at times when food is available (Koeller et al. 2009). While there appears to be a match between bottom temperature, hatching times, and food availability that enhances the survival of young shrimp, surface water temperatures are increasing more rapidly than bottom water temperatures. If this trend continues, there may be a mismatch between hatching time of shrimp (dependent on bottom temperature) and their prey (dependent on sea surface temperature), creating a mismatch that would lead to poor shrimp recruitment. This would have negative effects for the predators that rely on shrimp for food and to commercial fishing of this species.

4.4 Ocean Acidification

Few time series exist to document the change in ocean pH over time and much controversy surrounds those time series of pH measurements that do exist. There are several possible responses of organisms to ocean acidification, but the most direct threat would be that marine "calcifiers" or "animals with shells" may not be able to make the hard calcified shells to protect them from predators. Secondly, a change in pH may have metabolic costs such that growth decreases. A decrease in growth of marine calcifiers like American lobster, ocean quahog, and scallops mean less shell meat to sell and to eat. Several recent studies have started to elucidate the ways in which ocean acidification may affect organisms and ecosystems. An analysis of eighteen marine calcifiers showed that the response to acidic waters is different for each species (Ries et al. 2009). In fact, some species like the blue crab and American lobster may respond favourably to acidification. However, most organisms responded unfavourably with increasing acidity, particularly bivalve species that constitute important commercial fisheries such as American oyster, soft shell clams, and ocean quahog. Studies have documented a decrease in calcification (or a softening) of shells, decreases in growth, and increases in mortality in marine species (Green et al. 2009; Findlay et al. 2010). The pictures at right (Figure 10) show the dissolution of the shells of juvenile hard clams (*Merceneria mercenaria*) after 7 days in sediments just slightly more acidic than their typical environment today (Green et al. 2009).

Day 0

Day 4



Day 7

Figure 10: Dissolution of hard clam shells (*Merceneria merceneria*) after 7 days in water just slightly more acidic than "average" sediment pH. Note jagged surfaces and pitting in the shell at Day 4 and 7 as compared to Day 0. Modified from Green et al. 2009

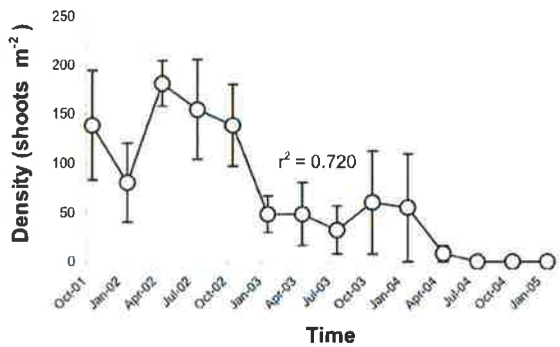


Figure 11: Changes in density of shoots in a New Hampshire seagrass habitat.
Source: Frederick Short, University of New Hampshire, pers. comm., 2010

al. 2008). Species invasions by opportunistic species are more common when overfishing occurs in a warming environment (Harris and Tyrell 2001; see theme paper on *Invasive Species*).

4.6 Changes in Fisheries Productivity

Global climate models predict overall declines in catch potential of marine fisheries in the Gulf of Maine region. Projections in the year 2055 range from decreases as low as 5% if 2000 level emissions were maintained to as high as 30% in high emissions scenarios (Cheung et al. 2009). The relative abundance of Atlantic cod is expected to decrease in the Gulf of Maine (Cheung et al. 2008). Warmer temperatures in the Gulf of Maine will positively influence the growth of adult cod, but will negatively impact survival of cod in early life stages (Fogarty et al. 2007b). These temperature-mediated effects will result in a loss of yield for this species.

5.2 Monitoring and Research

To detect changes in the ecosystem at the large temporal and spatial scale at which global climate change is occurring, monitoring must be coordinated between local, state, and national organizations in the region. The Gulf of Maine is monitored and managed by the states of Maine, New Hampshire, and Massachusetts and by both US and Canadian federal agencies. While there are many sources of data to detect changes in temperature, salinity, and precipitation, few time series exist to detect changes in acidity or changes in timing of ecological events. Many fish stocks have been assessed and managed by the US and Canada jointly since 1998 (http://www.mar.dfo-mpo.gc.ca/science/TRAC/TRAC.HTML).

Data on oceanography, the abundance and distribution of phytoplankton, zooplankton, macroinvertebrates, fish, and marine mammals are collected by Fisheries and Oceans Canada (DFO) and the US National Marine Fisheries Service (NMFS). However, the timing of these surveys and the methods used to collect biological samples are different, making it difficult to combine data collected in different survey programs within the Gulf of Maine. Efforts to combine data from Canadian DFO surveys with US NMFS surveys are ongoing (Nye et al. 2010; Shackell et al. in review). These efforts to compare data amongst surveys will be important to detect changes in spatial distribution of marine species and to predict the rate of species invasions into adjacent areas (Blanchard et al. 2007). These data can then be used in ecosystem level models to predict the effects of climate change on marine and coastal habitats and potentially to evaluate the effects of different management scenarios.

The Gulf of Maine Council on the Marine Environment established the Climate Change Network Task Force in 2003 to develop climate change indicators for the Gulf of Maine. This task force identified key indicators for the Gulf of Maine and surrounding areas (Wake et al. 2006). Similar efforts are in place to monitor changes in the marine ecosystem using US data (http://www.nefsc.noaa.gov/omes/OMES/) and a joint effort between the US and Canada to develop Integrated Ecosystem Assessments (IEA) began in April 2010 with the initiation of a Working Group on the Northwest Atlantic Regional Sea. Part of the IEA process will include risk analysis of the effects of climate change (and other factors) and provide multiple potential management scenarios.

6. References

Beaugrand G, Reid PC, Frederic I, Lindley JA and Edwards M. 2002. Reorganization of North Atlantic Marine copepod biodiversity and climate. Science 296: 1692-1694.

Belkin IM. 2009. Rapid warming of Large Marine Ecosystems. Progress in Oceanography 81: 207-213.

Blanchard JL, Maxwell DL and Jennings S (2007) Power of monitoring surveys to detect abundance trends in depleted populations: the effects of density-dependent habitat use, patchiness, and climate change. ICES Journal of Marine Science 65:111-120.

Brewer PG. 1997. Ocean chemistry of the fossil fuel CO_2 signal: The halie signal of "business as usual". Geophysical Research Letters 24 (11): 1367-1369.

Cheung WWL, Lam VWY and Pauly D. 2008. Modelling present and climate-shifted distribution of marine fishes and invertebrates. Fisheries Centre Research Reports, Vancouver, BC, Canada.

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Zeller D and Pauly D. 2009. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology 16:24-35.

City of Keene. 2004. Keene, New Hampshire, climate adaptation action plan summary report. ICLEI-Local governments for sustainability, Keene, NH.

Collie JS, Wood AD and Jeffries HP. 2008. Long-term shifts in the species composition of a coastal fish community. Canadian Journal of Fisheries and Aquatic Sciences 65: 1352-1365.

Ecosystem Assessment Program. 2009. Ecosystem Assessment Report for the Northeast US Continental Shelf Large Marine Ecosystem. Report No. 09-11, US Department of Commerce, Northeast Fisheries Science Center Reference Document, Woods Hole, MA.

Findlay HS, Kendall MA, Spicer JI and Widdicombe S. 2010. Relative influences of ocean acidification and temperature on intertidal barnacle post-larvae at the northern edge of their geographic distribution. Estuarine, Coastal and Shelf Science 86: 675-682.

Fogarty M, Incze L, Wahle R, Mountain D, Robinson A, Pershing A, Hayhoe K, Richards A and Manning J. 2007a. Potential climate change impacts on marine resources of the northeastern United States. Northeast Climate Impacts Assessment.

Fogarty MJ, Incze L, Hayhoe K, Mountain DG and Manning J. 2007b. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change 13:1573-1596.

Greene CH and Pershing AJ. 2007. Climate drives sea change. Science 315: 1084-1085.

Greene CH, Pershing AJ, Cronin TM and Ceci N. 2008. Arctic climate change and its impacts on the ecology of the North Atlantic. Ecology 89:S24-S38.

Harris LG and Tyrell MC. 2001. Changing community states in the Gulf of Maine: synergism between invaders, overfishing and climate change. Biological Invasions 3: 9-21.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate Change 2007 – Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. IPCC, Geneva.

Intergovernmental Panel on Climate Change (IPCC). 2007b. Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. IPCC, Geneva.

Johns DG, Edwards M and Batten SD. 2001. Arctic boreal plankton species in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 58: 2121-2124.

Joyce TM and Kwon Y-O and Yu L. 2009. On the relationship between synoptic wintertime atmospheric variability and path shifts in the Gulf Stream and Kuroshio Extension. Journal of Climate 22: 3177-3192.

Kane J and Prezioso J. 2008. Distribution and multi-annual abundance trends of the copepod *Temora longicornis* in the US Northeast Shelf Ecosystem. Journal of Plankton Research 30:619-632.

Koeller P, Fuentes-Yaco C, Platt T, Sathyendranath S, Richards A, Ouellet P, Orr D, Skuladottir U, Wieland K, Savard L and Aschan M. 2009. Basin-Scale Coherence in Phenology of Shrimps and Phytoplankton in the North Atlantic Ocean. Science 324:791-793.

Leterme SC, Edwards M, Seuront L, Attrill MJ, Reid PC and John AWG. 2005. Decadal basin-scale changes in diatoms, dinoflagellates, and phytoplankton color across the North Atlantic. Limnology and Oceanography 50: 1244-1253.

Leys V. 2009. Sea Level Rise and Storm Events. In: CBCL Ltd, Nova Scotia State of the Coast Report. Second Draft Report. Prepared for Provincial Oceans Network, Halifax, NS.

Lucey SM and Nye JA. In review. Shifting species assemblages in the northeast US continental shelf large marine ecosystem. Marine Ecology Progress Series.

Maine Department of Environmental Protection (Maine DEP). 2010. A report to the Joint Standing Committee on Natural Resources of the 124th Maine Legislature pursuant to Resolves 2009, ch. 16.

McCabe GJ, Clark MP and Serreze MC. 2001. Trends in Northern Hemisphere Surface Cyclone Frequency and Intensity. J. Climate 14: 2763–2768.

CLIMATE CHANGE AND ITS EFFECTS ON HUMANS

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2010

1. Issue in Brief

Accelerated climate change is anticipated to have wide-ranging effects on the future sustainability of the Earth due to adverse ecological, social and economic impacts (Stern 2006; McMullen and Jabbour 2009). The driving force is an increase in the Earth's temperature as a result of human activities (e.g., release of greenhouse gases and changes in landscape characteristics). The Intergovernmental Panel on Climate Change (IPCC) projects a global mean temperature increase of 1.1°C to 6.4°C by 2100, which is likely to affect storms and floods, and lead to a rise in sea level due to the thermal expansion of the oceans and the melting of ice sheets and glaciers (IPCC 2007a). Recent research efforts estimate a global sea level rise of between 50 cm and 190 cm from 1990 to 2100 (see Vermeer and Rahmstorf 2009). There are several parts of the Gulf of Maine coast line that are classified as highly sensitive to the impacts of sea level rise because of risks associated with storm events. The physical extent of climate-related impacts will vary depending on regional and local situations (Burtis 2006). Coastal communities in the Gulf of Maine will be impacted in numerous ways, including: health and well-being of communities (e.g., injury, mortality, migration, crime and security); access to services; design and placement of structures (e.g., buildings, bridges, and utilities); cost of living; loss of livelihoods, and the cumulative magnitude of climate change impacts (see Figure 1). Climate change mitigation and adaptation are becoming increasingly important to community management and there are numerous ongoing federal, provincial/state, county, and municipal plans addressing these issues within the Gulf of Maine.

LINKAGES

This theme paper also links to the following theme papers:

- Climate Change and Its Effect on Ecosystems, Habitat and Biota
- Landuse and Coastal Development

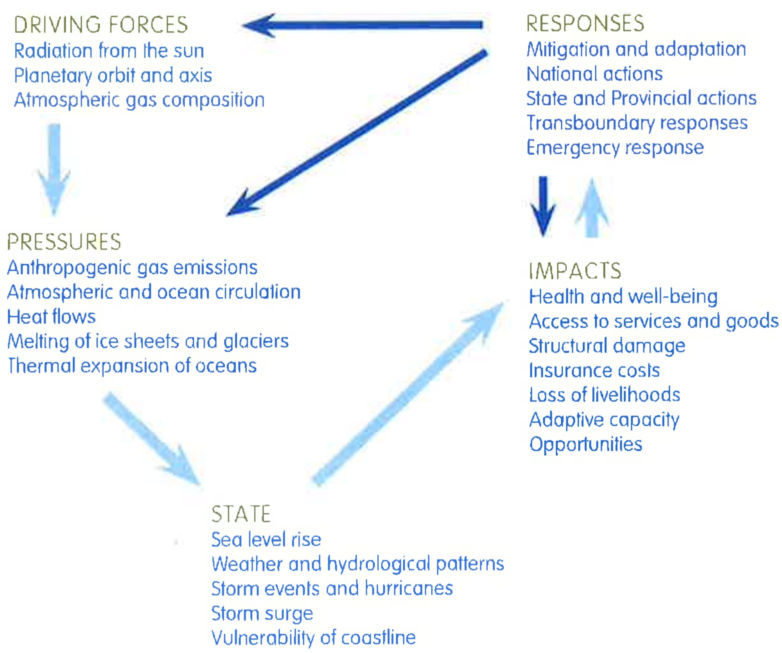


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to climate change and its effects on humans in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments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

Global climate scenarios examined by the IPCC (2007b) project global mean temperature increases varying between 1.1°C and 6.4°C by 2100. Observations at the regional and local level (North Eastern United States and Canadian Maritimes Cross Border Region) support that a trend in warming is taking place in the Gulf of Maine where monitoring sites in the Gulf of Maine display a trend of an increase in annual average temperature of the order of 0.1°C/decade (Burtis 2006 - see Figure 3).

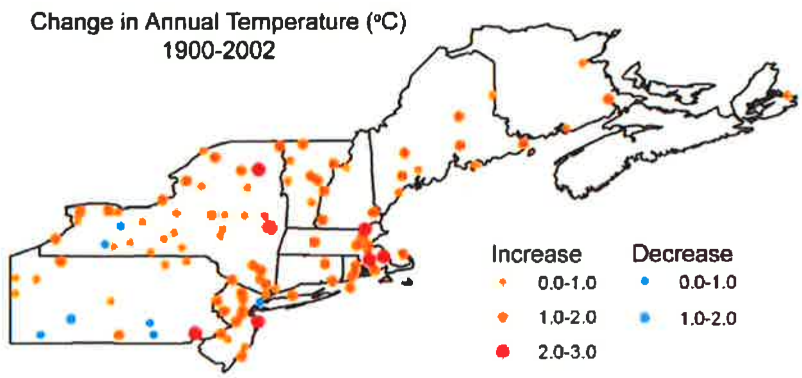


Figure 3: Map illustrating the pattern in annual temperature changes (°C) at sites in the Cross-Border Region for the period 1900-2002. Cooling trends are shown with blue dots, while warming trends are shown with orange and red dots (from Burtis 2006).

Increases in the gas composition of the Earth's atmosphere have an impact on numerous aspects of the planet's physical properties and characteristics, all of which interactively affect changing climate and increasing variability at the regional and local levels (IPCC 2007a). These include:

- The changing thermal properties of the Earth's atmosphere, which contributes to changes (a general increase) in global moisture content and atmospheric water balance (McMullen and Jabbour 2009).
- Changes to the global distribution of heat flows and atmospheric circulation patterns. The differential heating and cooling patterns will influence major regional air flow systems (e.g., the jetstream, North Atlantic Oscillation, Arctic Oscillation) and ocean currents (the Deep Sea Circulation System, Gulf Stream, the Nova Scotian Current etc.), which dictate continental weather patterns over the Eastern United States and Atlantic Canada. It is thought that this could cause an increase in the intensity of storms in the northern hemisphere, as well as a possible northward shift of storm tracks (McCabe et al. 2001, Wang et al. 2006).

Greenhouse Gas (GHG) Emissions for Provinces and States Associated with the Gulf of Maine

GHG emissions in CO_2 equivalents (Mt) for Canadian provinces (1990 and 2006). Source: Environment Canada, 2008.

Province	1990	2006
Nova Scotia	19.0	19.6
New Brunswick	15.9	17.9

CO_2 emissions (Mt) for power plants in US states (2000 and 2007). Source: RGGI, 2009.

State	2000	2007
Maine	3.2	3.4
New Hampshire	5.2	7.6
Massachusetts	25.5	25.4

- The average number of extreme precipitation events (more than 50 mm of rain or water equivalent if the storm results in snowfall) during a 48-hour period for the entire region is 2.6 events per year. Sites in parts of Massachusetts have more than 4 events per annum. Of the 51 monitoring stations in the Cross-Border Region, 36 stations showed an increase of greater than 10 % in the number of extreme events since 1949.
- There are indications that the timing of melting and thawing of snow and ice is occurring earlier with resultant changes to the hydrological patterns of rivers flowing into the Gulf of Maine.

3.2 RISING SEA LEVEL

Recent projections (Vermeer and Rahmstorf 2009) estimate a global mean sea level rise of between 50 cm and 190 cm over the period 1990 to 2100. According to Burtis (2006), sea level in Atlantic Canada and the north-eastern United States has risen approximately 25 cm since 1920. Permanent tide gauges have been established in the Gulf of Maine as part of the global network (see http://www.pol.ac.uk/psmsl/). For stations with the most long-term data (Yarmouth NS, Saint John NB, Eastport ME, Bar Harbor ME, Portland ME and Boston MA) average sea level rise is given in Table 1.

Table 1: Average sea level rise for stations in the Gulf of Maine

Station	Start Year	End Year	Average Sea Level Rise (mm/a)
Yarmouth, NS	1929	1999	4.1
Saint John, NB	1967	2007	2.5
Eastport, ME	1930	2007	2.2
Bar Harbor, ME	1948	2007	1.6
Portland, ME	1912	2007	1.2
Boston, MA	1921	2007	2.4

Source: Permanent Service for Mean Sea Level 2010, http://www.pol.ac.uk/psmsl

3.3 STORM EVENTS AND HURRICANES

Tropical storms of hurricane strength carry winds in excess of 100 km/h and wind- and flood-related impacts are always experienced. Eastern Canada and the north eastern US are vulnerable to landfall from tropical cyclones, which arise in the Atlantic. Although no specific long-term trend of increase is apparent over the period 1900 to 2000 (see Figure 4), a cyclical pattern is evident and the Atlantic Basin is currently experiencing an active period. Burtis (2006) reported that the highest frequency of tropical cyclones of any decade on record was for the period 1995 to 2005. The Gulf of Maine is an area that receives between two and five

3.5 VULNERABILITY

Vulnerability (or sensitivity) of coastal areas to sea level rise is the degree to which coastal systems (human and ecological) are susceptible to adverse impacts from sea level rise (see Section 4). The United States has undertaken a nationwide assessment of vulnerability of coastal areas to sea level rise (Thieler et al. 2001, http://woodshole.er.usgs.gov/project-pages/cvi/). The assessment focused on the physical response of the coastline to sea-level rise. The relative vulnerability of different coastal environments to sea-level rise was quantified at a regional scale using a coastal vulnerability index (CVI), based on coastal geomorphology, shoreline erosion and accretion rates, coastal slope, rate of relative sea-level rise, mean tidal range and mean wave height (Thieler and Hammer-Klose 1999). The results of the analysis for the Atlantic Coast, including Massachusetts, New Hampshire and Maine, are indicated in Figure 6. Although the findings indicate that most of the Gulf of Maine coast is considered to have a relatively low risk ranking, there are areas which are of high risk, particularly in the southern parts.

A similar analysis for coastal sensitivity (or vulnerability) to sea level rise has been undertaken for Canadian coastal areas (Shaw et al. 1998). The coastal sensitivity index is based on general relief, rock type, coastal landform, sea level rise trend, shoreline displacement, tidal range and wave height using large-scale 1:50,000 maps (Shaw et al. 1998). Figure 7 depicts the broad regional scale sensitivity of Atlantic Canada to such physical impacts. There is no accounting for small areas of very high sensitivity, so the map should not be used for developing local, site-specific policies.

Figure 6: Map of the CVI for Maine, New Hampshire and Massachusetts. The CVI shows the relative vulnerability of the coast to changes due to future rise in sea-level. Areas along the coast are assigned a ranking from low to high risk, based on the analysis of physical variables that contribute to coastal change.

Source: http://woodshole.er.usgs.gov/project-pages/cvi

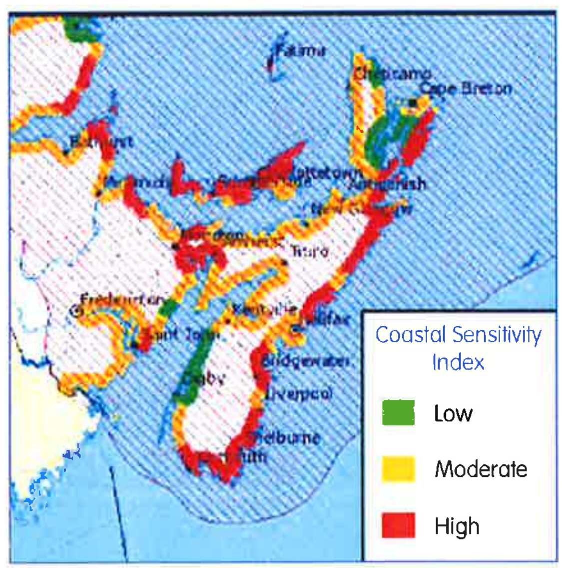


Figure 7: Regional physical sensitivity of coastline to sea level rise in Nova Scotia and New Brunswick.

Source: http://atlas.nrcan.gc.ca/site/english/maps/climatechange/potentialimpacts/coastalsensitivitysealevelrise

HEALTH AND WELL-BEING	
Physical injuries	• Increased injuries and deaths due to flooding, high winds, and storms. • Reduced access to health care due to disruption of services.
General health	• Increased heat-related mortality and morbidity particularly the elderly. • Increase in infectious diseases due to flooding and increase in damp conditions. • Exposure to chemicals from damage and overflow from pipelines and other storage utilities. • Increase in disease vectors resulting from temperature and precipitation shifts.
Mental health	• Anxiety, stress and other mental health problems due to heat, flooding and storm events, as well as possible evacuation or migration.
Safety and crime	• Increased risk of social unrest, crime and violence. • Increased risk of exposure to fires, chemical spillages, electricity.
ACCESS TO GOODS AND SERVICES	
Land	• Loss of land along the coastline and riparian areas for multiplicity of purposes (e.g., housing, agriculture, recreation). • Increased costs of land preparation to prevent flooding along coastline and riparian areas.
Water	• Threat of access to potable water due to saline intrusion of freshwater aquifers. • Threat of access to potable water due to contamination of water supplies and and disruption of treatment works and supply infrastructure. • Risk of sewer overflows.
Food	• Loss of riparian and coastal land area suitable for agriculture. • Reduced availability and increased cost of agricultural (animal, dairy and vegetable) products due to wet weather and flooding. • Reduced availability of fish/shellfish due to water quality.
Housing	• Damage and loss of buildings and property during floods and storms. • Increased cost of housing in coastal areas. • Employment and business opportunities in sustainable construction and design.
Energy	• Disruption to electricity supplies during weather events. • Outages of production lines for manufacturing.
Employment and education	• Opportunities for business, education, skills and jobs relating to climate change. • Loss of business, skills and jobs relating to agriculture and tourism due to business failure and/or costs to business from storm events, etc. • Loss of pupil/teaching days due to storm damage to educational buildings.
Leisure and recreation	• Disruption of sports events and recreational activities. • Reduced access to leisure, cultural facilities and historic buildings and sites. • Opportunities for alternative activities.
Landscapes and nature	• Damage and reduced access to ecosystems, historic and cultural landscapes, green spaces and gardens.
Transport and mobility	• Disruption of transport and communication networks.
Business and finance	• Increased costs for establishing and maintaining business facilities and operations in sensitive areas. • Increased costs of insurance. • Opportunities for new technology and business.
ADAPTIVE CAPACITY	
Social inclusion/cohesion	• Dislocation from family and community through evacuation. Disadvantaged and elderly people are particularly at risk. • Community conflict over resource allocations. • Increases in the sense of community in face of common risks.
Participation in climate change adaptation measures	• Exclusion and/or non-participation of vulnerable groups.

Table 3: Examples of response activities and actions being undertaken by governments associated with the Gulf of Maine.

JURISDICTION	POLICY	LEGISLATION	ACTION PLAN/ PROGRAMS	COMMENTS
United States of America	✓	✓	✓	House of Representatives passed a climate change bill in 2009, which did not win passage in the Senate. New legislation is being proposed. Federal research being coordinated by the Office of the President through an integrated program. http://www.globalchange.gov
Canada	✓	✓	✓	Climate Change Accountability Bill C-311 passed by Parliament in 2007. National activities on climate change impacts and adaptation are being coordinated by the Department of Natural Resources http://adaptation.nrcan.gc.ca/index_e.php
Massachusetts	✓	✓	✓	Global Warming Solutions Act passed in 2008. Climate change planning and implementation under the Executive Office of Energy and Environmental Affairs. The Office of Coastal Zone Management advancing adaptation through its StormSmart Coasts program. http://www.mass.gov/czm/stormsmart/index.htm
New Hampshire	✓		✓	Climate Change Action Plan published in 2009. Program operated through the Department of Environmental Services. http://des.nh.gov/organization/divisions/air/tsb/tps/climate/index.htm
Maine	✓	✓	✓	Maine legislature passed a bill in 2003 charging the Department of Environmental Protection with responsibility for developing and implementing action plan. http://www.maine.gov/dep/air/greenhouse/
New Brunswick	✓		✓	Climate Change Secretariat within the Department of Environment and an Action Plan 2007-2012 http://www.gnb.ca/0009/0369/0015/0001-e.pdf
Nova Scotia	✓		✓	Action plan being developed and coordinated by the Department of Environment http://climatechange.gov.ns.ca/ActionPlan

and states around the Gulf of Maine:

- New Brunswick – Emergency Measures Act, 1978 (http://www.gnb.ca/0062/PDF-acts/e-07-1.pdf)
- Nova Scotia – Emergency Management Act, 1990 (http://www.gov.ns.ca/legislature/legc/index.htm)
- Maine – Maine Emergency Management Act, 1987 (Maine Revised Statutes Title 37-B, Chapter 13; http://www.mainelegislature.org/legis/statutes/37-B/title37-Bch13sec0.html)

All jurisdictions have provincial/state emergency management and response organizations that are mandated to co-ordinate emergency response at all levels

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	TREND*	ASSESSMENT
Average annual land and water temperatures	Global warming	Pressure	–	Poor
Land subsidence	Exacerbates sea level rise	Pressure	–	Fair
Sea level in the Gulf of Maine	Causes inundation and flooding	State	–	Poor
Coastal vulnerability indices	Sensitivity to sea level rise	State	/	Fair
Occurrence of storm events	Worsens impacts from sea level rise	State	–	Poor
Costs of damage	Increasing costs of impacts	Impact	/	Fair

* KEY:
– Negative trend
/ Unclear or neutral trend
\+ Positive trend
? No assessment due to lack of data

Data Confidence

- Projected global sea level rise determined through modelling based on scientific research. Sea level rise in the next century ranges from 50 cm to 190 cm, an order of magnitude difference.
- Regional land subsidence estimates are also modelled to determine current subsidence levels. However, these have been verified through values from local sea level gauges.
- Sea level rise at fixed points provide a close estimate of current sea level rise, although future trends are uncertain.
- Comprehensive information is available on storms that have affected the Gulf of Maine, but there is little confidence in future storm predictions.

Data Gaps

- Vulnerability of communities to sea level rise needs to be determined at a local level.
- There is little information on local responses to sea level rise.
- There is little information on any of the possible impacts from climate change. There are few data on cost estimates of events causing damage.

COASTAL DEVELOPMENT

Humans have been an integral part of the Gulf of Maine since the earliest native settlers in the region. The initial influx of people to the Gulf of Maine began approximately 12,000 years ago. It is only in the last 500 years, however, that the region has witnessed extensive coastal settlement and development.

European settlers were first drawn to the Gulf's shores in search of fortune, religious freedom or a new life. Settlements grew up near natural salt and fresh water marshes. In the upper reaches of the Bay of Fundy, a vast network of dykes was constructed to convert tidal salt marshes into farmland. Cod was plentiful and well-suited to salt curing, which was essential for the long shelf-life necessary for export. Salt, hay and cod were the first steps in a maritime enterprise that would bring the region two centuries of prosperity. By the 1730s, shipbuilding in the Gulf grew up to support the salt cod trade with Europe.

Spurred on by the Industrial Revolution that was taking hold in Great Britain, entrepreneurs in the Gulf began to develop an industrial base of their own in the late 1790s. New England inventors and entrepreneurs transformed old mercantile cities into manufacturing centers. Fuelled by industrialization of its shores, after 1880, farms declined in size and the number and size of urban areas expanded. By 1940, two-thirds of the population lived in coastal counties of the Gulf in a limited number of urban centres. People continued to migrate from rural to urban areas, following employment opportunities and services.
Modern Day

As of 2007, nearly 10.8 million people live within the Gulf of Maine region and the yearly population growth in the area was just over 1%. This population trend and the migration of human settlement toward the coast

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Nova Scotia Canada

Massachusetts Office of Coastal Zone Management

National Oceanic and Atmospheric Administration
NOAA

COASTAL LAND USE AND DEVELOPMENT

STATE OF THE GULF OF MAINE REPORT

TABLE OF CONTENTS

Gulf of Maine Council on the Marine Environment

Environment Canada Environnement Canada

This publication was made possible through the support of the Gulf of Maine Council on the Marine Environment and funding from Environment Canada and the Maine Coastal Program, Department of Agriculture, Conservation and Forestry (NOAA Coastal Zone Management Grant NA11NOS4190077).

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.

Cover photo: Eastport, Maine. Sam Mudge, Creative Commons License

Cover map (background): Courtesy of Census of Marine Life/Gulf of Maine Area Program

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Coastal communities along the Gulf of Maine that seek to sustain healthy ecosystems and economies will need new planning, management, modeling, and monitoring tools. Many actions are underway to address coastal management needs in the Gulf region, but better coordination and additional incentives are needed to achieve best land management practices.

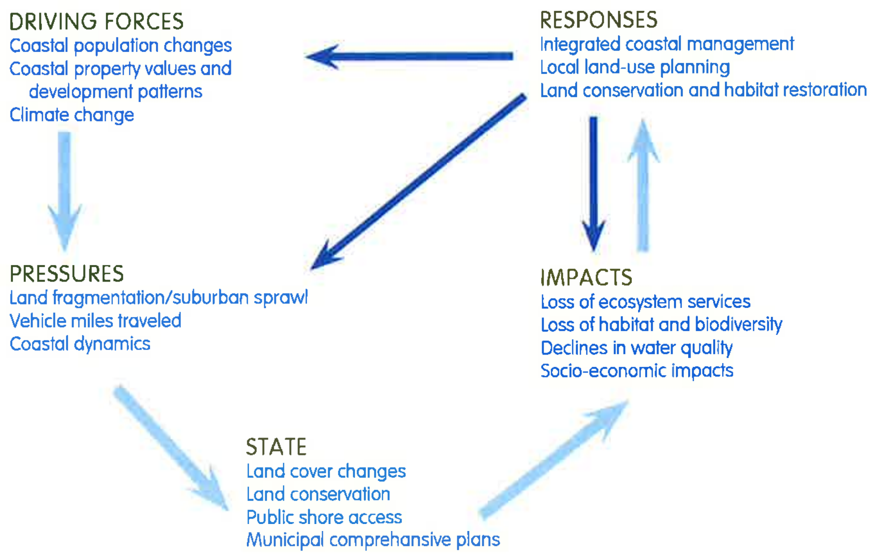

Figure 1: Driving forces, pressures, state, impacts, and responses (DPSIR) to coastal land use and development around the Gulf of Maine. In general, the DPSIR framework provides an overview of the relation between different aspects of the environment, including humans and their activities. According 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.

Table 2: Percent population change in Canadian Gulf of Maine coastal counties, 1981-2011 (data from Statistics Canada 2013b).

COUNTIES BORDERING THE GULF OF MAINE	1981 POP.	2011 POP.	% CHANGE
Westmorland County, NB	107,640	144,158	33.93
Hants County, NS	33,121	42,304	27.73
Albert County, NB	23,632	28,846	22.06
Kings County, NS	49,739	60,589	21.81
Colchester County, NS	43,224	50,968	17.92
Charlotte County, NB	26,571	26,549	–0.08
Yarmouth County, NS	26,290	25,275	–3.86
Annapolis County, NS	22,522	20,756	–7.84
Cumberland County, NS	35,231	31,353	–11.01
Saint John County, NB	86,161	76,550	–11.15
Shelburne County, NS	17,328	14,496	–16.34
Digby County, NS	21,689	18,036	–16.84

More rural and remote coastal locations are losing population as people migrate to urban areas for job opportunities (PNS 2009). In New Brunswick, for example, population grew 2.9 percent province-wide between 2006 and 2011, while the Moncton area saw marked population increases—25.6 percent in Dieppe, 6.3 percent in Moncton, and 7.3 percent in Riverview (data from Statistics Canada 2013b).

Those migrating to urban centers for jobs are not necessarily settling within city limits. Some buy or build homes in the surrounding countryside, contributing to sprawl (uncontrolled development and land fragmentation in a widening arc around urban centers). In Cumberland County, Maine, for example, roughly 60 percent of housing units built between 2000 and 2005 occurred outside the county's seven traditional population centers (Brookings 2006). This pattern likely contributed to increased vehicular use: between 2000 and 2010, vehicle registrations in Cumberland County outpaced population by 41 percent (Casco Bay Estuary Partnership 2010).

Although population has been increasing in coastal urban centers, development is far outpacing it. Between 1982 and 1997, for example, the amount of farm and forest land converted to urban uses in Portland, Maine increased by 108 percent, while its population grew by only 17 percent. In southeastern Massachusetts, the amount of developed land is increasing at three times the rate of population growth, and models show that by 2030 between 50 and 63 percent of the region's land may be developed (Stone et al. 2006). Some coastal resort communities along the Gulf shoreline have seen particularly dramatic change in both population and development. Cape Cod, Massachusetts, experienced a 400 percent increase in population between 1951 and 2005, transforming the character of its communities and integrity of its natural ecosystems (Figure 2).

2.2 COASTAL PROPERTY VALUES AND DEVELOPMENT PATTERNS

Industrial and coastal-dependent uses are declining in many Gulf of Maine coastal communities (given depletion of fisheries stocks, changes in technology and shipping, and other market forces), and residential and commercial development are taking over former working waterfronts. Market demand for waterfront property drives up property values, speeding the conversion of traditional working harbors into condominiums, homes or restaurants, which can close off public shore access. A 2005 study of Maine's coastal municipalities found both high real estate appreciation and a proliferation of high-priced houses—trends that typically raise taxes and drive out long-time owners, irreversibly altering land use and community traditions (Brookings 2006). Over the decade spanning from 2003 to 2013, property assessments in Nova Scotia's Gulf of Maine coastal counties rose between 70 and 114 percent (S. Lemmon, Property Valuation Services Corporation, pers. comm.).

Much of the new development occurring along the Gulf of Maine coastline is dispersed along the shoreline, rather than concentrated in existing town and village centers. Differences in property values (with outlying communities having lower-priced lots and lower taxes); municipal zoning (which often favors minimum lot sizes to provide for adequate septic fields or prevent dense developments); and consumer desire (for space, quiet and, most especially, water views) can all drive a dispersed pattern of development (DeNormandie et al. 2009).

Sprawl has far-reaching effects on land use. Dispersed, large-lot development consumes more land per capita and fragments the large tracts critical for many wildlife species. Creation of additional roads and parking lots can lead to incremental filling of wetlands and degradation of wildlife habitat (USEPA ND). Estimates of wetland loss since European settlement among the five Gulf jurisdictions, attributable to sprawling development and agricultural conversion, vary greatly. For example, salt marsh loss is estimated to range from 18 to 50 percent in New Hampshire, 25 to 50 percent in Maine, 40 to 50 percent in Massachusetts, and 75 percent in Nova Scotia and New Brunswick, with the highest levels along the Bay of Fundy (Bromberg and Bertness 2005; Dionne et al. 1998; Reed and Smith 1972).

Increases in impervious surface area typically generate more contaminated runoff (nonpoint source pollution) to coastal waterways and wetlands. New road construction also drives up vehicle miles traveled (VMT), through a combination of increased driving by current residents, heightened commercial transportation activity, and inmigration of new residents (Duranton and Turner 2009). Added vehicular traffic exacerbates air pollution, greenhouse gas emissions, and nonpoint source pollution. While VMT per capita in states bordering the Gulf appeared to peak around 2005 (see Table 3) (no data could be found for the provinces), levels remained high through 2010 due to the dispersed population, recreational travel and long work commutes.

the province—suggesting that a high portion may be for seasonal residences (PNS 2009). Census data supports this: in Nova Scotia, population in Gulf of Maine coastal counties declined slightly (0.66 percent) from 2006 to 2011, yet the number of personal residences in those counties rose by 3.38 percent (data from Statistics Canada 2013a, 2013b). Similar patterns are evident in the United States: growth projections indicate that nearly half of Maine's coastline will qualify as suburban by 2050 (Brookings 2006).

Residential construction appears to be the dominant driver of development along the Gulf of Maine coastline—reflecting the region's shift from a resource-based economy to one dependent on tourism and recreation. Available province-wide data in Nova Scotia, for example, indicate that the predominant type of development is residential (76 percent) with industrial (8.7 percent) and commercial (5.7 percent) far less significant (PNS 2009).

The cumulative impact of construction of single-family dwellings is significant—particularly as individual house footprints increase. The average size of new homes constructed in Massachusetts rose steadily over recent decades to more than 2,700 square feet in 2006. These larger residences involve more impermeable surface area, more potential habitat disruption, and more hydrological changes (both above and below ground) (DeNormandie et al. 2009). This impact can be particularly severe in coastal areas with abundant wetlands and in shorefront settings subject to storm surge and flooding.

Industrial development tends to be concentrated, highly regulated, and routinely monitored, but residential projects are often dispersed and minimally regulated, with no follow-up environmental monitoring (PNS 2009). Along portions of the Gulf of Maine coastline where lands are increasingly built out, new development is migrating inland along what some planners call a "sprawl frontier."

As coastal residences escalate in size and value, landowners can become more protective of their substantial shorefront investments—closing off traditional public access and taking measures to armor the shore against storm damage. Sandy beaches represent less than 40 miles of Maine's 5,300-mile coastline, and about half of these are hardened with structures like seawalls that limit formation of beaches and dunes (Maine Sea Grant 2011). Since shore armoring techniques can foster erosion and disrupt coastal ecosystems (see Section 4, Impacts), private property interests are often pitted against the health of coastal ecosystems and interests of the larger community. The region is seeing increased conflict and litigation over both shoreline hardening and traditional beach access (Woodard 2012), trends that may accelerate as climate change begins affecting more coastal properties.

3. Status and Trends

3.1 LAND COVER CHANGES

As of 2006, land cover in the U.S. counties bordering the Gulf of Maine was dominated by forests (43 percent) and open water (30 percent), with significant wetlands (10 percent) and development (9 percent), according to data compiled by NOAA's Coastal Services Center (NOAA 2013a). Agriculture, scrub, grass and barren collectively made up less than 10 percent of the total land area. Between 1996 and 2006, the region saw just over 2 percent change in land cover—with scrub experiencing the largest net increase (93 square miles) and forests the largest loss (213 square miles, just less than 3 percent net loss) (Figure 4). Less than 1 percent of the total wetland area (3.52 square miles) changed during that decade—gaining areas formerly mapped as open water. Agricultural land cover experienced a small net gain over the decade (despite losses to development), representing 4 percent of the coastal counties in 2006.

Developed lands grew 3 percent between 1996 and 2006 in the U.S. Gulf of Maine coastal counties, with most new development occurring in previously forested areas. That increase added 46 square miles to the total developed area, the equivalent of a football field every 9.75 hours throughout the decade (N. Herold, NOAA Coastal Service Center/C-CAP Program, pers. comm.).

In the Canadian Maritimes, Statistics Canada analyzed land cover in the Annapolis-Minas Lowlands along the eastern coast of the Bay of Fundy. Coniferous forests made up 43 percent of the land area, with cropland/pasture covering 23.4 percent, mixed forests 9.9 percent, and deciduous forests 4.6 percent (Mustapha 2012). Between 2001 and 2006, the number of farms declined 6.1 percent and the area with tree fruit and berries declined 18.7 percent.

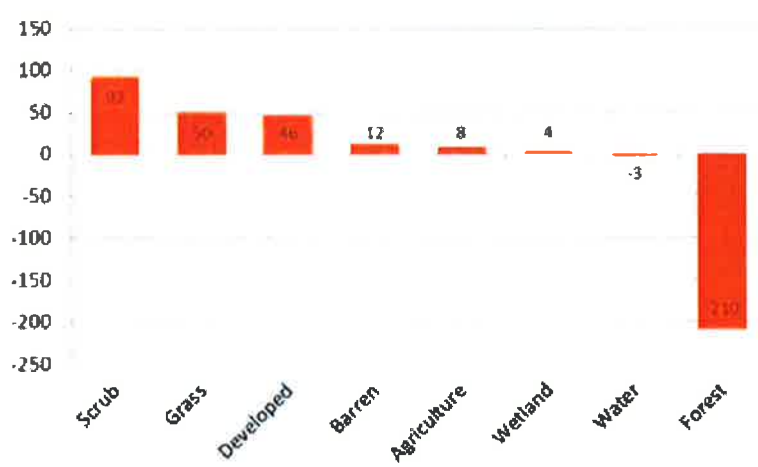

Figure 4: Distribution of net land cover change from 1996 to 2006 in U.S. counties bordering the Gulf of Maine (shown in square miles) (N. Herold, NOAA Coastal Service Center/C-CAP Program, pers. comm.).

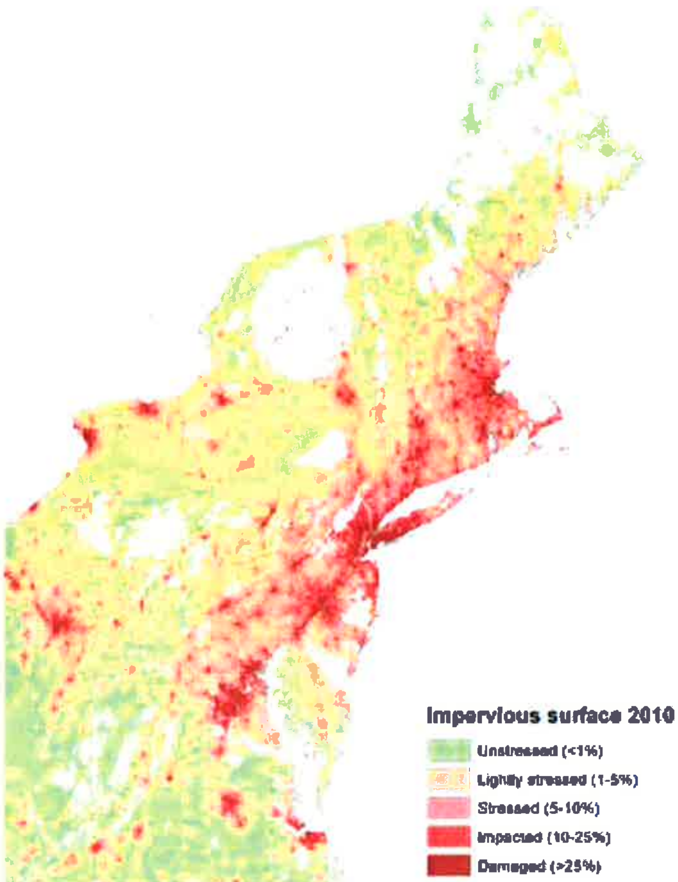

Figure 6a: Impervious surface cover in the U.S. Northeast—2010 (Theobald et al. 2009).

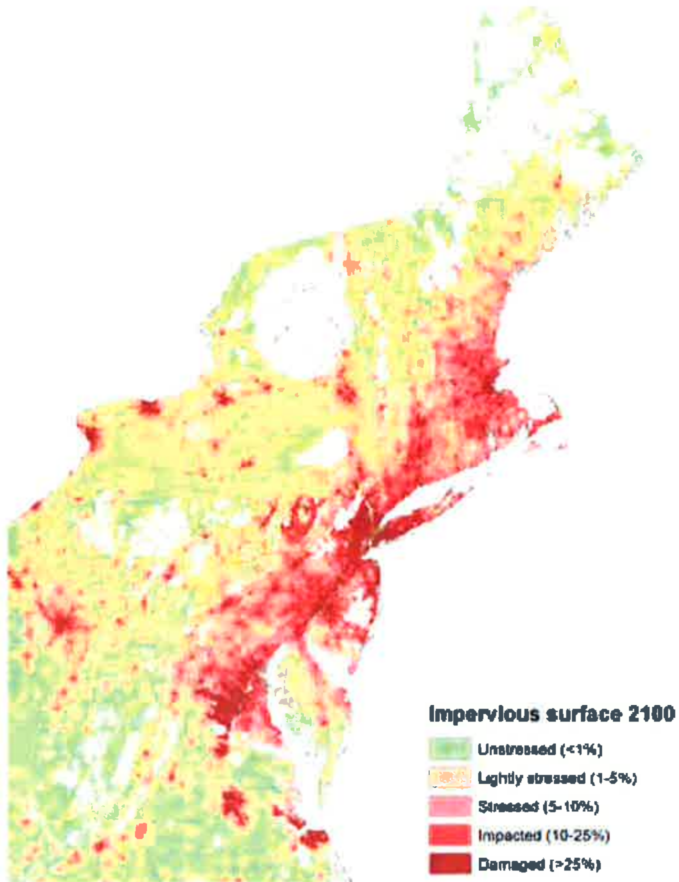

Figure 6b: Projected impervious surface cover in the U.S. Northeast—2100 (Theobald et al. 2009).

Several watersheds along the Gulf of Maine coastline have conducted detailed analyses of impervious surface cover. The Casco Bay Estuary Partnership, tracing impervious surface area in Maine's most urban watershed, found that between 2005 and 2010, the percentage of impervious surfaces remained at 6 percent (Casco Bay Estuary Partnership 2010). Another relatively urban watershed surrounding the Piscataqua River (including Portsmouth, New Hampshire) reported in 2010 that impervious surface cover represented 9.6 percent of the land area. The amount of impervious surfaces there increased by 120 percent over two decades, six times the rate of population increase. The rate of new impervious surfaces nearly doubled in the period between 2005 and 2010, relative to the period from 1990 to 2005 (PREP 2013).

As of September 2012, Nova Scotia had 9.4 percent of its land base province-wide legally protected, including land trust and non-governmental holdings (PNS 2013). Along the immediate coastline, about 15 percent of lands are publicly owned but less than 5 percent of coastal lands are protected through a mixture of conservation easement properties, non-government organization holdings, and Crown protected areas. The Bay of Fundy shoreline, due to its long history of settlement and subdivision, may have an even lower percentage of protected lands (D. Garratt, Nova Scotia Nature Trust, pers. comm.). Nova Scotia recently proposed a Parks and Protected Areas plan that would raise the percentage of legally protected lands to 13 percent and would protect 437 additional miles of coastline province-wide including 163 beaches, 64 salt marshes and 25 estuarine flats. Of the proposed additions, more than 247,000 acres are in counties bordering the Bay of Fundy (PNS 2013).

3.3 PUBLIC SHORE ACCESS

Coastal communities bordering the Gulf of Maine rely heavily on shore access for recreation, harvesting, and other traditional maritime uses. Maintaining access is a growing concern in the face of increasing coastal development, rising property values and taxes (which can restrict access for lower-income residents), changes in land ownership, lack of enforcement and planning, growing costs of infrastructure maintenance, and declines in fisheries/maritime industries (Springuel 2007).

Massachusetts and Maine are among the few U.S. states that do not own the intertidal zone between high and low water marks. Due to colonial-era ordinances, public access in this portion of the shore is confined to "fishing, fowling, and navigating"—prompting concerns (and legal action in places) over the public's right to broader recreational use. New Hampshire owns up to the mean high water mark and in Canada, the provinces generally own the intertidal zone except for some colonial-era land grants that included the intertidal zone as part of private property holdings.

The Gulf jurisdictions vary greatly in the relevant data they have on shore access sites, and no jurisdiction has data tracking changes to access points over time. Much of the knowledge about access is local and the changes in permitted uses shift gradually—making the status of sites hard to track. Tourism New Brunswick promotes 11 accessible saltwater beaches along its Fundy shoreline, but no data could be located on the percentage of shoreline that is publicly owned or publicly accessible. Nova Scotia has no province-wide inventory or database of access sites, and the provincial government reported in 2009 that it did not have adequate information to determine the area or length of the Nova Scotia coast that is reachable by the public (PNS 2009). Roughly 15 percent of the Nova Scotia coast is publicly owned, but not all of that is accessible and the majority lies outside the Bay of Fundy shoreline.

3.4 MUNICIPAL COMPREHENSIVE PLANS

Since municipalities make many coastal land-use decisions on both sides of the border, the extent of local comprehensive planning can indicate whether communities are working toward sustainable future growth, although adequate resources are not always available for implementation. Planning at the municipal level does not guarantee that adequate planning is occurring at the regional or watershed scales, or that planning decisions afford sufficient protection to sensitive coastal ecosystems. Yet careful local planning is a first step in guiding many communities toward better land-use decisions.

A growing number of municipalities in the region are working to create climate adaptation plans as well, with federal and provincial incentives in New Brunswick and Nova Scotia (http://atlanticadaptation.ca). These plans consider the potential impact of projected sea-level rise and storm surges, and the need to site new infrastructure outside flood-prone areas. At least a dozen coastal communities in both Massachusetts and New Brunswick have begun work on adaptation plans. In Massachusetts, communities receive help preparing to manage storm damage and sea-level rise through the state's Storm Smart Coast Program. More information on adaptation plans can be found in the Gulf of Maine Council's theme paper, Climate Change and Its Effect on Ecosystems, Habitats and Biota.

Because Massachusetts is a home rule state, municipal comprehensive plans are not required, and the only data on their status are maintained by Regional Planning Associations. Only one such association provided data for this paper (see box in section 5 on Cape Cod), so the status of comprehensive planning among the state's coastal communities is uncertain. Massachusetts does require towns to develop and regularly update municipal open space plans in order to qualify for any state funding for conservation, recreation, and open space funding, but there is no state tracking of these plans.

Nearly all of New Hampshire's coastal cities and towns have adopted a town plan, a comprehensive plan, or a master plan, and almost all of those include natural resource chapters (Sowers 2010; J. LaBranche, Rockingham Planning Commission, pers. comm.). While none of the plans currently have separate sections on coastal planning and management, there is a bill pending in the state legislature that would enable creation of separate chapters on coastal planning and management in municipal master plans (J. LaBranche, Rockingham Planning Commission, pers. comm.). Seacoast New Hampshire had two recent planning federal gas sales tax revenues to municipalities that have completed an Integrated Community Sustainability Plan (ICSP) for "green projects." This incentive has helped foster rural environmental planning and municipal consideration of environmental issues from a land-use planning perspective (D. Smith, Service Nova Scotia and Municipal Relations, pers. comm.)

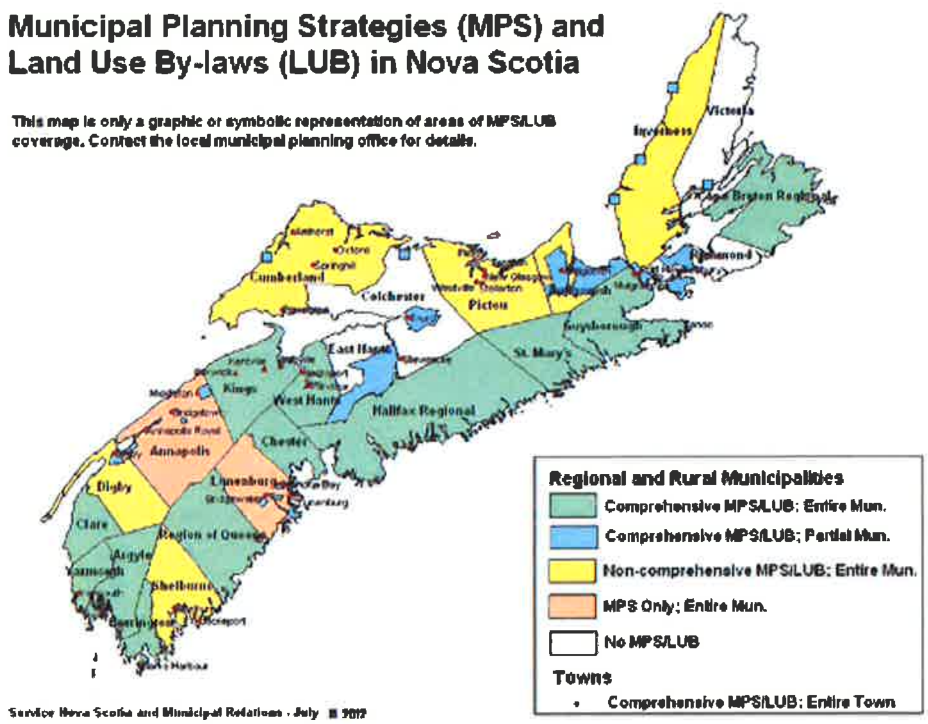

Figure 7: State of municipal planning strategies and land-use bylaws in Nova Scotia municipalities.

Table 4: Cumulative impacts of poorly planned development (with regional examples).

IMPACTS	EXAMPLES FROM THE GULF OF MAINE
Ecological Impacts	
Decreased protection from erosion and storm surge	• Where dykes have disrupted the natural capacity of wetlands to absorb storm surge and floodwaters, in settings such as the tidal isthmus near Sackville, New Brunswick, there is increased risk of flooding and damage to coastal infrastructure (Figure 8).
Loss of mature forests that provide carbon sequestration	• Research over a 25-year period in New England demonstrates that many forests do not stop or slow their storage of carbon as they mature and age: in fact carbon uptake actually increases (Foster et al. 2010).
Loss of wetlands and nursery areas for juvenile fish/shellfish	• Among the five Gulf jurisdictions, wetland loss ranges from a low of 25-50 percent in Maine; to 50 percent in Massachusetts and New Hampshire; to 65-85 percent in Nova Scotia and New Brunswick, with the highest levels along the Bay of Fundy (Gustavson 2010). Work is underway throughout the region to halt and reverse this trend (see box, "Moving toward No Net Wetland Loss").
Fragmentation of wildlife habitat and declines in threatened species	• Some of Maine's most rare plant communities have already been lost or altered by development in coastal counties of southern Maine (Stone 2011). • The World Wildlife Fund (ND) reports that 5 percent or less of the New England-Acadian forests covering the region remain intact in pre-settlement condition.
Loss of sandy beaches (degrading the economic potential of the habitat with highest "natural capital" value) (Troy 2012)	• Roughly 30 percent of Massachusetts' south shore has shoreline protection structures that have contributed to extensive loss of recreational beaches and alteration of marine habitats (Figure 9) (O'Connell 2010). In southeastern New Brunswick, beach and dune habitat at five study sites declined between 8 and 40 percent between 1941 and 2001 (Gustavson 2010).
Decline in water quality with more runoff from impervious surfaces and less filtration by coastal wetlands	• A one-acre parking lot produces about 16 times the volume of runoff that comes from a one-acre meadow (Beach 2002). • Shellfish harvesting is prohibited in 37 percent of the surveyed areas in the Maritimes due to nonpoint source pollution, primarily fecal coliform bacteria from urban and agricultural areas (Stewart et al. 2003). • Excess nitrogen and algal blooms (see Gulf of Maine Council Eutrophication fact sheet and Eutrophication theme paper). • Concentrations of suspended sediment at one site in Great Bay, New Hampshire, increased 122 percent between 1976 and 2011 (PREP 2013). • Groundwater contamination (see Gulf of Maine Council theme paper on Microbial Pathogens and Toxins). • In Maine, only one-third of municipal water supplies lie within conservation areas; the balance are vulnerable to contamination from increased development (Cronan et al. 2010).

(continued on next page)

Moving toward No Net Wetland Loss

As noted in Table 4, the jurisdictions surrounding the Gulf of Maine have experienced a dramatic loss in wetlands, particularly in coastal regions where development pressures historically have been most intense. Infilling for development, agricultural conversion (including cranberry production), and tidal restrictions (from dams, culverts and causeways) have diminished the number and degraded the health of many coastal wetlands.

To help reverse this trend, all five jurisdictions bordering the Gulf have committed to policies and regulations that will prevent wetland loss. Massachusetts has pioneered a system that helps address losses outside the regulatory system as well. Realizing in 2004 that roughly 59 percent of its wetland loss was due to illegal fill, the Massachusetts Department of Environmental Protection launched a "Wetland Loss Mapping Project" that has reduced wetland loss by two-thirds since the project began (USEPA ND). Along portions of the Gulf coastline, communities are working to restore historic wetlands as well (e.g., removing dams and dykes).

Further information on state and provincial approaches to wetlands conservation can be found in the following resources:

- Massachusetts Wetland Program Plan
- New Hampshire Wetland Program Plan
- Maine Wetland Program Plan
- New Brunswick Wetlands Conservation Policy
- Nova Scotia Wetland Conservation Policy

Figure 9: Loss of beach at Ocean Bluff, Massachusetts. A postcard from the early 1900s depicts this sandy shore environment before shoreline armoring. The second image, taken in 2005, demonstrates how source sediment impoundment and passive erosion have completely eroded the fronting beach (J. O'Connell, Coastal Erosion Advisory Services, http://jimoconnell28.wordpress.com).

coastal management are occurring primarily through the work of the Northeast Regional Ocean Council.

In 2002, New Brunswick created a Coastal Area Protection Policy that has helped limit development within 100 feet of coastal wetlands, tidally affected lands, and other vulnerable locations—helping ensure a resilient natural shoreline that in turn protects infrastructure and properties. Nova Scotia is working toward addressing coastal land-use issues in a more integrated manner, a need clearly outlined in its 2009 State of Nova Scotia's Coast Summary Report.

5.2 LOCAL LAND-USE PLANNING

Along the Gulf of Maine coastline, municipalities make many of the most critical land-use decisions—determining the siting of development, setting and enforcing (or not) shoreline and wetland buffers, and laying the groundwork to guide future growth and development (PNS 2009). Relying on volunteer planning boards and town staff with multiple responsibilities, few local governments are well-positioned to take on the breadth of coastal management and planning duties accorded them (CCNS 2008).

With help from federal, provincial and state programs, regional planning entities, and watershed councils, many municipalities are trying to institute a range of "best management practices" (BMPs). BMPs can help direct development to appropriate settings, preventing infrastructure damage and supporting the continued health of coastal ecosystems. These practices include:

- Minimizing impervious surface cover with new and existing development;
- Encouraging low-impact development approaches like porous paving materials, green roofs, and rain gardens to reduce stormwater runoff and nonpoint source pollution;
- Using smart-growth strategies to direct new development into more urban areas, keeping rural lands available for agriculture, forestry, and open space;
- Establishing or strengthening regional planning commissions that can coordinate among municipalities (see box, "Cape Cod, Massachusetts: Managing Growth");
- Employing Transfer of Development Rights (TDRs), a market-based planning tool that channels development from rural to higher density areas;
- Setting and enforcing generous buffer zones around sensitive ecosystems (e.g., New Brunswick's Coastal Area Protection Policy);
- Encouraging compact development and cluster or density zoning (where development density is based on a specified area rather than lot-by-lot,

Cape Cod, Massachusetts: Managing Growth

Cape Cod, a unique geologic feature along the Gulf of Maine coast (with a substrate entirely of sand and gravel), represents one of the region's most extreme examples of land-use change. In the half-century between 1951 and 2003, the Cape's year-round population grew 400 percent, reaching 229,000 (Woods Hole Research Center 2012).

Exponential population growth has wrought irreversible changes on Cape Cod (Figure 2). The vast majority of the Cape's prime agricultural lands have been developed, primarily as residential subdivisions, leaving less than 3,000 acres (mostly fragmented in small parcels) (Beauchamp et al. 2011). Despite rampant residential development, workforce housing is a concern since 32 percent of the housing stock Cape-wide is held by seasonal visitors (according to 2010 U.S. Census data).

Concerned by loss of open space, increasing road congestion and threats to water quality, residents of the 15 Cape towns voted in 1990 to transform their regional planning agency into the Cape Cod Commission, giving it power to regulate "developments of regional impact" and impose limited moratoria within "districts of critical planning concern" to allow for planning and development of targeted regulations. These powers give the Commission critical input into how and whether proposed developments happen (H. McElroy, Cape Cod Commission, pers. comm.).

Nearly all Cape municipalities have a local comprehensive plan and a more comprehensive Open Space and Recreation Plan. While the Commission regulates subdivision plans over 30 acres, most residential development is regulated at the municipal level, where performance standards are typically less restrictive. The Commission invites local municipalities to participate in far-sighted regional planning efforts such as a land use vision map; a Regional Ocean Management Plan (which addresses offshore renewable energy and sand and gravel mining for beach nourishment); a Regional Wastewater Management Plan (which addresses both treatment system options and green infrastructure); and a Regional Multi-hazard Mitigation Plan (H. McElroy, Cape Cod Commission, pers. comm.).

The Commission's work is complemented by the efforts of a community-based nonprofit, the Association to Preserve Cape Cod. This group supports land use planning and natural resource protection zoning; advocates for smart growth; monitors salt marshes, herring runs and marine invasive species; and recently completed a farmland assessment and a study of the effects of sea-level rise on aquifers.

Having contended with the side effects of rapid growth, many area residents now value the role that regional land-use planning can play in sustaining the Cape's ecological and economic future.

5.3 LAND CONSERVATION AND HABITAT RESTORATION

While land conservation efforts are gaining momentum along the Gulf of Maine coastline, they will need to become better coordinated, concentrating on land linkages and contiguous parcels—particularly in more populous regions (Cronan et al. 2010). In addition to commonly employed devices such as conservation easements, communities may want to consider using tools that compensate landowners for protected resources while directing development to higher density areas (such as transfer of development rights) (Cronan et al. 2010).

Conservation work in the Gulf of Maine coastal region is increasingly focused on collaborative conservation initiatives that protect vital ecosystem processes in areas defined more by biophysical traits than jurisdictional boundaries. These initiatives, many of which build on the state, provincial and federal coastal protection efforts described in section 3, seek to conserve critical tracts of the region's natural infrastructure, helping to sustain its resilience in the face of a warming climate and changing land uses (Foster et al. 2010). Some organizations in the Gulf of Maine region participate in the North Atlantic Landscape Conservation Cooperative, a partnership that aims to address land use pressures and widespread resource threats and uncertainties amplified by a rapidly changing climate.

A growing number of regional initiatives—at the watershed scale—are linked to an ambitious 50-year vision articulated by researchers at Harvard Forest in Massachusetts, outlined in the Wildlands and Woodlands report. They seek to build public support for an unparalleled conservation effort that would retain 70 percent of New England in forestland, permanently free from development. Ninety percent of these would be managed for forest products, water supply, wildlife habitat, recreation and aesthetics while the remaining 10 percent would be large-landscape wildland preserves with minimal human impact (Foster et al. 2010). There are currently six regional conservation partners in this effort along the US Gulf of Maine shoreline: Taunton River Coalition; Great Bay Resource Protection Partnership; Mount Agamenticus to the Sea Conservation Initiative; Portland North Land Trust Collaborative; River Link; and Twelve Rivers Collaborative.

Habitat restoration is important to improve the function and provision of ecosystem goods and services from previously degraded habitats. A wide range of activities have been undertaken, many of them supported by the Gulf of Maine Council on the Marine Environment (see http://restoration.gulfofmaine.org/)—one example of which is highlighted in the salt marsh restoration box.

6. Indicator Summary

INDICATOR	DPSIR FRAMEWORK	STATUS	TREND
Coastal Population Density	Pressure	Fair—Many coastal communities contend with increased congestion and other negative impacts from year-round residents and seasonal visitors.	Worsening and Improving—Population density is increasing along much of the southern Gulf coast, but is stable or decreasing in some coastal counties.
Population dispersal and spread of suburban sprawl	Pressure	Fair—While an economic downturn has slowed this trend temporarily, the region is still suffering from sprawling growth and its negative impacts.	Worsening—Development is outpacing population growth, and projections indicate sprawl will keep spreading unless marked changes in planning/ zoning occur.
Changes in per capita annual Vehicle Miles Traveled	Pressure	Fair—Available U.S. data indicate miles are declining slightly, but remain high due to dispersed population and long work commutes.	Improving—While transportation alternatives are still inadequate and per capita rates are still high, VMTs are declining slightly.
Change in impervious surface cover	Pressure	Fair—Impervious surface cover percentages are still relatively low but locally high percentages are problematic in some settings.	Worsening—Land-use cover data (where it exists) indicate steady growth in impervious surface cover.
Storm intensity and frequency	Pressure	Fair—Some evidence of increased number and intensity of storms.	Worsening—Storm frequency and intensity are increasing, damaging infrastructure (particularly in low-lying and beach areas).
Flooding/erosion due to sea-level rise	Pressure	Fair—Vulnerable communities are contending with some effects to date and coastal municipalities are increasingly concerned with coastal resilience and mitigation.	Worsening—Frequency of flooding and erosion is increasing in vulnerable areas.
Loss of productive working landscapes	State	Fair—Agricultural and forest lands are getting developed—primarily for residential use—at a rate that far exceeds population growth.	Worsening—Projections are that this trend will increase, particularly in populous coastal counties.
Changes in acreage of permanently conserved land	State	Fair—Many parts of the Gulf of Maine region have seen significant conservation gains, but fewer and smaller parcels are being protected in congested, coastal areas.	Improving—A renewed commitment to land protection is increasing acreages and percentages, but land values near the coast make conservation expensive.
Public access to the shore	State	Fair—Increasing shoreline development threatens some traditional access across private lands, but efforts are underway to inventory, publicize, and protect access points.	Unknown—Much shore access is informal and not all jurisdictions have inventoried sites so trend data are not available.
Municipal comprehensive plans	State	Unknown—Most land-use decisions along the Gulf shoreline rest with municipalities which have widely divergent capacity for planning and for implementation of plans.	Unknown—Many municipalities lack the financial resources or technical support to do more comprehensive planning.
Provincial/state coastal policies or strategies	Response	Fair—Ongoing efforts are underway to create both comprehensive policies and ones that address priority issues.	Unknown—There are few means of tracking the effectiveness of current efforts (formal evaluations are rare and not readily accessible).

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

7. References

Beach D. 2002. Coastal sprawl: The effects of urban design on aquatic ecosystems in the United States. Arlington, VA: Pew Oceans Commission. 40 pp. http://www.pewtrusts.org/uploadedFiles/wwwpewtrustsorg/Reports/Protecting_ocean_life/env_pew_oceans_sprawl.pdf (accessed January 2013).

Beauchamp K and Geist M. 2011. Agricultural land use on Cape Cod: Looking to the future. Barnstable, MA: Association to Preserve Cape Cod. 77 pp. http://www.apcc.org/documents/pdfs/agriculture/exec-summary.pdf (accessed February 2013).

Brennan, Morgan. 2012. Thanks to Superstorm Sandy, northeastern real estate may get even more expensive. Forbes (online). November 11, 2012. http://www.forbes.com/sites/morganbrennan/2012/11/07/thanks-to-supe rstorm-sandy-the-northeasts-real-estate-may-get-even-more-expensive/ (accessed February 2013).

Bromberg, K.D. and M.D. Bertness. 2005. Reconstructing New England salt marsh losses using historical maps. Estuaries 28: 823–832.

Brookings Institution Metropolitan Policy Program. 2006. Charting Maine's future: An action plan for promoting sustainable prosperity and quality places. 146 pp. http://www.brookings.edu/~/media/research/files/reports/2006/10/cities/maine (accessed January 2013).

Casco Bay Estuary Partnership. 2010. State of the Bay 2010. 82 pp. http://www.cascobay.usm.maine.edu/pdfs/State_Bay_2010.pdf (accessed January 2013).

CCNS (Coastal Coalition of Nova Scotia). 2008. CCNS coastal policy factor summary: Land use and resource planning. 8 pp. http://ccns.chebucto.org/publications.htm (accessed February 2013).

Collini K. 2008. Coastal community resilience: An evaluation of resilience as a potential performance measure of the Coastal Zone Management Act. 20 pp. Washington, DC: Coastal States Organization. http://coastalstates.org.seedevelopmentprogress.com/wp-content/uploads/2010/07/final_resilience-white-paper_25july08.pdf (accessed January 2013).

Commission for Environmental Cooperation. 2013. Community-based salt marsh restoration in the Canadian Gulf of Maine. 1 p. http://www.cec.org/Page.asp?PageID=122&ContentID=1646&SiteNodeID=377 (accessed February 2013).

Corbalis J. 2008. Climate change and land use: Smart growth recommendations from New Jersey Future. 4 pp. http://www.njfuture.org/wp-content/uploads/2011/06/Climate-Change-and-Land-Use-10-08.pdf (accessed February 2013).

Cronan CS, Lilieholm RJ, Tremblay J and Glidden T. 2010. An assessment of land conservation patterns in Maine based on spatial analysis of ecological and socioeconomic indicators. Environmental Management 45: 1076-95.

DeNormandie J, Corcoran C and Clarke JJ. 2009. Losing ground: Beyond the footprint (patterns of development and their impact on the nature of Massachusetts). Fourth edition. Lincoln, MA: Mass Audubon. 32 pp. http://www.massaudubon.org/PDF/advocacy/losingground/LosingGround_print.pdf (accessed February 2013).

Dionne M, Burdick D, Cook R, Buchsbaum R and Fuller S. 1998. Scoping Paper 5: Physical Alterations to Water Flow and Salt Marshes. Protecting and Restoring Flow and Habitat in Gulf of Maine Salt Marshes and Watersheds. Workshop II: Protecting the Gulf of Maine from Land-based Activities. Prepared for the Secretariat of the Commission for Environmental Cooperation, through a partnership with the Global Programme of Action Coalition for the Gulf of Maine. Montreal QC. http://www.gulfofmaine.org/knowledgebase/salt_marsh_restoration/ (accessed March 2013).

Duranton G and Turner M. 2009. The Fundamental Law of Road Congestion: Evidence from US Cities. University of Toronto Department of Economics Working Paper 370. 45 pp. http://www.economics.utoronto.ca/public/workingPapers/tecipa-370.pdf (accessed March 2013).

Finn J-G. 2008. Building stronger local governments and regions: An action plan for the future of local governance in New Brunswick. 196 pp. http://www.gnb.ca/cnb/promos/flg/PDF/MainReport/mainreport-e.pdf (accessed March 2013).

Fisheries and Oceans Canada. 2011. Divestiture. http://www.dfo-mpo.gc.ca/sch-ppb/divestiture-dessaisissement-eng.asp (accessed February 2013).

Foster DR, Donahue BM, Kittredge DB, Lambert KF, Hunter ML, Hall BM, Irland LC, Lilieholm RJ, Orwig DA, D'Amato AW et al. 2010. Wildlands and woodlands: A vision for the New England landscape. Harvard Forest, dist. by Harvard University Press, Cambridge, Massachusetts. 36pp. http://www.wildlandsandwoodlands.org/vision/maps-figures (accessed January 2013).

GrowSmart Maine. 2012. Charting Maine's future: Making headway. Revisiting the 2006 action plan for promoting sustainable prosperity and quality places. 40 pp. http://www.growsmartmaine.org/sites/default/files/cmfMH_Final.pdf (accessed January 2013).

Gustavson K. 2010. Coastal ecosystems and habitats. State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment. 20 pp. http://www.gulfofmaine.org/state-of-the-gulf/docs/coastal-ecosystems-and-habitats.pdf (accessed January 2013).

Island Institute. 2010. Mapping Maine's working waterfront: A statewide inventory. Rockland, ME. 50 pp. http://www.islandinstitute.org/publications/Mapping-Maines-Working-Waterfront/12270/ (accessed February 2013).

MCHT (Maine Coast Heritage Trust). 2012. MCHT conservation planning phase I (PowerPoint presentation by James DeNormandie).

Maine Sea Grant and University of Maine Cooperative Extension. 2011. Building a resilient coast: Executive summary. 4 pp. http://www.seagrant.umaine.edu/files/Kristen%20Grant/MSGreport_finalrev.pdf (accessed January 2013).

McCloskey JT, Lilieholm RJ and Cronan C. 2011. Using Bayesian belief networks to identify potential compatibilities and conflicts between development and landscape conservation. Landscape and Urban Planning 101: 190-203.

Mustapha I. Ecoregion profile: Annapolis-Minas Lowlands. Statistics Canada: Environment Accounts and Statistics Division. http://www.statcan.gc.ca/pub/16-002-x/2012003/part-partie3-eng.htm (accessed February 2013).

The Heinz Center and Ceres. 2009. Resilient coasts: A blueprint for action. Washington, DC: The H. John Heinz III Center for Science, Economics and the Environment. 6 pp. http://www.heinzctr.org/Major_Reports_files/Resilient%20Coasts%20Blueprint%20for%20Action.pdf (accessed February 2013).

Theobald DM, Goetz SJ, Norman JB and Jantz P. 2009. Watersheds at risk to increased impervious surface cover in the conterminous United States. Journal of Hydrologic Engineering 14: 362-368.

Troy A. 2012. Valuing Maine's natural capital. Manomet, MA: Manomet Center for Conservation Sciences. 74 pp. http://www.manomet.org/sites/manomet.org/files/reports/Troy_2012_Value_of_Maine.pdf (accessed January 2013).

USEPA (United States Environmental Protection Agency). ND. Coastal wetlands review: North Atlantic Region. 54 pp. http://www.habitat.noaa.gov/media/news/pdf/north-atlantic-review_final.pdf (accessed February 2013).

Walmsley D. 2010. Climate change and its effects on humans. State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment. 14 pp. http://www.gulfofmaine.org/state-of-the-gulf/docs/climate-change-and-its-effects-on-humans.pdf (accessed January 2013).

White SK, Grant K, Leyden K and Stancioff E. 2010. Climate variability and coastal community resilience: Developing and testing a national model of state-based outreach. Orono, ME: Maine Sea Grant College Program, University of Maine. 28 pp. http://www.seagrant.umaine.edu/files/pdf-global/10SARPtech_final.pdf (accessed January 2013).

Woods Hole Research Center. 2012. Cape Cod: Land cover and ecology. 1 pp. http://www.whrc.org/mapping/capecod/index.html (accessed January 2013).

Woodard C. 2012. War for Maine's shore. Portland Press Herald. December 2, 2012. http://www.pressherald.com/news/war-for-maine-shore_2012-12-02.html?pagenum=full (accessed March 2013).

World Wildlife Fund. ND. New England-Acadian forests. http://worldwildlife.org/ecoregions/na0410 (accessed March 2013).

Xian G, Homer C, Dewitz J, Fry J, Hossein N and Wickham J. 2011. Change of impervious surface area between 2001 and 2006 in the conterminous United States. Photogrammetric Engineering and Remote Sensing 77: 758-762.

Yale University School of Forestry and Environmental Studies. 2004. Dynamic models of land-use change in northeastern USA: Developing tools, techniques and actions for effective conservation action. GISF Research Paper 003. 87 pp. http://environment.yale.edu/gisf/files/pdfs/landuse_complete.pdf (accessed January 2013).

Zankel, M, Copeland C, Ingraham P, Robinson J, Sinnott C, Sundquist D, Walker T, and Alford J. 2006. The Land Conservation Plan for New Hampshire's Coastal Watersheds. The Nature Conservancy, Society for the Protection of New Hampshire Forests, Rockingham Planning Commission, and Strafford Region Planning Commission. Prepared for the New Hampshire Coastal Program and the New Hampshire Estuaries Project, Concord, NH. http://www.epa.gov/owow_keep/estuaries/pivot/habitat/pdf/piscataqua_land_conservation_plan.pdf (accessed March 2013).

human diseases from exposure to contaminated shellfish and water.

Gulfwatch is a chemical contaminants monitoring program organized and administered by the Gulf of Maine Council. Since 1993, Gulfwatch has measured contaminants in blue mussels (Mytilus edulis) to assess the types and concentration of contaminants in coastal waters of the Gulf of Maine. It is one of the few monitoring programs and the only one in the Gulf of Maine to be coordinated across international borders.

Contaminant Theme Papers

Two theme papers have been identified for the State of the Gulf of Maine Report:

- Microbial Pathogens and Toxins (PDF, 1.2 mb)
- Toxic Chemical Contaminants (PDF, 1.3 mb)

In addition, a longer and more detailed review of Toxic Chemical Contaminants in the Gulf of Maine has been completed:

- Toxic Chemical Contaminants Review (PDF, 1.6 mb)

Actions and Responses

In addition to the Actions and Responses described in each theme paper, many different organizations have developed guidelines, codes of conduct, best management practices, or other types of advice aimed at addressing the issues described in the theme papers. Some of the guidelines related to Contaminants can be found here. These links are maintained by outside agencies and are provided for information purposes. The linked documents are not endorsed by the Gulf of Maine Council on the Marine Environment.

Search

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Quick Links

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MICROBIAL PATHOGENS AND BIOTOXINS

STATE OF THE GULF OF MAINE REPORT

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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.

Cover photo: Woods Hole Oceanographic Institution
Cover map (background) courtesy of Census of Marine Life/Gulf of Maine Area Program

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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2. Driving Forces and Pressures

2.1 ECOSYSTEM CONDITIONS

Natural conditions and the adaptation of organisms to those conditions largely influence extent, distribution and structure of microbial and algal communities. Two different types of public health threats come from microorganisms found in the Gulf of Maine. Some microorganisms, called pathogens, cause infectious diseases, while others produce toxins that can poison humans who eat contaminated shellfish. There are some similarities between the two, like in mode of exposure (contaminated shellfish), but also some important differences, like the fact that cooking shellfish can kill disease-causing microorganisms and render the shellfish safe for consumption, while cooking does not neutralize biotoxins, so contaminated shellfish cannot be safely consumed even if they are fully cooked.

2.1.1 Microbial Pathogens

The microbial pathogens include different bacterial species, viruses and protozoa, with some that occur naturally in the marine environment and others that are sewage-borne pollutants. Different bacterial species respond to environmental conditions in different ways, partially because they associate with different environmental matrices (sediment, shellfish, plankton, infaunal burrows, etc.). For *Vibrio* spp.(see box), temperature is the major driving force. All three of the major pathogenic species thrive best in warm waters, and actually appear to vanish from colder waters (temperatures below 15°C (FAO/WHO 2005)), as they 'go dormant' during fall through spring in the Gulf of Maine. During the summer when their populations are at their peaks, nutrients indirectly affect Vibrio concentrations

Table 1: Types, species, sources, indicators for, potential health effects of and safety standards for microbial pathogens and marine biotoxins in the Gulf of Maine.

MICROBIAL ISSUE	SPECIES	SOURCES	INDICATORS	POTENTIAL HEALTH EFFECTS	SAFETY STANDARD
Fecal-borne microbial pathogens	Numerous bacteria, viruses and protozoan pathogens	Human sewage, feces from warm blooded animals; shellfish and recreational waters	Fecal coliform (FC), enterococci (ENT), *Escherichia coli* (Ec)	Mostly gastroenteritis, hepatitis	Shellfish: 14 FC/100 ml Marine recreation: 35 ENT/100 ml
Naturally-occurring bacterial pathogens	*Vibrio vulnificus* (Vv), *Vibrio arahaemolyticus*, *Vibrio cholerae* (Vc), *Vibrio alginoyticus*	Naturally occurring in estuarine and marine ecosystems; shellfish and recreational waters	No indicators, only direct detection of the species or suspected virulence marker genes	Gastroenteritis (Vp,Vc,Vv), wound infections (Vp,Vv), cholera (Vc), severe septicemia and death (Vv)	Shellfish (Gulf of Maine): monitoring of water temperature for favorable conditions
Harmful algal blooms	*Alexandrium fundyense*	Naturally occurring in marine ecosystems; shellfish	Mouse bioassay	Tingling, numbness, paralysis, death	80 µg PSP toxin/ 100 g shellfish meat or scallop roe

increases in PSP occurrence linked to elevated, near-shore nutrient (nitrogen) concentrations, especially in Casco Bay. For the larger regional open-water blooms, eutrophication effects are not well quantified, although a recent report on long-term monitoring in the Bay of Fundy suggests there is no link between nutrient (nitrogen, phosphorus, silica) concentrations and cell densities of *A. fundyense* and other harmful algal species (Martin et al. 2009).

2.2 HUMAN POPULATION AND COASTAL DEVELOPMENT

The continuing increase in human population in coastal areas (see Land Use and Coastal Development) and accompanying development, with its impacts to the natural ecosystem, are factors that have significant impacts on the concentrations and spatial extent of microbial pathogens and harmful algal blooms. Increases in population place greater demand on wastewater treatment facilities and associated infrastructure. There are limitations on existing infrastructure for conveying waste, and the need for increased resource allocation to maintain and upgrade facilities. Wastewater pipes in sewered areas can convey too much volume to treatment facilities due to from improper connections, stormwater and infiltration of groundwater into leaky pipes. Leaky pipes can also release untreated sewage to surface and ground waters. Pressure on these facilities is worsened by the increasing number of large rainfall events that may cause water treatment facilities to be bypassed and result in discharges of untreated, pathogen-laden waste matter. Land areas not served by centralized sewage treatment systems are also potential problems, with septic systems causing contamination both to ground water and surface waters.

The discharge of nutrients have no direct public health impacts, but can have

SPATIAL INFLUENCE OF RAW SEWAGE DISCHARGE

The discharge of plastic discs from the Hooksett NH Wastewater Treatment Facility (WWTF) in March 2011 when heavy rains caused the discharge of 300,000 gallons of raw sewage discharge to the Merrimack River illustrates the potential spatial influence (southern Maine to Martha's Vineyard) and long-term potential impact of effluent discharge from one facility located well up into the Gulf of Maine watershed. Catastrophic events that cause bypass of treatment and discharges of untreated, pathogen-laden effluent can thus have major effects on water quality over time and space. An animated model of the spread of the discs with support from NERACOOS (Northeast Regional Association of Coastal Ocean Observing Systems):

The modeled distribution of discs reflects the eventual fate of the discs (Figure 2).

Figure 2: Distribution of sewage treatment discs in the Gulf of Maine on June 13, 2011 that were discharged from the Hooksett, NH WWTF on March 6, 2011. Map provided by NH DES Department of Environmental Services.

species and possibly harmful algae. In contrast enteric viruses tend to be less prevalent as environmental temperatures increase. A concern with *Vibrio* species is that increased levels and persistence may lead to evolution of virulent strains in existing populations that do not already include virulent strains (Mahoney et al. 2010).

The occurrence and dynamics of harmful algal blooms in coastal areas of the Gulf of Maine are driven by physical aspects of climate and weather conditions, including ocean currents, photosynthetically available radiation, the timing of freshening events, the nature of the North Atlantic Oscillation and hurricanes. Baker-Austin et al. (2010) presented recent evidence of the importance of changing ocean currents as a means for transport of pathogenic strains of Vibrio species to areas where they do not normally exist.

Runoff is a significant source of microbial pathogens, nutrients and toxic chemicals to coastal waters. The reduced salinity from increased freshwater volumes from more severe rain events can help to increase the persistence of enterococci, *E. coli* and sewage-borne pathogens in estuarine and coastal marine waters. Lower salinity also tends to favor the growth of *V. cholerae* and *V. vulnificus*. Runoff also delivers nutrients to coastal waters. Increased nutrients from runoff indirectly stimulates all three *Vibrio* species and the growth and persistence of nuisance harmful algae (eg. *A. fundyense*; Anderson et al. 2008).

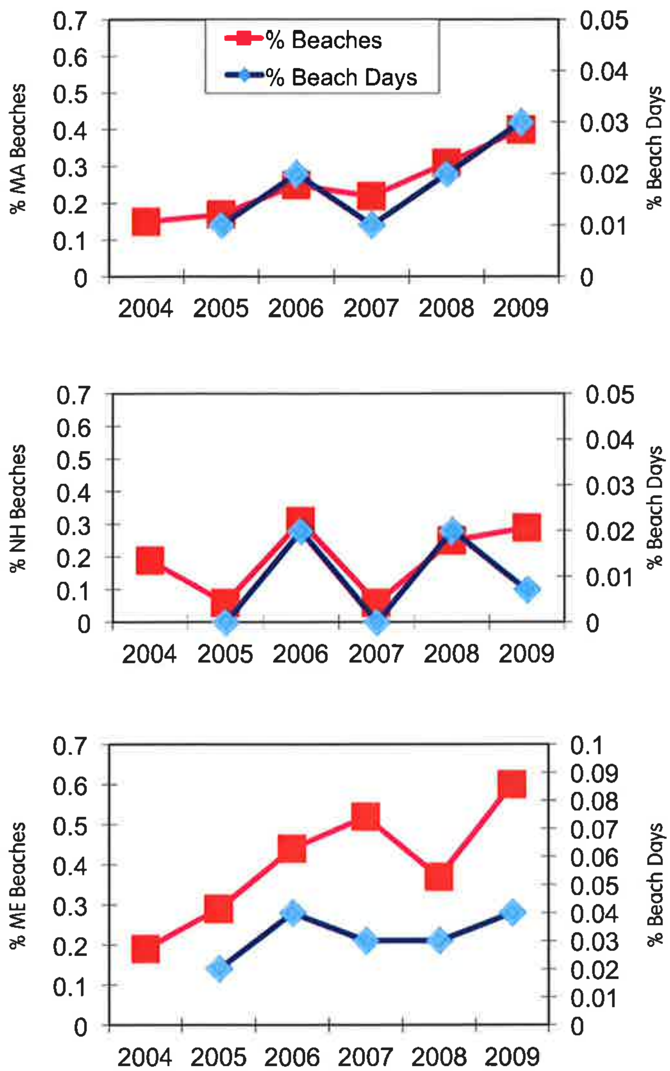

Figure 4: The annual percentage of days and the number of coastal beaches that were under advisories warning against contact with ocean water. Data from US EPA Beaches website: http://water.epa.gov/type/oceb/beaches/index.cfm

Closure of shellfish harvesting areas is an indicator for presence of microbial pathogens and toxin-producing algae. The Gulf of Maine Council's Ecosystem Indicator Partnership (ESIP) program has recently compiled shellfish harvest closure information for all five jurisdictions in the Gulf of Maine, building on previous efforts to track trends for pollution impacts on shellfish harvesting (Jones 2004).

The chosen indicator for levels of bacterial pollution is the percentage of harvest area classified as approved or conditionally approved, as opposed to prohibited (closed) or restricted (requiring depuration). The approved and conditionally approved areas in Massachusetts and New Hampshire have increased since the early 1990's, whereas little change has occurred in Maine and an overall decrease is apparent in the Bay of Fundy (Figure 4). These trends reflect a variety of influences, most notably efforts to eliminate pollution sources and changes to the way jurisdictions classify coastal waters. Based on the most recent available information, 80-90% of the harvest areas in Massachusetts and Maine are approved/conditionally approved, in contrast to <50% of the areas in the Bay of Fundy and New Hampshire.

3.2 NATURALLY OCCURRING BACTERIAL PATHOGENS

Vibrios tend to be most prevalent in the Gulf of Maine during warm summer months, and marine invertebrates may serve as reservoirs during colder months (Preheim et al. 2011).Vibrio studies in the Gulf of Maine have shown *V. parahaemolyticus* (Bartley and Slanetz 1971 Shiaris et al. 1987), *V. vulnificus* (O'Neill et al. 1990) and *V. cholerae* (Jones et al. 2010) to be present in coastal waters. Since the 1990s, studies in the Great Bay Estuary show increased occurrence and persistence of vibrios during 2007-2011, even during winter months when they were previously not detected (Jones et al. 2010). This is a concern, given the increasing occurrence of significant vibrio disease outbreaks in more northern US waters over the past 15 years. At present, no strains of *V. parahaemolyticus, V. vulnificus* and *V. cholerae* collected from

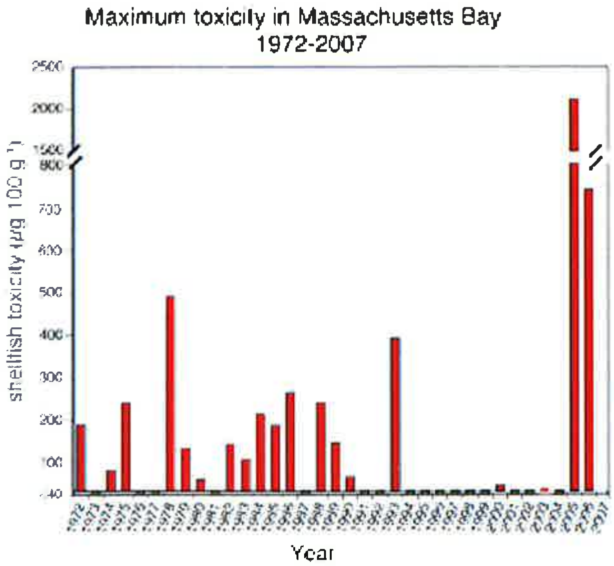

Figure 6: Maximum shellfish toxicity in Massachusetts Bay, 1972-2007 (WHOI, Don Anderson et al. 2011).

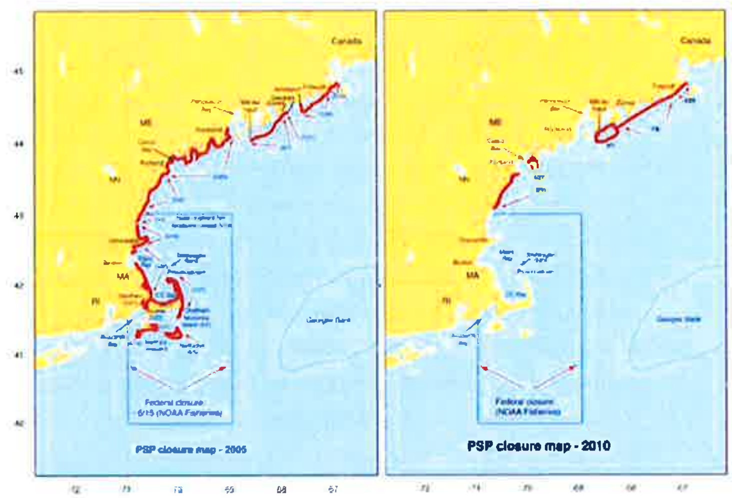

Figure 7: Interannual comparison of shellfish harvest closure maps caused by PSP toxicity: 2005 and 2010. Figures from WHOI/Don Anderson laboratory

Massachusetts waters, though it had been documented in Maine since 1958. From 1972 to 2004, PSP blooms occurred almost yearly in Maine but less frequently in Massachusetts and New Hampshire, with practically no toxicity detected in Massachusetts from 1994 to 2004 (Figure 6). In 2005, a bloom occurred that extended further south, and had both higher shellfish toxicities and cell densities of *A. fundyense*. A significant regional bloom occurred again in 2008, and variable degrees of severity in the blooms has occurred in other years since 2004, a factor due in part to different hydrographic and nutrient conditions in the Gulf of Maine. The spatial extent of shellfish harvesting closures due to PSP can differ greatly between years (Figure 7).

Blooms of *Psuedo-nitzschia* species, producers of domoic acid and the cause of amnesic shellfish poisoning, have been observed infrequently in the Bay of Fundy (Martin et al. 2009), with peaks in 1988, 1995 and 2004. Eight different *Psuedo-nitzschia* species have been observed in the Bay of Fundy, but they differ in domoic acid production and not all are detected each year. They also tend to bloom from May to October and the different species differ in ecosystems conditions favorable to blooms.

Vibrio surveillance system. It is important to reiterate that most, though not all, incidences of shellfish-borne vibrio infections have been attributed to shellfish harvested from areas outside of the Gulf of Maine. Marketed shellfish are tagged to identify harvest location, and many shellfish consumed around the Gulf of Maine are imported from outside the region. Massachusetts publishes the annual incidence of vibrio infections and have reported a higher rate of infections than in New Hampshire and Maine over the past 10 years (MADPH 2009).

Only *V. cholerae* is a reportable disease in the Gulf of Maine, as it is considered to be of great public health importance and thus is required to be reported by healthcare providers. For the three states in the Gulf of Maine, the National Shellfish Sanitation Program only requires assessment of shellfish growing waters for conditions that may be conducive to vibrio growth; if favorable conditions persist and/or there is incidence of disease, then active monitoring would be required. The Canadian Shellfish Sanitation Program requires the same for the two Gulf of Maine provinces. *Vibrio alginolyticus* is also a concern for recreational activities, as are *V. vulnificus* and *V. parahaemolyticus*, as wound infections can occur in contaminated waters. Recreational activities where people can be exposed to pathogens include swimming, surfing, diving, wading, boating, skiing and walking of falling on shore or rocks (Yoder et al. 2008).

For PSP toxins, the concern is poisoning of humans who consume shellfish with toxin levels that cause health-threatening symptoms. However, biotoxins and pathogenic vibrio species can also cause diseases in marine biota. The rare Gulf of Maine cases of poisoning from marine biotoxins are reported based on source location and shellfish species. PSP poisoning has recently become a reportable disease in Canada. A critical issue is educating the public about risks associated with recreationally harvested shellfish. A recent consumer awareness survey in Canada showed little public awareness and understanding about the risks of consuming bivalve shellfish, especially for recreationally harvested oysters (CREATEC 2006). The survey also reported Canadians on the East coast are more at risk than West coast residents.

PSP illnesses occurred in Maine in 2007, 2008 and 2009, all from consumption of shellfish taken from closed areas. The most notable set of cases was the July 31, 2007 incident where a family of four from Washington County consumed contaminated mussels and two people were hospitalized in critical condition, though they recovered. Recent investigations have shown lobster 'tomalley' should also be avoided during the summer as toxins can accumulate there and cause poisoning. Consumption warnings for lobster tomalley due in part to the potential of elevated levels of PSP toxin have been recently released in both Canada and the US.

The spatial and temporal trends for PSP closures Gulf-wide are complex, as closure of areas to shellfish harvesting changes annually, seasonally and spatially, from mooring areas, wastewater effluent discharge and other pollution sources and are clean enough to support shellfishing. For restricted areas, harvesting is allowed if shellfish are then depurated. In Massachusetts, the Newburyport Shellfish Purification Plant is managed by the Department of Fish and Game, Division of Marine Fisheries and processes an average of 560 bushels of soft shell clams every week that are harvested from conditionally restricted areas of Boston Harbor. In Maine, many areas have become available for harvest because the shellfish can be depurated at a commercial facility (Jones et al. 1991). This helps to maintain a greater degree of employment for local clam diggers. Unfortunately, the demand for soft shell clams in the Gulf of Maine is highest during summer months when red tides occur.

4.3 BIOLOGICAL IMPACTS OF INCREASED FREQUENCY, DURATION AND INTENSITY OF MICROBIAL PATHOGEN AND BIOTOXIN OCCURRENCE

Significant mortalities of caged Atlantic salmon occurred in New Brunswick during a bloom of *Alexandrium fundyense* in 2003 (Sephton et al. 2007). PSP toxins in right whales have also been detected during a bloom of *Alexandrium fundyense* (Doucette et al. 2006). These studies suggest that elevated concentrations of PSP toxin can be lethal to salmon and compromise the health of whales. Both studies investigated links through the marine food chain and found elevated levels of PSP toxin in zooplankton, blue and horse mussels and lobsters, even well after the blooms.

Vibrio species, including species not yet mentioned as human pathogens, are significant and well documented pathogens of finfish, eels and other marine organisms. In the Gulf of Maine, limp lobster disease has been a significant loss to the lobster fishery, and there is evidence that vibrios are the causative agent (Tall et al. 2003). Fecal-borne microbial pathogens are generally thought to have little impact on the marine ecosystem, as they are allochthonous organisms. *Salmonella* spp. have been implicated in fledgling tern die off on Cape Cod, and there are some suggestions that enteric bacteria may be involved in seal diseases. Fecal-borne bacteria can be transported from wastewater facilities and landfills to marine ecosystems via sea gulls (Nelson et al. 2008), thus representing a potential zoonotic (i.e. non-human animal) reservoir and vector for human diseases. Their build up in favorable niches within coastal ecosystems suggests they may have some influence on microbial communities and their potential for ecosystem impacts.

Table 2: Legislative actions related to microbial pathogens and harmful algal blooms in the Gulf of Maine.

JURISDICTION	LEGISLATIVE ACTION	AGENCY	DESCRIPTION
Canada	Canadian Shellfish Sanitation Program (CSSP)	Canadian Food Inspection Agency, Environment Canada, Fisheries and Oceans Canada	Interagency effort to inspect shellfish, monitoring growing areas and enforcement in accordance with CSSP requirements, including issues related to microbial pathogens and biotoxins
US	National Shellfish Sanitation Program (NSSP)	Food & Drug Administration (FDA), Interstate Shellfish Sanitation Conference (ISSC)	Cooperative federal/state program for sanitary control of shellfish used for human consumption
		MICROBIAL PATHOGENS	
Canada	Wastewater System Effluent Regulations	Environment Canada	A new federal set of regulations and standards
US	Beaches Environmental Assessment and Coastal Health Act	US Environmental Protection Agency	Improve the quality of coastal recreational waters in the US
US	Stormwater Discharges from Municipal Separate Storm Sewer Systems (MS4)	US Environmental Protection Agency	Under the NPDES program of the Clean Water Act (CWA), to require NPDES permit coverage for stormwater discharges
US	Impaired Waters and Total Maximum Daily Loads (TMDL)	US Environmental Protection Agency	Under section 303(d) of the CWA, list and develop TMDLs for impaired waters
		HARMFUL ALGAL BLOOMS	
US & Canada	Consumption advisory for lobster tomalley	US FDA, Health Canada, MA & ME state shellfish programs	Advisories issued following the severity of the 2008 red tide bloom in the eastern seaboard
US	Red Tide Relief Program	NOAA	Following the 2005 and 2008 red tides, shellfish industry stakeholders in ME, MA & NH were compensated and monitoring, research and outreach were supported.

systems and national standards for wastewater effluent quality has been published (Canada Gazette 2010). Part two, which will include responses to part one, will be published in 2011 in the Canada Gazette under the title "Wastewater System Effluent Regulations."

The recent focus in the northeast US on reducing nutrient loading to coastal waters where harmful algal blooms and vibrios problems often occur will in part be addressed through the National Pollutant Discharge Elimination System (NPDES) permitting and the Total Maximum Daily Load (TMDL) processes. Municipal wastewater treatment facilities (WWTF) may well face expensive upgrades to reduce nitrogen. It is critical with these significant expenditures for nutrient removal that reducing the discharge of microbial pathogen should also be considered.

US federal support was made available through the National Oceanic and Atmospheric Administration (NOAA) following the 2005 and 2008 red tides in the in New Hampshire and at many sites in Maine on a weekly basis from March through October. Volunteer phytoplankton monitoring programs in the three states, and the DFO monitoring program in southwest New Brunswick serve as useful early warning systems for the presence of HABs and other phytoplankton. Though most monitoring effort is for PSP, there is evidence that domoic acid, amnesic shellfish poisoning and DSP may become future problem areas that would require enhanced effort and monitoring.

Non-governmental organizations are putting pressure on the US EPA to improve water quality at beaches by conducting new swimmer health studies, develop tests that give same-day results, and addressing a wider array of potential water-borne illnesses. The Natural Resources Defense Council (NRDC) rates each state's water quality conditions. In 2010, Maine ranked 25th nationally, Massachusetts ranked 15th and New Hampshire 1st in the nation in beach water quality. This is an effective way for communicating to the public the potential risks and needs for addressing ongoing pathogen issues.

5.3 MODELING AND FORECASTING NEEDS

The most critical need for addressing impacts from microbial pathogens and harmful algal blooms is improved risk prediction. Development of predictive models for forecasting the potential for red tide incidence and intensity is well underway through partnered research involving academic and government researchers across the Gulf of Maine. These models are focusing on the relationships between numbers of *A. fundyense* cysts in sediments, nutrients (particularly nitrogen), climatic conditions and physical forcing factors. For all categories of pathogens and harmful algae, improved understanding of climate and ecosystem factors is also a critical research need. The potential emergence of new microbial pathogens, and the potential for continued increases in the extent and intensity of HABs and pathogenic vibrio problems are real issues. Given the nature of our collective response to the soaring increase in Lyme disease incidence in the Gulf of Maine states, it would be prudent to anticipate these problems and be better prepared to educate the public of risks and to improve our detection methods and disease diagnostic capabilities.

One of the key limitations of monitoring programs for both types of microbial issues is detection methods. The traditional use of a mouse bioassay has worked well, but it has a number of limitations and is undesirable because of the necessity to kill mice in the process. Efforts worldwide and within the Gulf of Maine are underway to replace this method with methods involving chemical detection of toxins. Detection methods that can detect virulent strains of all three vibrio species in a timely and cost-effective fashion are needed, especially for colder water areas like the Gulf of Maine.

For fecal-borne pathogens, the traditional bacterial indicators have generally

6. References

Anderson, D.M. 2011. Northeast PSP: Current status and history. New England harmful algal bloom/red tide information, Woods Hole Oceanographic Institution. http://www.whoi.edu/northeastpsp/

Anderson, D.M., J.M. Burkholder, W.P. Cochlan, P.M. Glibert, C.J. Gobler, C.A. Heil, R.M. Kudela, M.L. Parsons, J.E. J. Rensel, D.W. Townsend, V.L. Trainer and Vargo, G.A.. 2008. Harmful algal blooms and eutrophication: Examining linkages from selected coastal regions of the United States. Harmful Algae 8: 39-53.

Baker-Austin, C., L. Stockley, R. Rangdale and Martinez-Urtaza, J.. 2010. Environmental occurrence and clinical impact of Vibrio vulnificus and Vibrio parahaemolyticus: a European perspective. Environ. Microbiol. Rep. 2: 7-18.

Bartley, C.H. and Slanetz, L.W.. 1971. Occurrence of Vibrio parahaemolyticus in estuarine waters and oysters of New Hampshire. Appl. Microbiol. 21: 965-966.

Bolster, C.H., J. M. Bromley, and Jones, S. H.. 2005. Recovery of Chlorine-Exposed Escherichia coli in Estuarine Microcosms. Environ. Sci. Technol. 39: 3083-3089.

Burkhardt, W. and Calci, K.R. 2000. Selective accumulation may account for shellfish-associated illness. Appl. Environ. Microbiol. 66: 1375-1378.

Burkhardt, W., J. Marchant, J. Woods, T. Howell, L. Stadig and Calci, K.. 2011. Seasonal depuration of male-specific coliphage and norovirus, p. 84, In 8th International Conference on Molluscan Shellfish Safety. Conference Proceedings and Abstracts. June 12-17, 2011. Charlottetown, PEI, Canada. Canadian Food Inspection Agency and Fisheries and Oceans Canada.

Canada Gazette. 2011. Wastewater Systems Effluent Regulations. Canada Gazette, Vol. 144. No. 12, March 20, 2010. http://www.gazette.gc.ca/rp-pr/p1/2010/2010-03-20/html/reg1-eng.html

Center for Disease Control and Prevention (CDC). 2011. Vessel Sanitation Program web site: http://www.cdc.gov/nceh/vsp/surv/gilist.htm (June 28, 2011).

Createc. 2006 Consumer awareness nd perceptions of shellfish consumption and recreational harvesting: Findings from the baseline survey. Final Report. Canadian Shellfish Sanitation Program, Canadian Food Inspection Agency, Ottawa, Ontario.

Doucette, G.J., A.D. Cembella, J.L. Martin, J. Michaud, T.V.N. Cole and Rolland, R.M.. 2006. Paralytic shellfish poisoning (PSP) toxins in North Atlantic right whales Eubalaena glacialis and their zooplankton prey in the Bay of Fundy, Canada. Mar. Ecol. Prog. Ser. 306: 303-313.

Environment Canada. 2001. The state of municipal wastewater effluents in Canada: State of the Environment report. Indicators and Assessment Office, Environment Canada, Ottawa, Ontario. http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=ED03E31E-8A4E-4934-96B1-0A3697410588

Environmental Protection Agency (EPA). 1986. Ambient water quality criteria for bacteria- 1986. EPA440/5-84-002. United States Environmental Protection Agency, Office of Water Regulations and Standards, Washington DC.

Epstein, P.R. 2005. Climate change and human health. N. Engl. J. Med. 353: 1433-1436.

FAO/WHO (Food and Agriculture Organization of the United Nations/World Health Organization). 2005. Risk Assessment of Vibrio vulnificus in raw oysters. Interpretive Summary and Technical Report. Food and Agriculture Organization of the United Nations/World Health Organization, Geneva, Switzerland.

Henroth, B., A. Lothigius and Bolin, I. 2010. Factors influencing survival of enterotoxigenic Escherichia coli, Salmonella enterica (serovar Typhimurium) and Vibrio parahaemolyticus in marine environments. FEMS Microbiology Ecology 71: 272-280.

Hunter, P.R. 2003. Climate change and waterborne and vector-borne disease. J. Appl. Microbiol. 94: 37S-46S.

Jin, D., E. Thunberg and Hoagland, P. 2008. Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. Ocean and Coastal Management 51: 420-429.

Jones, S.H. 2004. Contaminants and Pathogens. pp. 33-41, In: The Tides of Change Across the Gulf. An Environmental Report on the Gulf of Maine and Bay of Fundy. Pesch, G.G. and P.G. Wells (Eds.). Gulf of Maine Council on the Marine Environment, Concord, NH

Jones, S.H. 2008. Environmental Sources of Microbial Contaminants in Shellfish and Their Public Health Significance. J. Foodservice 19: 238-244.

Jones, S.H. 2009. Microbial contamination and shellfish safety, pp. 3-42, Ch. 1, In, Shellfish Safety and Quality. S. Shumway and G. Rodrick (Eds). Woodhead Publishing Ltd, Cambridge, England.

Jones, S.H. and Summer-Brason, B.W. 1999. Incidence and detection of pathogenic Vibrio sp. in a northern New England estuary, USA. J. Shellfish Res. 17: 1665-1669.

Jones, S.H., K.R. O'Neill, and Howell, T.L. 1991. Differential elimination of indicator bacteria and pathogenic Vibrio sp. from Maine oysters (Crassostrea virginica) in a commercial controlled purification facility. J. Shellfish Res. 10: 105-112.

Jones, S., M. Striplin, J. Mahoney, V. Cooper and Whistler, C. 2010. Incidence and abundance of pathogenic Vibrio species in the Great Bay Estuary, New Hampshire, pp. 127-134, In, Proceedings of the Seventh International Conference on Molluscan Shellfish Safety. Lassus, P. (Ed.). Nantes, France, June 14-19, 2009. Quae Publishing, Versailles, France.

TOXIC CHEMICAL CONTAMINANTS

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

May 2013

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
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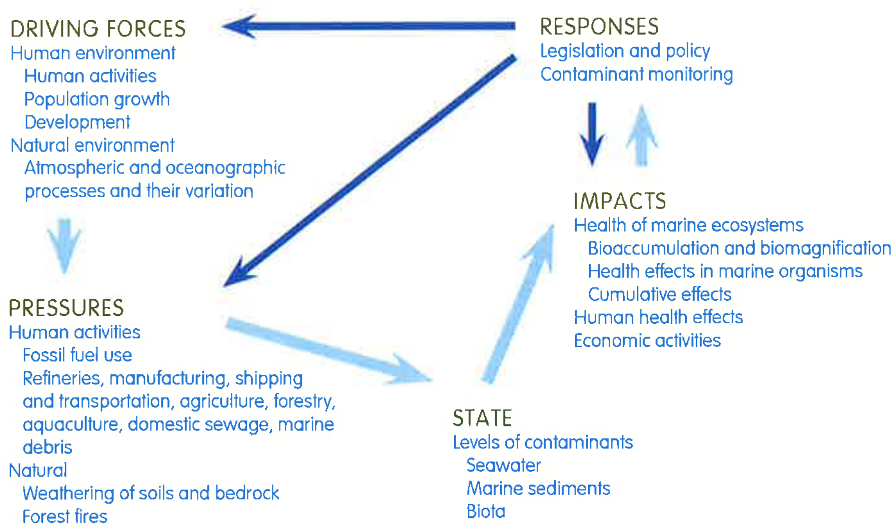


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to toxic contaminants in the Gulf of Maine. In general, the DPSIR framework provides an overview of the relation between different aspects of the environment, including humans and their activities. According to this reporting framework, 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.

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.

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."

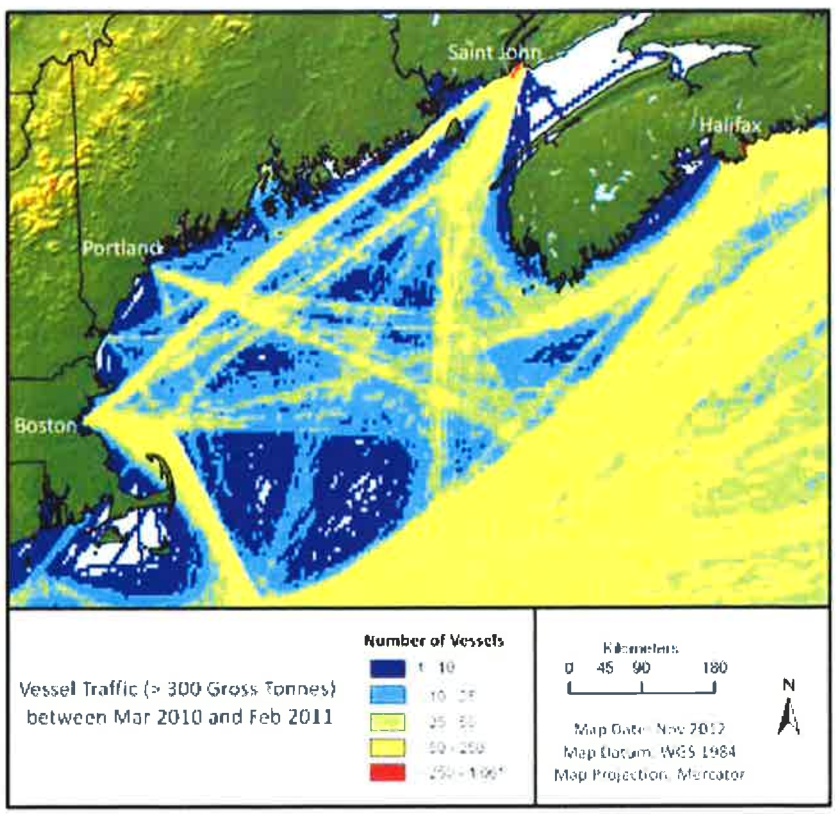


Figure 2: Vessel traffic in the Gulf of Maine from the Long Range Identification and Tracking (LRIT) system, March 2010-February 2011. This figure underestimates the total ship traffic in the Gulf as only vessels over 300 gross tonnage on international voyages are included. However, it does provide an 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).

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.

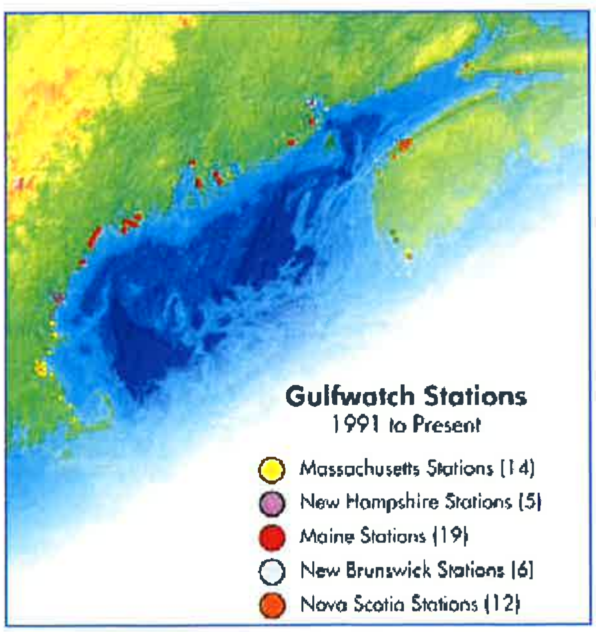


Figure 3: Location of Gulfwatch monitoring sites in the Gulf of Maine (Gulfwatch 2012).

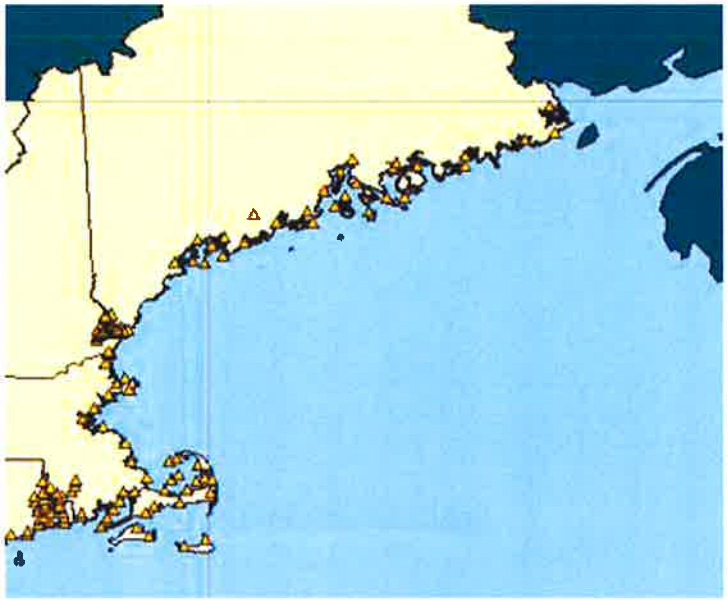


Figure 4: Location of NCA sampling stations in the Gulf of Maine in 2000 (US EPA 2010).

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 (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
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, Mierzykcwski 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

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

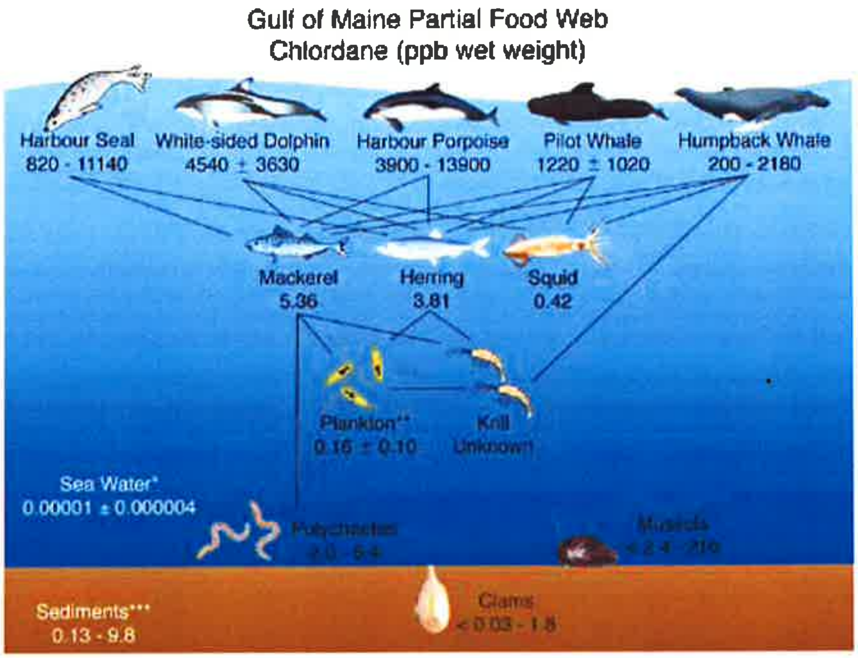


Figure 5. Biomagnification of chlordane in the Gulf of Maine food web. The concentration of chlordane increases at each trophic level in the food web. Sea water values are from the western Arctic Ocean, 1998-2001 (Hoekstra et al. 2003); plankton values are from the southern Gulf of St. Lawrence, 1993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

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.

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

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.

Gaskin DE, Holdrinet, M and Frank R. 1982. DDT residues in blubber of harbour porpoise, *Phocoena phocoena* (L), from Eastern Canadian waters during the five year period 1969–1973. In: Mammals in the seas. FAO Fish. Ser. (5) Vol. 4: 135–143.

Gaskin DE, Stonefield KI, Suda P and Frank R. 1979. Changes in mercury levels in harbour porpoises from the Bay of Fundy, Canada, and adjacent waters during 1969–1977. Arch. Environ. Contam. Toxicol. 8: 733–762.

Goodale MW, Evers D, Allen B, Ellis J, Hall S, Kress S, Mierzykowski S and L Welch. 2006. Mercury levels in seabirds in the Gulf of Maine. Report BRI 2006 - 08. Submitted to Gulf of Maine Council. BioDiversity Research Institute, Gorham, Maine. http://www.fws.gov/northeast/mainecontaminants/EC_Reports_and_Publications.html (accessed February 4, 2013).

Gottholm BW and Turgeon DD. 1992. Toxic contaminants in the Gulf of Maine. National Status and Trends Program for the Marine Environmental Quality. Rockville, MD: NOAA, U.S. Dept. Commerce. 15 pp.

Gulfwatch. 2012. About Gulfwatch Contaminants Monitoring Program. http://www.gulfofmaine.org/gulfwatch (accessed August 13, 2012).

Gustafson O, Buesseler KO, Rockwell Geyer W, Moran SB and Gschwend PM. 1998. An assessment of the relative importance of horizontal and vertical transport of particle-reactive chemicals in the coastal ocean. Continental Shelf Res. 18: 805–829.

Halling-Sorensen B, Nors Nielson S, Lanzky PF, Ingerslev F, Holten Lutzhoft HC and Jorgensen SE. 1998. Occurrence, fate and effects of pharmaceutical substances in the environment – a review. Chemosphere 36: 357-393.

Harding GC, Dalziel J, Sunderland E and Vass P. In prep. Mercury in the food web of the Bay of Fundy and approaches (Gulf of Maine).

Harding G, Dalziel J, and Vass P. 2003. Preliminary results of a study on the prevalence and bioaccumulation of methylmercury in the food web of the Bay of Fundy, Gulf of Maine. In: Collaborative Mercury Research Network (COMERN) 4th Annual Congress. November 5–7, 2003, St. Andrews, NB. Montreal: COMERN. pp. 73–74

Harding GC, LeBlanc RJ, Vass WP, Addison RF, Hargrave BT, Pearre Jr. S, Dupuis A and Brodie PF. 1997. Bioaccumulation of polychlorinated biphenyls (PCBs) in the marine pelagic food web, based on a seasonal study in the southern Gulf of St. Lawrence, 1976–1977. Mar. Chem. 56: 145–179.

Hauge P. 1988. Troubled waters: Report on the environmental health of Casco Bay. Boston: Conservation Law Foundation. 71 pp.

Health Canada. 2009. Mercury and Human Health. http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/merc-eng.php#mi (accessed August 13, 2012).

Hoekstra PF, O'Hara TM, Karlsson H, Solomon KR and Muir DCG. 2003. Enantiomer-specific biomagnifications of a-hexachlorocyclohexane and selected chiral chlordane-related compounds within an Arctic marine food web. Environ. Toxicol. Chem. 22: 2482–2491.

Houde M, Martin JW, Letcher RJ, Solomon KR and Muir DCG. 2006. Biological monitoring of polyfluoroalkyl substances: a review. Environ. Sci. Technol. 40: 3463–3473.

Johnson AC and Larsen PF. 1985. The distribution of polycyclic aromatic hydrocarbons in the surficial sediments of Penobscot Bay (Maine, USA) in relation to possible sources and to other sites worldwide. Mar. environ. Res. 15: 1–16.

Jones S, Krahforst K and Harding G. 2010. Distribution of mercury and trace metals in shellfish and sediments in the Gulf of Maine. In: P Lassus (ed), Proceedings of the 7th International Conference on Molluscan Shellfish Safety, June 14–19, 2009, Nantes, France. Versailles, France: Quae Publishing. pp. 308–315.

Jones SH, Krahforst C, White L, Klassen G, Schwartz J, Wells P, Harding GCH, Brun GL, Hennigar P, Page D, Shaw SD, Trowbridge P, Taylor D and Aube J. In prep. The Gulfwatch Program 1993–2008. A review of scientific results. Final report. Gulf of Maine Council on the Marine Environment. Will be available at: http://www.gulfofmaine.org/council/publications/

Kayal S and Connell DW. 1995. Polycyclic Aromatic Hydrocarbons in biota from the Brisbane River estuary, Australia. Estuarine Coast. Shelf Sci. 40: 475–493.

Kennicutt MC, Wade TL, Presley BJ, Requejo AG, Brooks JM and Denoux GJ. 1994. Sediment contaminants in Casco Bay, Maine: inventories, sources, and potential for biological impact. Environ. Sci. Technol. 28: 1–15.

Kidd KA and Mercer A. 2012. Chemicals of emerging concern in the Bay of Fundy watershed. Bay of Fundy Ecosystem Partnership (BOFEP) report. 21 pp. + app.

Kimbrough KL, Johnson WE, Lauenstein GG, Christensen JD and Apeti DA. 2009. Mussel watch program. An assessment of polybrominated diphenyl ethers (PBDEs) in sediments and bivalves of the US coastal zone. Silver Spring, MD: Center for Coastal Monitoring and Assessment. http://ccma,nos.noaa.gov/about/coast/nsandt/pdf/PBDEreport.pdf

Koropatnick T, Johnston SK, Coffen-Smout S, Macnab P and Szeto A. 2012. Development and applications of vessel traffic maps based on long range identification and tracking (LRIT) data in Atlantic Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2966. vi+29 pp.

Kuehl DW, Haebler R and Potter C. 1991. Chemical residues in dolphins from the U.S. Atlantic coast including Atlantic bottlenose obtained during the 1987/88 mass mortality. Chemosphere 22: 1071–1084.

Lake CA, Lake JL, Haebler R, McKinney R, Boothman WS and Sadove SS. 1995. Contaminant levels in harbor seals from the northeastern United States. Arch. Environ. Contam. Toxicol. 29: 128–134.

Larsen PF, Gadbois DF and Johnson AC. 1985. Observations on the distribution of PCBs in the deepwater sediments of the Gulf of Maine. Mar. Pollut. Bull. 16: 439–442.

Rapaport RA and Eisenreich SJ. 1988. Historical atmospheric inputs of high molecular weight chlorinated hydrocarbons to eastern North America. Environ. Sci. Technol. 22: 931–941.

Ray LE, Murray HE, Giam CS. 1983. Organic pollutants in marine samples from Portland, Maine. Chemosphere 12: 1031–1038.

Ray S and MacKnight SD. 1984. Trace metal distributions in Saint John Harbour sediments. Mar. Pollut. Bull. 15: 12–18.

Rios LM, Moore C, and Jones PR. 2007. Persistent organic pollutants carried by synthetic polymers in the ocean environment. Marine Pollution Bulletin 54: 1230-37.

Ross PS, Stern GA and Lebeuf M. 2007. Trouble at the top of the food chain: environmental contaminants and health risks in marine mammals. A white paper on research priorities for Fisheries and Oceans Canada. Can. Tech. Rep. Fish. Aquat. Sci.2734: viii + 30 pp.

Shaw SD. 2003. An investigation of persistent organic pollutants (POPs) and heavy metals in tissues of harbor seals (*Phoca vitulina concolor*) and gray seals (*Halichoerus grypus*) in the Gulf of Maine. Final report. Augusta, ME : Maine Department of Environmental Protection. 16 pp.

Shaw SD, Berger ML, Brenner D, Kannan K, Lohmann N and Papke O. 2009. Bioaccumulation of polybrominated diphenyl ethers and hexabromocyclododecane in the northwest Atlantic marine food web. Sci. Total Environ. 407: 3323–3329.

Shaw SD, Brenner D, Berger ML, Carpenter DO, Hong C-S, and Kannan K. 2006. PCBs, PCDD/Fs, and organochlorine pesticides in farmed Atlantic salmon from Maine, eastern Canada, and Norway, and wild salmon from Alaska. Environ. Sci. Technol. 40: 5347–5354.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Addink R. 2008. Bioaccumulation of polybrominated diphenyl ethers in harbor seals from the northwest Atlantic. Chemosphere 73: 1773–1780.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Storm R and O'Keefe P. 2007. Patterns and trends of PCBs and PCDD/Fs in northwestern Atlantic harbor seals: revisiting threshold levels using the new TEFs. Organohalogen Compounds 69: 1752–1756.

Shaw SD, Brenner D, Bourakovsky A, Mahaffey CA and Perkins CR. 2005. Polychorinated biphenyls and chlorinated pesticides in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic coast. Marine Pollut. Bull. 50: 1069–1084.

Shaw SD and Kannan K. 2009. Polybrominated diphenyl ethers in marine ecosystems of the American continents: foresight from current knowledge. Rev. Environ. Health 24(3): 157–229.

Simcik MF, Hoff RM, Strachan WMJ, Sweet CW, Basu I and Hites RA. 2000. Temporal trends of semivolatile organic contaminants in Great Lakes precipitation. Environ. Sci. Technol. 34: 361–367.

Skarphedinsdottir H, Gunnarson K, Gudmundsson GA and Nfon E. 2010. Bioaccumulation and biomagnifications of organochlorines in a marine food web at a pristine site in Iceland. Arch. Environ. Contam. Toxicol. 58: 800–809.

Sobek A, McLachlan MS, Borga K, Asplund, L, Lundstedt-Enkel K, Polder A and Gustafsson O. 2010. A comparison of PCB bioaccumulation factors between an arctic and a temperate marine food web. Sci. Total Environ. 408: 2753–2760.

Stein JE, Tilbury KL, Brown DW, Wigren CA, Meador JP, Robisch PA, Chan S-L and Varanasi U. 1992. Intraorgan distribution of chemical contaminants in tissues of harbor porpoises (*Phocoena phocoena*) from the northwest Atlantic. NOAA Tech. Memo, US Dep. Commer. NMFS-NWFSC-3. 76 pp.

Stewart PL and White L. 2001. A review of contaminants on the Scotian Shelf and in adjacent coastal waters: 1970–1995. Can. Tech. Rep. Fish. Aquat. Sci. 2351: xviii + 158 pp.

Sunderland E, Amirbahman A, Burgess NM, Dalziel J, Harding G, Jones SH, Kamai E, Karagas MR, Shi X and Chen CY. 2012. Mercury sources and fate in the Gulf of Maine. Environ. Res. In press. http://dx.doi.org/10.1016/j.envres.2012.03.011

Sunderland EM, Gobas FAPC, Heyes A, Branfireun BA, Bayer AK, Cranston RE and Parsons MB. 2004. Speciation and bioavailability of mercury in well-mixed estuarine sediments. Mar. Chem. 90: 91–105.

Tanabe S. 1999. Butyltin contamination in marine mammals – a review. Mar. Pollut. Bull. 39: 62–72.

Tuerk KJS, Kucklick JR, Becker PR, Stapleton HM, Baker JE. 2005. Persistent organic pollutants in two dolphin species with focus on toxaphene and polybrominated diphenyl ethers. Environ. Sci. Technol. 39:692–698.

US EPA. 2012. National Coastal Condition Report IV. United States Environmental Protection Agency Office of Research and Development/Office of Water, Washington, DC. EPA-842-R-10-003. http://water.epa.gov/type/oceb/assessmonitor/nccr/upload/NCCR4-Report.pdf (accessed January 6, 2013).

US EPA. 2010. National Coastal Assessment EMAP Mapping Application. http://www.epa.gov/emap/nca/html/data/mapuse.html.

US FDA. 2011. Fish and Fishery Products Hazards and Controls Guidance. Fourth Edition. U.S. Department of Health and Human Services, Food and Drug Administration. http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/Seafood/FishandFisheriesProductsHazardsandControlsGuide/default.htm (accessed August 13, 2012).

US FDA and US EPA. 2004. What You Need to Know About Mercury in Fish and Shellfish. http://www.fda.gov/food/foodsafety/product-specificinformation/seafood/foodbornepathogenscontaminants/methylmercury/ucm115662.htm (accessed August 13, 2012).

U.S. Fish and Wildlife Service. 2012. Maine Contaminants Program. http://www.fws.gov/northeast/mainecontaminants/index.html (accessed February 4, 2013).

Vorkamp K, Strand J, Christensen JH, Svendsen TC, Lassen P, Hansen AB, Laresen MM and Andersen O. 2010. Polychlorinated biphenyls, organochlorine pesticides and polycyclic aromatic hydrocarbons in a one-off global survey of bivalves. J. Environ. Monit. 12: 1141–1152.

TOXIC CHEMICAL CONTAMINANTS: REVIEW

STATE OF THE GULF OF MAINE REPORT

COMPANION DOCUMENT TO
TOXIC CHEMICAL CONTAMINANTS THEME PAPER

Gulf of Maine
Council on the
Marine Environment

May 2013

1. Issue in Brief

THE GULF OF MAINE IS BEING SUBJECTED TO AN EVER-INCREASING NUMBER of chemical contaminants that are being introduced by human activities both locally and globally. Some of these contaminants make seafood unsafe for human consumption, are quite toxic to coastal organisms and are suspected of altering ecosystem composition and functioning (Figure 1).

Humans first began to noticeably alter the planet by clearing the forests, cultivating the soil, sluicing the salt marshes or otherwise modifying the landscape. This led to increased soil erosion, leaching of heavy metals to the sea and increased siltation of estuaries, coastal habitats and basins. This stage was quite recent in the Gulf of Maine region, starting with the Acadian and New England settlers in the 1600s. Second, the invention of the steam engine in the 1770s culminated in the industrial revolution fueled by fossil fuels, first coal followed by oil and gas (Steffen et al. 2007). This introduced not only the greenhouse gases carbon dioxide (CO_2), methane (CH_3) and nitrous oxide (N_2O) to the atmosphere, but also contributed toxic organic hydrocarbons, such as polycyclic aromatic hydrocarbons (PAHs), that precipitate, settle or partition to the both terrestrial and aquatic environments. Third, a chemical industrial revolution followed in the middle of the twentieth century with a plethora of synthetic chemicals being created and produced for use in almost every human activity, from manufacturing, agriculture, aquaculture, and forestry to medicine and cosmetics.

Polycyclic aromatic hydrocarbons, organochlorines, organometals and metals are all well-documented contaminants of concern in the Gulf of Maine. Various research groups over the past thirty years have documented this contamination most comprehensively with tissue analysis of marine mammals and mussels. There are many more categories of contaminants that are known to be of environmental concern such as organobrominated compounds, perfluorinated compounds, organophosphates, pyrethroids, antibiotics, other pharmaceuticals, and steroidal hormones; however, there is limited information on them in the Gulf of Maine. Some contaminants are known to be highly toxic or disruptive to the normal physiology of marine organisms which results in species depletion and changes to the ecosystem (Johnston and Roberts 2009). Not surprisingly, some species are evolving a resistance to certain toxicants in contaminated areas. The evolution of resistance is more rapid the simpler the organism, such as bacteria, which is partly a reflection of their shorter generation times (Grimes et al. 1984; Barkovskii et al. 2010). An increased resistance and/or reduced genetic diversity have been found in benthic invertebrates living in areas heavily contaminated with hydrocarbons and metals (Klerks and Weis 1987; Levinton et al. 2003; Ross et al. 2002; Street and Montagna 1996). However, aquatic communities exposed to contaminants are universally reduced in biodiversity (Johnston and Roberts 2009) and resilience to further perturbations (Hooper et al. 2005). An additional concern is that a number of the organochlorines (OCs) and methylmercury (MeHg) have the additional property of incrementally increasing in concentration at each level of the marine

LINKAGES

See also the following theme papers in the State of the Gulf of Maine Report:

- Microbial pathogens and toxins
- Eutrophication
- Climate change and its effects on ecosystems, habitats and biota
- Climate change and its effects on humans
- Emerging Issues
- Toxic chemical contaminants

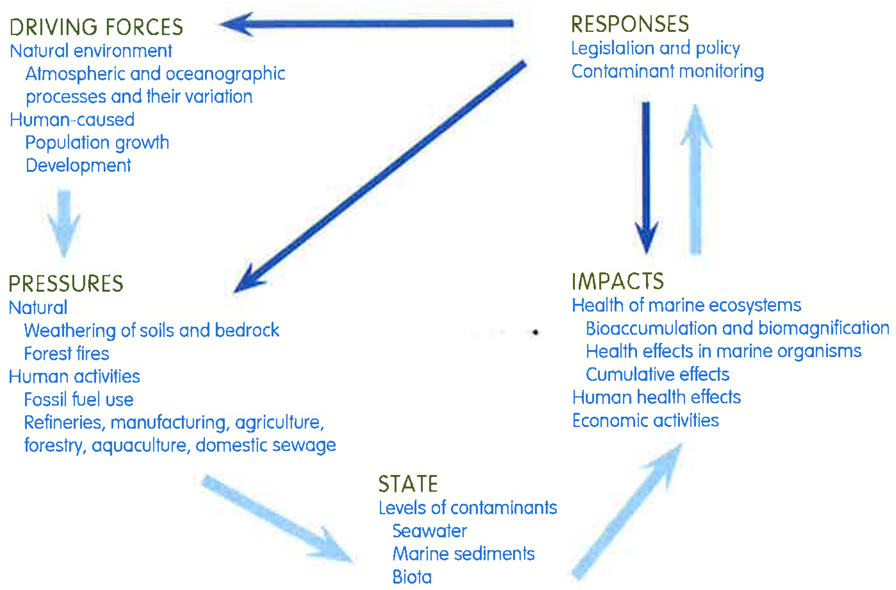


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to toxic contaminants in the Gulf of Maine. In general, the DPSIR framework provides an overview of the relation between different aspects of the environment, including humans and their activities. According to this reporting framework, 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.

Definitions of Terms

Bioaccumulation – the uptake and accumulation of a contaminant or element by an organism from food or seawater at a greater rate than that by which the substance is lost.
Bioconcentrate – the uptake of a contaminant directly from seawater.
Biodilution – the decrease in the concentration of an element or contaminant with each subsequent trophic level (step in the food chain).
Biomagnification – the increase in the concentration of a contaminant or element with each subsequent trophic level (step in the food chain). This means that consumers near the end of the food chain have higher levels of the element or contaminant than producers or consumers lower on the food chain.
Contaminant – any element or compound introduced into the environment by human activity.
Endocrine disrupter – an endocrine disrupter is an external chemical that has the ability to enter and deceive the endocrine system of an organism by altering its normal hormone synthesis.
Metabolize – a process by which organisms use and break down various substances they have ingested or absorbed.
ppb – parts per billion, expressed as ng/g dry or wet weight or µg/L.
ppm – parts per million, expressed as µg/g dry or wet weight or mg/L.
Pollutant – any contaminant that is known to be toxic to organisms.
Toxicant – a toxic substance made by humans or created by human activity.
Toxic – causes damage to organisms.
Trophic levels – the succession of steps from producers to ultimate consumer in a food chain.

Table 1: Primary sources of the major chemical contaminant groups in the Gulf of Maine as determined by this review, including past usage. The number of + signs indicates the degree to which each source contributes to levels of contaminants in the Gulf of Maine, with + indicating a small contribution and +++ a major contribution. The – sign indicates that the source does not contribute to levels of that contaminant.

	SOURCES						
Contaminants	NATURAL	URBAN	INDUSTRIAL	SHIPPING/ HARBOURS	AGRICULTURE: ANIMALS	AGRICULTURE & SILVACULTURE: CROPS	AQUACULTURE
PAHs	+	+++	+++	+	–	–	–
PCBs	–	++	+++	+	–	–	–
CHBs	–	–	–	–	–	+++	–
PCDDs/PCDFs	+	++	+++	–	–	–	–
∑DDT	–	+	–	–	–	+++	–
CBs	–	+	+	–	–	++	–
HCHs	–	+	–	–	–	+++	–
CHLs	–	+	–	–	–	+++	–
Mirex	–	+	–	–	–	+	–
Aldrin/Dieldrin	–	+	–	–	–	+++	–
OBs	–	+++	++	–	–	–	–
PFCs	–	+++	++	–	–	–	–
OPs flame retardants	–	+++	++	–	–	–	–
OPs pesticides	–	+	–	–	–	+++	+++
Pyrethroids/pyrethrins	+	+	–	–	–	+++	+++
Antibiotics	+	+++	+	–	+++	–	+++
Pharmaceuticals	–	+++	–	–	+++	–	–
Steroidal hormones	+	+++	–	–	+++	–	–
Butyltins	–	–	–	+++	–	–	–
Mercury/MeHg	+	++	+++	++	–	–	+
Trace metals	+	+	++	–	–	+	+

(PAHs are polyaromatic hydrocarbons; PCBs are polychlorinated biphenyls; CHBs are polychlorinated bornanes; PCDDs/PCDFs are dioxins and furans; ∑DDT is total DDT; CBs are chlorobenzenes; HCHs are hexachlorocyclohexanes; CHLs are chlordanes; OBs are organobromine compounds; PFCs are perfluorinated compounds; OPs are organophosphates).

2.1 NATURAL

A number of chemical elements and compounds, also known to be contaminants, are also introduced into the Gulf of Maine through natural processes. The weathering of continental crust involves the dissolution of the earth's elements, such as the metals (e.g., mercury), their transfer in the hydrosphere via groundwater to stream to river to estuarine to coastal environments and beyond. This process created the natural baseline in marine sediment layers that predated the European arrival that drastically altered both the terrestrial and aquatic environments. This has been documented for mercury from the sedimentary record in the bottom mud of Passamaquoddy Bay (Sunderland et al. 2010). Natural hydrocarbon seeps occur over fossil petroleum deposits and recent organic deposits. 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 polycyclic aromatic hydrocarbons (PAHs), dioxins and furans, and also metals like mercury.

The hydrosphere is the total mass of water on the planet. The water cycle, also known as the hydrologic cycle, is the movement of water around, over, and through the Earth, including its transformation into the different states of liquid (water), air (water vapour) and solid (ice).

Many contaminants enter the Gulf of Maine watershed primarily through atmospheric transport and deposition. The 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; Jurdao and Dachs 2008). Pesticides that have been banned in North America for 40 years but used in Central America, such as undegraded DDT, appear in present-day mussel monitoring programs in the Gulf of Maine (Jones et al. in prep). An array of chemicals, such as heavy metals, polycyclic aromatic hydrocarbons, alkanes and other hydrocarbons and one of the most toxic chemical groups known, the polychlorinated dibenzodioxins and furans (PCDD/DFs) are produced by combustion of fossil fuels for urban and industrial power, and by other human activities such as pulp and paper mills, chemical manufacturing, petroleum refining and metal smelting. This atmospheric input is inclusive of industrial stacks, domestic furnaces and transportation. The more troublesome chemicals, because of their toxicity and persistence, are those that have been created as pesticides and for high-pressure industrial use. The organohalides (e.g., PCBs, PFCs, PBDEs) are of particular concern because of their persistence, bioaccumulation and extreme toxicity in the environment.

Table 2: Percentage of Gulf of Maine Gulfwatch sites within each state/province with low, medium and high organic contaminant concentrations in blue mussels (Jones et al. in prep). Contaminants were grouped into three categories—low, medium and high—using cluster analysis, so that "low" and "high" means low and high relative to the other levels measured.

		AVERAGE-ALL CHEMICALS	Pest	tDDT	tChl	Dield	PCBs	PAHs
Mass.	Low	1%	0%	0%	0%	7%	0%	0%
	Medium	32%	21%	36%	29%	21%	14%	71%
	High	67%	79%	64%	71%	71%	86%	29%
N.H.	Low	6%	8%	8%	8%	8%	0%	0%
	Medium	71%	75%	75%	58%	83%	75%	58%
	High	24%	17%	17%	33%	8%	25%	42%
Maine	Low	31%	22%	22%	39%	39%	28%	33%
	Medium	55%	67%	56%	50%	50%	61%	44%
	High	15%	11%	22%	11%	11%	11%	22%
N.B.	Low	21%	0%	13%	25%	25%	13%	50%
	Medium	69%	88%	75%	75%	50%	88%	38%
	High	10%	13%	13%	0%	25%	0%	13%
N.S.	Low	67%	91%	82%	64%	36%	82%	45%
	Medium	29%	9%	18%	36%	55%	18%	36%
	High	5%	0%	0%	0%	9%	0%	18%

(PEST is sum of all pesticides, tDDT is total DDT, tCHL is total chlordanes, Dield is dieldrin, PCBs are polychlorinated biphenyls and PAHs are polyaromatic hydrocarbons).

3.2 ORGANOCHLORINES (OCS)

An organochlorine is an organic compound containing at least one covalently bonded chlorine atom, which makes them more highly persistent in the environment. The OCs considered here are those synthesized for either their toxicity as pesticides or stability at high temperatures for industrial uses.

Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a man-made mixture of 140 to 150 chlorinated biphenyl compounds of a possible 209, known as congeners. PCBs were originally recognized for their application as heat and pressure resistant lubricating oils in electrical capacitors and transformers in the 1920s (Cairns et al 1986; Frame et al. 1996). It has been estimated that 1.2 million tonnes have

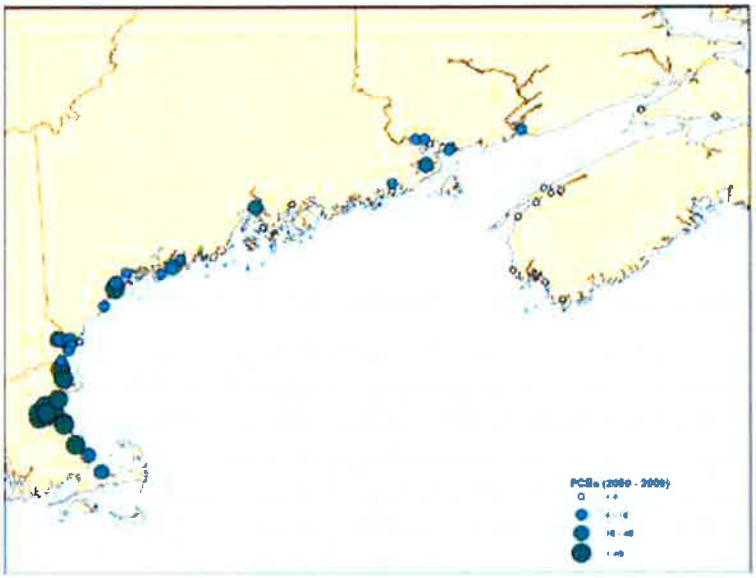


Figure 3: Average polychlorinated biphenyl (PCB) concentrations (ng/g dry weight) from the Gulf of Maine mussel monitoring (Gulfwatch) program between 2000 and 2009 (ESIP 2012).

et al. 2009).The prevalence of PCBs in the biota in the Gulf of Maine, combined with their persistence and toxicity, make them a present day concern despite the restriction and ban on their use in the 1970s.

Dioxins (polychlorinated dibenzo-p-dioxins; PCDDs) and Furans (polychlorinated dibenzofurans; PCDFs)

Some of the 210 congeners of PCDD/PCDFs are considered to be the most toxic man-made chemicals. They were never produced intentionally but are present everywhere both naturally as a combustion byproduct and as a result of industrial activities (Fletcher and McKay 1993). Agent Orange, a herbicide containing dioxin, was sprayed on forests in the Gulf of Maine watershed near Gagetown, New Brunswick in the 1960s to 70s (Wikipedia 2012). PCDDs and PCDFs have been measured in sediments of Casco Bay, Maine (Wade et al. 2008). The PCDD concentrations within Portland Harbor were slightly higher than at the mouth of the Casco Bay, indicating an urban source for PCDDs but not PCDFs. PCDD/PCDF concentrations in aquaculture salmon raised at Maine and New Brunswick sites were low with only 20% of the fish found to have levels above the analytical detection limit (Shaw et al. 2006). Trace amounts of PCDDs and PCDFs were detected in the blubber of a few harbour seals from the coast of Massachusetts (Lake et al. 1995). Shaw et al. (2007) reported extremely low PCDD/PCDF concentrations in the Gulf of Maine female and pup harbour seals, which may reflect a species specific degradation capacity. Bottlenosed whale samples, from the mass mortality of 1987/88 off the Atlantic coast of the United States, were in biota from the Gulf of Maine are relatively high decades after the pesticide's introduction in the 1950s because of the persistence of the equally toxic DDE breakdown product (Weisbrod et al. 2001).

Polychlorinated bornanes (CHBs)

Toxaphene, a product made up of polychlorinated bornanes, was widely used in the southern United States from 1947 as a pesticide on soybean and cotton crops until its gradual ban from 1982 to 1986 (Seleh 1991). It was the most widely used pesticide in North America in the 1970s as a replacement for the banned DDT. It was extensively used in the subtropics, and now has spread atmospherically to temperate and Arctic regions (Kidd et al. 1995; Li et al. 2001). Toxaphene was not reported as regularly as other organochlorines until quite recently because of practical problems related to quantifying the over 1000 constituent compounds (Korytar et al. 2003). CHBs were produced in quantities similar to PCBs (de Geus et al. 1999).

Studies found that both sexes of harbour porpoises collected between 1989 and 1991 from the Gulf of Maine had high levels of CHBs in the blubber (Westgate et al. 1997). Tuerk et al. (2005) reported similar CHB levels in juvenile, female and male Atlantic white-sided dolphins stranded on Cape Cod between 1993 and 2000. More research is needed in the Gulf of Maine as there is no information on the bioaccumulation or toxicity of these compounds on the more sedentary organisms lower in the food chain.

Chlorobenzenes (CBs)

Hexachlorobenzene (HCB) was used in industry and agriculture, mainly as a seed dressing for several crops to prevent fungal disease from the late 1940s to 1970s. HCB is the only CB found in measurable quantities in environmental samples of the Gulf of Maine. Sediment concentrations of HCB in the Gulf of Maine were lowest at the mouth of the Merrimack River, Mass., intermediate at the mouth of the Kennebec River, Maine and highest in Salem Harbor, Mass. (Hauge 1988). HCB was rarely detected (>2.4 ng per g dry) in the Gulf of Maine mussel tissues in the 1990s and 2000s (Jones et al. in prep). White-sided dolphin and pilot whale blubber samples collected from strandings near Cape Cod in the early to mid 1990s contained high concentrations of HCB in blubber (0.18±0.16 and 0.21±0.18 ppm wet weight respectively; Weisbrod et al. 2001). There is no obvious trend of HCB concentrations in harbour porpoises collected between 1973-77 (Gaskin et al. 1983) and 1989-91(Westgate et al. 1997). Low levels of HCB were found in the blubber of harbour seals with an almost twofold decrease observed between 1991 and 2001 (Shaw et al. 2005). A long-term study in the Arctic of HCB levels in seabird eggs indicates a decline in HCB levels between 1975 and 2003 (Braune 2007). HCB, therefore, is present throughout the Gulf of Maine but at much lower concentrations than the other organochlorines and its presence is declining.

Chlordanes (CHLs)

Technical chlordane is a manufactured pesticide that is a mixture of more than 140 compounds, of which trans- and cis-chlordane, heptachlor and trans- and cis-nonachlor are major components (Dearth and Hites 1991). Heptachlor is the most toxic component of the chlordane group, and its rapid breakdown product heptachor epoxide has been used as a pesticide in its own right. The presence of CHLs in the Gulf of Maine reflects the widespread historical application of this extremely persistent pesticide on agricultural and urban soils for about 40 years, including lawns and golf courses on the New England east coast (Phillips and Birchard 1991). It was used as a pesticide for seed crops, such as corn, from 1948 to the mid 1970s in North America.

The sediments of Boston Harbor, Merrimack River, Kennebec River and Portland Harbor had low ppb CHL concentrations (dry weight) in the 1980s (Figure 4; Ray et al. 1983; Hauge 1988). In a later study of Portland Harbor and Casco Bay in 1990, sediment CHL values were found to decrease towards the outer bay indicating either urban or riverine contamination of this harbor (Kennicutt et al. 1994). The associated polychaetes (worms) and clams from the 1980 Portland Harbor study had CHL values in the low ppb levels on a wet weight basis (Ray et al. 1983). Chlordane levels determined in mussels from around the Gulf of Maine between 1993 and 2008 were composed of the alpha-chlordane, trans-nonachlor, heptachlor and heptachlor epoxide isomers and were also in the low ppb range (Jones et al. in prep). Highest chlordane values for mussels were obtained along the Massachusetts shoreline indicating an urban influence (Table 2). Weisbrod et al. (2001) reported CHLs at ppm levels in white-sided dolphins and pilot whale blubber from stranded animals in the Cape Cod area from the early to mid 1990s (Figure 4), whereas their presumed prey, mackerel, herring and squid, contained only ppb CHL concentrations in whole ground organisms. The average CHLs measured in farmed Atlantic salmon fillets (with skin) from Maine and Canada ranged from about 7.5 to 24.5 ppb wet (Shaw et al. 2006). Humpback whales sampled in the Gulf of Maine in 2005/6 had lower ppm CHLs levels in blubber than either dolphins or pilot whales, as expected because they can feed lower in the food chain (Elfes et al. 2010). Blubber samples taken from stranded harbour seals from the Gulf of Maine and New England coast between 2001 and 2002 also ranged in the low ppm CHLs (Shaw et al. 2005). The above CHL values taken together illustrate how organochlorines, such as the chlordane group, bioaccumulate in the higher trophic levels of the Gulf of Maine (Figure 4).

Casco Bay was revisited in 1990 and sediment chlordane concentrations were found to be unchanged from the early 1980s in the immediate area of Portland Harbor (Ray et al. 1983; Kennicutt et al. 1994). CHL levels in mussels were found to be increasing over the 1993-2008 period at Merrimac River, Massachusetts and Limekiln Bay, New Brunswick; however, no trends were observed at the other 16 sites around the Gulf of Maine with six or more years sampled (Jones

1970s (Gaskin et al. 1983) and those sampled between 1989 and 1991 (Westgate et al. 1997). However, Lake et al. (1995) found an apparent twofold drop in cis-Chlordane and trans-nonachlor values in harbour seals from 1980 to 1990-92 on the New England coast. The lack of temporal trends in mussel CHL values since the 1990s throughout the Gulf of Maine (Jones et al. in prep) is consistent with CHL values reported for harbour seals collected between 1991 and 2001 (Shaw et al. 2005). This lack of change in recent CHL concentrations in mussel and seal studies in the Gulf of Maine is supported by the results of a time series analysis of 17 biota types in the Arctic with greater than six years of observations where only two species had decreasing concentrations (Riget et al. 2010).

It is estimated that 25 to 50% of the chlordane applied in the United States since the 1940s remains unaltered in the environment with unknown ecological consequences for the northern hemisphere (Shaw et al. 2005).

Mirex

Mirex is another organochlorine pesticide that was used extensively between 1958 and 1978 as both a fire retardant and a pesticide to control an epidemic of fire ants, originating from Europe, in the southeastern United States. Mirex was never used in agriculture in Canada. Mirex was found in the sediments of Casco Bay in 1991 in the low ppb range, with no indication of any concentration gradient out from Portland Harbor (Kennicutt et al. 1994). Mirex was not detected by the NOAA NS&T mussel monitoring along the coast of Maine between 1965 and 1970 (Butler 1973). Weisbrod et al. (2001) was unable to detect Mirex in mackerel, herring or squid in the Gulf of Maine, however white-sided dolphin and pilot whales were found to contain ppb levels in blubber, between the early and mid 1990s. Lake et al. (1995) reported Mirex at ppb levels in harbour seal blubber along the coast of Massachusetts in 1980 and around Long Island, NY, in 1990-92. Shaw et al. (2005) found ppb Mirex concentrations in blubber of female, male and yearling harbour seals along the Gulf of Maine coast between 2001 and 2002. Westgate et al. (1997) reported higher ppb Mirex levels in the blubber of male and female harbour porpoise collected between 1989 and 1991 from Grand Manan and Jeffreys Ledge in the Gulf of Maine. Stein et al. (1992) found ppb Mirex levels in the blubber of three harbour porpoises in 1991 from the Boston and Boothbay Harbor regions.

This is an example of an organochlorine used selectively in the southwestern United States over 30 years ago that is presently widespread at ppb levels in the higher trophic levels of the Gulf of Maine.

Aldrin/Dieldrin/Endrin

Aldrin, endrin and dieldrin are another organochlorine group widely used as pesticides in Canada and the United States for crops like corn and cotton from the 1950s to 1970s. Aldrin breaks down rapidly in the environment to dieldrin

Ledge, found lower levels than reported in an earlier study in the 1960s (Gaskin et al. 1983; Westgate et al. 1997). These marine mammal data are consistent with the decline in dieldrin concentrations in shellfish in the Gulf of Maine following the mid-1970s ban of this insecticide. Thus, dieldrin concentrations in bivalves and the blubber of harbour porpoise have decreased since the 1960s, following the North American ban on crop applications but appear to have levelled out since this time due to its environmental persistence.

3.3 ORGANOBROMINE COMPOUNDS

Organobromine compounds are organic compounds that contain carbon bonded to bromine. They are the most common organohalides naturally present in marine organisms although bromide is only 0.3% of the concentration of chloride in seawater. The application of concern here is the use of polybrominated diphenyl ethers (PBDEs) as fire retardants. PBDEs are a synthetic category of brominated aromatic compounds developed for their flame resistant properties for use in the production of domestic and commercial products such as polyurethane foam in upholstery, plastics and electronics. PBDEs are widespread persistent compounds that are bioaccumulated in the marine food chain and known to have a variety of toxic effects (see Shaw and and Kannan 2009).

PBDEs have not been measured in seawater in the Gulf of Maine but are reported in the pptr range elsewhere in marine waters (see Shaw and Kannan 2009). PBDEs were quantified at 2.5 ppb, on a dry weight basis, in sediments sampled off Massachusetts. In the Gulf of Maine there is clear evidence for food chain magnification with 21 to 143 ppb on a lipid basis, measured in blue mussels, 71 to 91 ppb in herring, 2340 ppb in herring gull eggs, 80 to 3827 ppb in harbour seal blubber, 610 to 2410 ppb in white-sided porpoise blubber and 8627 ppb in bald eagle eggs (Goodale et al. 2008; Kimbrough et al. 2009; Shaw et al. 2008; 2009; Tuerk et al. 2005). PBDE levels in herring gull eggs from colonies in the Bay of Fundy were low, at mid ppb wet weight, compared to inland Canadian colonies, which can be attributed to a reduced source due to lower human population densities (Chen et al. 2012). PBDEs have increased exponentially in marine life and humans since their introduction in the 1970s (Shaw and Kannan 2009).

Two other brominated compounds, tetrabromobisphenyl A (TBBPA) and hexabromocyclo-dodecane (HBCD), are currently unregulated alternatives to PBDEs as flame retardents. HBCD was present at ppb lipid in most fish specimens analyzed from the Gulf of Maine (Shaw et al. 2009). Low HBCD levels (ppb wet weight) were measured in eggs from herring gull colonies in the Bay of Fundy (Chen et al. 2012). Atlantic white-sided dolphins, stranded along the United States east coast, had concentrations ranging between 3 to 340 ppb HBCD in blubber lipid between 1993 and 2004 (Peck et al. 2008). However, TBBPA and rapid degradation in the environment. Diazinon (*O,O*-Diethyl *O*-[4-methyl-6-(propan-2-yl)pyrimidin-2-yl] phosphorothioate) is an OP pesticide that was used extensively in North America during the 1970s and early 1980s for domestic and agricultural purposes. Diazinon was measured in four of seven rivers flowing into the Gulf of Maine as recently as 1999 and 2000 in the low ppb range (Kolpin et al. 2002).

Azamethiphos (S-6-chloro-2,3-dihydro-2-oxo-1,3-oxazolo[4,5-*b*]pyridin-3-ylmethyl *O,O*-dimethyl phosphorothioate) is currently the only pesticide registered for "sea lice" removal from salmon grown in open sea pens in Canada. It is, therefore, a chemical of concern to east coast lobster fishermen. Azamethiphos has a short half-life in nature and therefore would have a limited effect on wild crustaceans (Ernst et al. 2001; Jackman et al. 2001). These properties make it difficult to quantify in seawater following aquaculture applications, so rhodamine dye was used to trace seawater as it dispersed from the cages (Ernst et al. 2001).

Organophosphate flame retardants

There has been renewed interest in OPs as flame retardants by chemical companies because of the recent human health concerns expressed by various American state governments about the possible toxic effects of organobromines used as flame retardants and plasticizers in household goods. California passed legislation to ban the use of polybrominated diphenyl ethers (PBDEs) as flame retardants in 2003, followed by eight other states and the European Union such that the only American manufacturer, Chemtura, voluntarily phased out production by 2004 (Levcik and Weil 2006; Stapleton et al. 2011). The OP replacements are man-made compounds that do not occur naturally, although other OPs make up the important building blocks for life, such as RNA and DNA. The chlorinated organophosphates, such as tris(2-chloroethyl) phosphate (TCEP) and tris(2-chloroisopropyl) phosphate (TCPP) are favoured as flame retardants in polyurethane foam, etc., whereas the non-chlorinated OPs, such as tris(2-butoxyethyl phosphate (TBEP), are mostly used as plasticizers.

Neither flame retardants nor plasticizers are chemically bonded so they are eventually emitted from the polyurethane or plastic surfaces on dust particles or volatized directly to the air. Studies on soil contamination have confirmed the importance of the atmospheric transport and deposition route of OPs by measuring their presence in field soils remote from urban and industrial centres (Fries and Mihajlovic 2011). However, sewage treatment plant outfalls are thought to be the biggest source of OPs escaping to the environment with the chlorinated OPs passing through the treatment process unscathed (Meyer and Bester 2004; Marklund et al. 2005). Two flame retardants (TCEP and TCPP) and one plasticizer (TBEP), have also been quantified in five of seven Massachusetts rivers sampled at >0.04 to 0.07 ppb and >01 to 0.16 ppb, and >0.2 to 0.62 ppm respectively (Barnes et al. 2002; Kolpin et al. 2002). There are presently no measurements of OPs for

3.7 PHARMACEUTICALS

The pharmaceuticals, as human and animal medicines are known, are often referred to as "emerging" categories of environmental contaminants. In fact, certain pharmaceuticals, such as a blood pressure lowering substance, were first detected thirty years ago in treated wastewater in the United States (Garrison et al. 1976). New analytical techniques developed in the last fifteen years have enabled trace quantities of polar compounds to be detected (Fent et al. 2006). There are currently estimated to be 3000 pharmaceuticals in use in Europe (Fent et al. 2006). Sewage treatment effluents have been well documented as a major source of pharmaceuticals to surface and ground waters that ultimately reach the sea (Halling-Sorensen et al. 1998; Metcalfe et al. 2004; Gros et al. 2007; Kasprzyk-Hordern et al. 2008; Schultz et al. 2010). Sewage treatment plants are unable to efficiently remove most pharmaceuticals with the exception of analgesics and anti-inflammatories (Fent et al. 2006). Many treatment plants around the Gulf of Maine are primary treatment (solids) at best. A number of these chemicals are also used as veterinary pharmaceuticals to improve growth and health in livestock and poultry operations, and these also end up in surface runoff from manure spread on fields and from farm effluent. Pharmaceuticals are also used in the aquaculture of fish species in sea pens.

The pharmaceuticals are an exceptionally chemically-diverse group of drugs best described here by usage, such as analgesics and non-steroidal anti-inflammatory drugs, beta-blockers, blood lipid lowering agents, cancer therapeutics, neuroactive compounds, synthetic steroidal hormones, antidiabetics, antiepileptics , X-ray contrast drugs, antiacids, broncodilators, antibiotics, biocides, stimulants and others. There has been little attention paid to pharmaceuticals entering the Gulf of Maine with the exception of the continental United States Geological Survey of 1999 and 2000, which included several rivers in Massachusetts.

Analgesics

A widely used analgesic, acetaminophen, and an analgesic/anti-inflammatory, ibuprofen, were found in Massachusetts rivers draining into the Gulf of Maine (Kolpin et al. 2002).

Synthetic steroidal hormones

Steroidal estrogens, used for human birth control pills, have been measured in Massachusetts rivers draining into the Gulf of Maine (Kolpin et al. 2002).

Antibiotics

The United States Geological Survey examined 139 waterways across the nation for chemical contaminants and found measureable quantities of 8 out of 29 antibiotics analyzed in Gulf of Maine rivers (Kolpin et al. 2002).

of TBT in their liver compared to oceanic species and cetaceans have higher concentrations of TBT in industrialized as compared with developing nation coastal waters (Tanabe 1999).

Tributyltin concentrations in Casco Bay sediments declined dramatically over a ten-year period following the introduction of paint restrictions on small boats in 1988, such that only two sites had levels above 15 ppb tin dry weight (maximum 60 ppb) in 2001 compared to seventeen sites scattered throughout the bay in 1991 (Wade et al. 2008). A similar decline was observed with oyster data from Galveston Bay between 1986 and 1994 (Jackson et al. 1998) and near Miami between 1988 and 1994 (Cantillo et al. 1997). The NOAA mollusc monitoring group reported only decreasing trends for butyltins at ~25% of the 196 sites sampled for the entire United States between 1986 and 1996 (O'Connor 1998). There is no comparable local information on marine mammals; however, butyltins have declined in Pacific sea otters and cetaceans since restrictions were introduced in the late 1980s (Murata et al. 2008; Tanabe 1999).

Mercury and methylmercury

Mercury is a natural element of the earth's crust that can be toxic to life at high concentrations. Mercury, in its many forms, is very mobile in the marine environment with methylmercury being the most toxic and only biomagnified form in aquatic food chains (Sunderland et al. 2012). Past anthropogenic inputs to the marine environment were through pesticide and pharmaceutical use and from industrial sites such as gold mining, chlor-alkali production and pulp and paper plants (Sunderland and Chmura 2000a). Mercury also has a long history of being introduced into the aquatic environment from the combustion of wood, coal and other petroleum products, which has proven to be more difficult to control and legislate than other sources (Sunderland and Chmura 2000b).

Mercury is transported via particulate matter and is concentrated in depositional areas in the Gulf of Maine: tidal flats, salt marshes, and deep basins (Dalziel et al. 2010; Hung and Chmura 2006; Sunderland et al. 2012). The mercury content of Bay of Fundy fine-grain sediments ranged between 0.02 and 0.09 ppm dry weight with highest values in Saint John Harbour, New Brunswick (Loring 1979; Loring et al.1996; Ray and MacKnight 1984). The sediments in Passamaquoddy Bay, New Brunswick ranged from 0.01 to 0.1 ppm dry weight (Sunderland et al. 2004).

Phytoplankton (25-63 μm size range) sampled at the approaches to the Bay of Fundy between 2000 and 2002 contain a median of 2.8 (range 1.9–4.3) ppb total mercury wet weight (Harding et al. in prep.). Mercury levels in filter-feeding blue mussels collected by Gulfwatch in the Gulf of Maine ranged between 0.04 and 0.60 with a median of 0.17 ppm total mercury wet weight from 51 locations around the Gulf of Maine between 2003 and 2008 (Jones et al. in prep). Copepods, predominantly filter-feeding *Calanus*, from surface plankton tows in recently with Canadian and American sources of lead being distinguishable by their isotopic ratios (Knowlton and Moran 2010).

Trace metals have been measured in sediments at various locations around the Gulf of Maine since the late 1970s (Larson 1992; Gottholm and Turgeon 1992; Loring 1979). Sediment studies of the late 1980s found that Boston and Salem Harbors, Massachusetts, had consistently the highest values of lead, cadmium, copper, chromium, nickel and zinc in the Gulf of Maine. The mid-Maine coastal embayments have been studied from the 1980s and been found to have moderate enrichment of arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc over pre-colonial conditions (Wade et al. 2008; Larsen and Gaudette 2010). The St. Croix estuary and Passamaquoddy Bay study results suggest that only cadmium and perhaps lead and zinc may be above the natural levels of the pre-colonial period due to human activity (Loring et al. 1998).

The seven trace metals analyzed in blue mussels by Gulfwatch between 1993 and 2008 were present at a wide range of concentrations from just above detection level to relatively elevated levels (Table 3). Median mercury and lead

Table 3: Percentage of Gulf of Maine Gulfwatch sites within each state/province with low, medium and high trace metal concentrations in blue mussels (Jones et al. in prep). Contaminants were grouped into three categories—low, medium and high—using cluster analysis, so that "low" and "high" means low and high relative to the other levels.

		AVERAGE-ALL CHEMICALS	Hg	Ag	Cd	Pb	Ni	Zn	Cr	Cu
Mass.	Low	12%	17%	7%	33%	0%	20%	0%	13%	7%
	Medium	57%	75%	27%	60%	40%	67%	73%	67%	47%
	High	31%	8%	67%	7%	60%	13%	27%	20%	47%
N.H.	Low	9%	0%	42%	8%	0%	8%	0%	8%	8%
	Medium	42%	30%	42%	25%	75%	33%	58%	17%	58%
	High	48%	70%	17%	67%	25%	58%	42%	75%	33%
Maine	Low	38%	29%	39%	39%	44%	39%	50%	39%	28%
	Medium	50%	57%	56%	44%	39%	50%	33%	56%	67%
	High	12%	14%	6%	17%	17%	11%	17%	6%	6%
N.B.	Low	38%	50%	38%	25%	63%	38%	13%	38%	38%
	Medium	41%	17%	38%	50%	38%	38%	75%	38%	38%
	High	20%	33%	25%	25%	0%	13%	13%	25%	25%
N.S.	Low	40%	60%	45%	45%	36%	18%	45%	18%	55%
	Medium	47%	40%	45%	27%	55%	55%	36%	82%	36%
	High	13%	0%	9%	27%	9%	27%	18%	0%	9%

Chemical symbols: mercury (Hg), silver (Ag), cadmium (Cd), lead (Pb), nickel (Ni), zinc (Zn), chromium (Cr) and copper (Cu).

Table 5: Increasing/decreasing trends for contaminants in blue mussel tissue at Gulfwatch sites that have been sampled for n = 4 or 5 years (Jones et al. in prep).

SITE n = 5	CONTAMINANT	TREND DIR.
Massachusetts		
Brewster Island	DDT	–
Boston inner harbor	Ag	–
	Dieldrin	–
Marblehead	Dieldrin	+
Maine		
Boothbay Harbor	Cr	–
	Cu	–
	DDT	–
	Pb	–
	Pest	–
Brave Boat Harbor	DDT	+
	Pest	+
Cobscook Bay	Chl	–
Dalmariscotta	Ag	+
	DDT	–
	Pest	–
Presumpscot River	PCB	+
Royal River	DDT	+
	PAH	+
	Pest	+
New Brunswick		
Tin Can Beach	Ag	–
	LWPAH	+
New Hampshire		
North Mill Pond	Ag	+
	Chl	–
	HWPAH	+
	PAH	+
Nova Scotia		
Argyle	Cd	–
	Cr	–
	Ni	–
	Zn	–
Spechts Cove	PAH	+

SITE n = 4	CONTAMINANT	TREND DIR.
Massachusetts		
Duxbury	Cd	–
	DDT	+
	PAH	+
	Pest	+
Ipswich	Ni	+
Plymouth – Manomet Point	Ag	–
	LWPAH	+
New Hampshire		
Pierce Island	Pb	–
	Pest	–
South Mill Pond	Cd	+
	Pb	+
	Zn	+

Chemical symbols: Ag (silver), Cd (cadmium), Cr (chromium), Cu (copper), Hg (mercury), Ni (nickel), Pb (lead) and Zn (zinc). Pest is the sum of organochlorine pesticides, Chl is the sum of all chlordanes, PCB is polychlorinated biphenyls, PAH is polyaromatic hydrocarbons, LWPAH is low weight PAHs, HWPAH is high weight PAHs.

4. Impacts

The anticipated impacts of the known contaminants in the Gulf of Maine are summarized below (see Table 6).

Table 6: Anticipated impacts of the contaminant categories found in the Gulf of Maine.

CONTAMINANT GROUP	PERSISTENT	ATMOSPHERICALLY TRANSPORTED	BIOMAGNIFIED	TOXIC	CONCERN LOCAL*	CONCERN GLOBAL
Polycyclic aromatic hydrocarbons	No	Yes	No	Yes/No	Yes	Yes
Organochlorines	Yes	Yes	Yes	Very toxic	Yes	Yes
Perfluorinated compounds	Yes	Probably	Yes/No	Very toxic	Yes	Yes
Organobromines	Yes	Yes	Yes	Very toxic	Yes	Yes
Organophosphates	No	Yes	No	Very toxic	Yes	No
Pyrethroids	No	No	No	Very toxic	Yes	No
Antibiotics	No	No	No	No	Yes	Yes
Pharmceuticals	No	No	No	No	Yes	No
Steroidal hormones	No	No	No	No	Yes	No
Organometals	Yes	Yes/No	Yes/No	Very toxic	Yes	Yes
Trace elements	Yes	Yes	No	Yes/No	Yes	No
Sweeteners	Yes	No	No	No	No	No
Stimulants	No	No	No	No	No	No
Disinfectants	No	No	No	Yes	No	No
Deicing fluid	No	No	No	Yes	Yes	No
Insect deterrent	No	No	No	No	No	No

* Gulf of Maine

4.1 POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

PAHs are of particular concern because of their mutagenic, carcinogenic and endocrine-disrupting effects on organisms and threat to human health (Bostrom et al. 2002; Santodonato 1997; Villeneuve et al. 2002). PAHs are bioaccumulated by benthic organisms (Pruell et al. 1986; Jones et al. in prep); however they are not known to biomagnify in aquatic food webs but rather have reduced concentrations further up the food chain due to the more efficient metabolic degradation in higher trophic organisms (Kayal and Connell 1995; Nakata et al. 2003; Wan et al. 2007). Nonetheless, coastal tissue levels of PAHs are close to levels that can impair reproduction, growth and cause larval mortality in salmon (Heintz et al. 1999). There is growing evidence that the lowest marine trophic level, the phytoplankton,

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)

PCDDs are the most toxic, man-made chemicals unintentionally released into the environment. Marine organisms take up PCDDs and PCDFs from the water, sediment and their prey (Pruell et al. 2000). Biodilution (decreasing concentrations through the food chain) was observed in a marine food chain of phytoplankton/seston, zooplankton, crab, shrimp, scallop, six species of fish, and gulls (Wan et al. 2005). The discrepancy between the behaviour of PCBs and PCDD/PCDFs in aquatic food webs appears to be due to the ability of organisms to metabolize the latter compounds (Pruell et al 2000).

DDT and its Metabolites (total DDT)

DDT is implicated for its endocrine disrupting properties in developing embryos (Guillette et al. 1994). It is known to be estrogenic and a potent anti-androgen (male hormone) thought to affect male reproductive health in humans and other animals (Gray et al. 2001; Toppari et al. 1996). DDT is biomagnified a thousand-fold between predator and prey in both white-sided dolphins and pilot whales in the Gulf of Maine if herring and mackerel were their chief food source, respectively (Weisbrod et al. 2001). Of the total DDT in the dolphin and whale, 93 and 86% respectively was in a degraded form, of which 79 and 77% was DDE. Nevertheless DDE has comparable toxicity to DDT.

Chlorobenzenes (CBs)

HCB is known to cause cancer in experimental animals, thus Environment Canada lists it as toxic in the Canadian Environmental Protection Act (CEPA). Hexachlorobenzene (HCB) is bioaccumulated at the higher trophic levels in the Gulf of Maine.

Hexachlorocyclohexane (HCHs)

Lindane (γ-HCH) is a toxin that primarily affects the nervous system and may be carcinogenic. HCHs are bioaccumulated in the marine food chain but not to the extent of other organochlorines with higher octanol-water partitioning coefficients (log K_{ow}).

Chlordane (CHLs)

Chlordane is a persistent and neurotoxic substance that is transported long distances through the atmosphere (Bidleman et al. 2002). Chlordane is highly toxic to birds in their food and freshwater fish at ppb water levels in 96-hour LC50 tests (US EPA 1986). It is estimated that 25 to 50% of CHL applied in the United States since the 1940s still remains unaltered in the environment (Shaw et al. 2005). It readily biomagnifies in aquatic food chains (Figure 4), although its compositional pattern is known to differ among different trophic levels and species (Norstrom et al. 1988; Kawano et al. 1988).

4.5 ORGANOPHOSPHATES (OPS)

Organophosphate pesticides

OP pesticides are used to control insect and crustacean pests by disabling their nervous systems. Diazinon, used agriculturally, is also a powerful neurotoxin for rainbow trout and has a high toxicity, particularly to birds.

Ernst et al. (2001) compared the toxicity of azamethiphos for a broad range of marine phyla, from bacteria to protistes to echinoderms to polychaetes to crustaceans to fish, and found that the crustaceans were the most susceptible. The toxicity of azamethiphos to planktonic lobster larvae has been well researched (Burridge et al. 1999; Burridge et al. 2000). Azamethiphos is also acutely toxic to adult lobster at 25 ppb over 15 to 20 minutes, which is a much lower concentration than the 300 ppb applied to fish pens for control of "sea lice" infestations of salmon (Burridge et al. 2000). The effect of azamethiphos on adult female lobsters was found to be most adverse from June through September, which coincides with the moulting, breeding and larval release period in nature (Burridge et al. 2005). It was found that repeated applications of azamethiphos to female lobsters in the lab to hundredfold lower concentrations than used in the sea pens (10 ppb) resulted in 43 to 100% mortality (Burridge et al. 2008).

Plume studies in the Bay of Fundy following a realistic experimental release of azamethiphos and rhodamine tracer dye from salmon pens demonstrated that the dispersing water was not toxic to a benthic crustacean after 20 minutes with few fatalities earlier (Ernst et al. 2001). A benthic crustacean (amphipod) was found to have a lethal dose for 50% of the individuals after a 10-day sediment exposure to approximately 200 ppb azamethiphos (Mayor et al. 2008). Dispersion and toxicity studies have shown that azamethiphos use in salmon pens presents a low to medium risk to the surrounding environment due to its water solubility and low persistence, with an estimated half-life of nine days (Burridge et al. 1999; Jackman et al. 2001).

Diazinon and azamethiphos do not bioaccumulate in aquatic food chains and have low persistence in the environment.

Organophosphate flame retardants

OPs have not been quantified in the marine food chain, although the physical-chemical properties of TCPP and TDCP indicate the possibility of their bioaccumulation in marine organisms (Reemtsma et al. 2008). Support for this prediction is provided by measurements on Baltic herring collected in 2007 with levels at 42-150 ppb TCPP and 2-3.4 ppb TCEP in lipid, although TBEP was below the detection limit (Sundkvist et al. 2010). Organophosphate flame retardants are carcinogenic, toxic, and environmentally persistent (WHO 1998).

the possible exception of the analgesic diclofenac and carbamazepine in fish (Schwaiger et al. 2004). A review of the known contaminants entering the Bay of Fundy from sewage treatment plants is available (Kidd and Mercer 2012).

Analgesics

Ibuprofen has the highest acute toxicity to algae and zooplankters at 8-10 ppm compared to fish at >100 ppm (Fent et al. 2006).

Synthetic and natural steroidal hormones

The steroidal estrogens of human origin are known endocrine-disrupting chemicals that bind with estrogen receptors of wild species with the potential to have an effect at extremely low concentrations. The synthetic 17α-ethynylestradiol has been found to be an order-of-magnitude more potent at inducing a vitellogenin response (egg protein production) in juvenile female trout (Thorpe et al. 2003). The steroidal estrogens, altogether, have an accumulative effect. It is well established that male fish subjected to estrogens in freshwater take on secondary female characteristics that results in reproductive impairment (Mills and Chichester 2005). More recently, Kidd et al. (2007) have demonstrated that a three-year exposure of minnows to parts per trillion concentrations of ethynylestradiol (ng/L) in an experimental lake resulted in the near extinction of this population. As we have seen earlier, treated sewage water ends up in our groundwater and marine coastal waters, which is of concern for municipalities, human consumption and marine fish. The presence of androgens in the water is known to cause pheromonal responses of young male salmon at concentrations as low as 0.003 pptr of testosterone (Moore and Scott 1991). This response of immature males could result in biochemical, as well as behavioural changes, that would be energetically wasteful and increase their risk to predation (Kolodziej et al. 2003).

Antibiotics

Microorganisms are developing an increasing resistance to antibiotics used in human and veterinary medicine and from large-scale livestock operations and aquaculture (Tenover and Hughes 1996; Reboucas et al. 2011; Beleneva 2011). Rhodes et al. (2000) have provided evidence for a connection between human and aquaculture environments in Northern England via tetracycline resistance-encoding plasmid exchange between *Aeromonas* species and *Escherichia coli*. The increasing presence of antibiotic resistant bacteria has the potential to become a problem for food production and a human health hazard. Oxytetracycline resistant species of *Pychrobacter* were found to be able to grow in Bay of Fundy sediments within 100 m of salmon pens at concentrations up to 160 µg/ml (Friars 2002). Antibiotics are known to have toxic effects on phytoplankton, particularly cyanobacteria; however, effects in zooplankton are minimal (Lanzky and Halling-Sorensen 1997; Guo and Chen 2012).

Mercury and methylmercury

Mercury is likewise very persistent in sediments as evidence shows for Passamaquoddy Bay, New Brunswick (Sunderland et al. 2010). Mercury is extremely toxic when it is converted to methylmercury in estuarine and coastal sediments by sulfate reducing bacteria (Compeau and Bartha 1985) and little understood processes in the marine water column (Topping and Davis 1981; Monperrus et al. 2007). Most sediment values measured in the Gulf of Maine are well below the threshold effects levels of 0.13 ppm and a probable effects level of 0.7 ppm dry weight derived for marine biota (MacDonald et al. 1996). Mercury toxicity levels in seafood are exacerbated by the biomagnification of methylmercury in aquatic food webs (Bargagli et al. 1998; Campbell et al. 2005; Hammerschmidt and Fitzgerald 2006) such that the terminal predators can contain unacceptable quantities for human consumption (Sunderland 2007). Methylmercury is a strong neurotoxin to humans (Grandjean et al. 1997). The tunas, swordfish, sharks and fish-eating mammals at the top of the marine food chain attain the highest levels of methylmercury; however, these levels do not appear to be detrimental to these predators themselves and there is some evidence that they have evolved selenium sequestration to counter the neurologic effects of methylmercury (Palmisano et al. 1995; Ikemoto et al. 2004; Branco et al. 2007).

4.9 TRACE ELEMENTS

Certain trace metals are essential for the healthy growth of plants and animals, such as copper, zinc, cadmium and iron but concentrations above certain thresholds can be toxic. Many trace elements are toxic to organisms such as arsenic, lead, mercury and selenium. It is well known that the methylated forms of arsenic and mercury are the most toxic. Thus, knowing the total concentration (all forms) of a potentially toxic trace element may be insufficient to assess its toxicity. Marine fish, in general, are equivalent to or 10 to 100 times less sensitive to toxic metals compared to invertebrates that have been studied, chiefly crustaceans and molluscs (Taylor et al. 1985). Moulting and reproduction in crustaceans are adversely affected by certain trace metals (Fingerman et al. 1996). Many trace metals are accumulated in organisms both directly from seawater and from their food, but they are not biomagnified in marine food chains because they are efficiently excreted (Wang 2002). Selenium can be an exception to this in certain trophic conditionis (Stewart et al. 2004).

Sediment studies of the late 1980s found that lead and chromium values were above the median biological effects range established by Long and Morgan (1990) in several bays and harbours of the Gulf of Maine. Measurements taken by the Gulfwatch program found that the Mussel Watch continent-wide mercury level of concern (85th percentile, 0.296 ppm dry weight) was exceeded in four urbanized regions: Penobscot Bay, Casco Bay, Great Bay estuary, and in and near Boston

5. Actions and Responses

5.1 LEGISLATION

Major pieces of legislation to restrict complex mixtures of chemical contaminants from entering U.S. and Canadian waters from industrial effluents, agricultural runoff, mining seepage and municipal wastewater treatment plant discharges were enacted in the late twentieth century as the United States *Toxic Substances Control Act* (1976) and the *Canadian Environmental Protection Act* (1999) and *Fisheries Act* (1972).[1] The EPA and Environment Canada use the *Toxic Substances Control Act* and the *Fisheries Act*, respectively, to impose guidelines and regulations, testing requirements, reporting and recording of chemical mixtures or substances to protect human health and the environment. These laws are enforced both by monitoring for select deleterious substances and by biological toxicity testing on effluents with standard organisms, usually rainbow trout and Cladocera (crustaceans). The EPA and individual states register pesticides under the *Federal Insecticide, Fungicide and Rodenticide Act* and establish tolerances for pesticides in food under the *Federal Food, Drug and Cosmetic Act*. In Canada, pesticide use is overseen by the *Pest Control Products Act* and the *Food and Drug Act*, both administered by Health Canada. The EPA establishes standards of wastewater release in surface waters under the *Clean Water Act*. The United States *Pollution Prevention Act* established a policy of pollution prevention, wherever possible, at source, as in Canada. The proliferation of synthetic chemicals and their often-inadvertent introduction to the environment has caused rising concern by the public, medical profession and in the scientific community for both human and ecosystem health. This has led to the regulation of organic contaminants by both national and international agencies (Table 7). In 2001, the United Nations Environmental Programme Governing Council banned the use of 12 organic compounds that are resistant to degradation, bioaccumulate, are toxic, and are subject to long-range atmospheric transport (Stockholm Convention 2012). The so-called "dirty dozen" are aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and polychlorinated bornanes (UNEP 2012). It has been suggested that carcinogenic polycyclic aromatic hydrocarbons, brominated flame retardants and butyltin should be included. The Organisation for Economic Co-operation and Development (OECD) and the United Nations, through the International Maritime Organization (IMO), also evaluate and classify the hazards of industrial chemicals that are shipped worldwide under international agreements, such as MARPOL 72/78.

[1] This discussion of legislation reflects the situation as of May 2012.

CONTAMINANT	RESPONSE
Perfluorinated compounds (PFCs)	• PFOS-based compound production voluntarily stopped by a major corporation (3M 2000). • New law formulated to regulate PFOS (US EPA 2002). • PFOS and POSF banned by the Stockholm Convention on Persistent Organic Pollutants in 2009. • PFOA – EPA requested 8 manufacturers voluntarily cease production (2006) (http://www.epa.gov/opptintr/pfoa/pubs/pfoastewardship.htm) • PFCAs continue to be produced worldwide.
Organphosphate pesticides	• OPs generally banned for residential use by EPA in 2001 but used for fruit and vegetable agriculture and for pest control in public places. • Diazinon banned in the United States in 2004 for all domestic and non-agricultural uses such as sod farms and golf courses. • Agricultural use of azamethiphos to be restricted in fruit and vegetable farming (EPA in 2001). • Azamethiphos was used for "sea lice" in finfish aquaculture in Canada until 2005 but in 2009 reinstated on an emergency status (Health Canada, Pest Management Regulatory Agency, 2009).
Pyrethrum and Pyrethroids	• Pyrethrum was allowed temporary registration for salmon aquaculture in the 1990s. • Cypermethrin is used in Maine aquaculture operations for "sea lice" control but it is not registered for use in aquaculture in Canada. • Deltamethrin was given emergency registration in Canada in 2009 (Health Canada, Pest Management Regulatory Agency, 2009).
Avermectins	• Ivermectin was used as an "off-label" treatment in the 1990s regulated by Health Canada under veterinary prescription. • Emamectin benzoate was regulated until 2009 under Health Canada's Emergency Drug Release program; in June 2009 it was registered for use under the *Food and Drugs Act.* • Emamectin benzoate is regulated by the United States Food and Drug Administration (FDA) under an Investigational New Animal Drug (INAD) exemption.
Pharmaceuticals	• FDA guidance for environmental assessment necessary if any human drug is expected to exceed 1 ppb wet weight in the aquatic environment (FDA-CDER 1998). • FDA have required environmental assessments of veterinary drugs since 1980 (Boxall et al. 2003).
Organotin compounds	• The US *Organotin Anti-fouling Paint Act* of 1988 and similar Canadian legislation in 1989 regulated tributyltin application to boats less than 25m in length. • The International Maritime Organization proposed to ban organotin antifouling paints in 2003 and ban their presence on ships by 2008 (http://www.imo.org/OurWork/Environment/Ati-foulingSystems?Documents/FOULING2003.pdf).
Methylmercury	• Canada has 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 of 0.5 µg/g wet weight. The FDA in the United States has an action level of 1 µg/g wet weight for methylmercury. There is basically little difference between the two countries because most fish have more than 90% of their mercury content in the methylated form. • Northeastern United States and the Maritime Provinces issued human mercury consumption advisories in fish in 1998 (NESCAUM 1998).

5.2 RESEARCH AND MONITORING

The following organizations have had the most extensive monitoring programs in the Gulf of Maine region.

Gulfwatch

Gulfwatch is a chemical contaminants monitoring program organized and administered by the Gulf of Maine Council on the Marine Environment (Gulfwatch 2012). Since 1993, Gulfwatch has measured contaminants in blue mussels (*Mytilus edulis*) at 64 locations to assess the types and concentration of contaminants in coastal waters of the Gulf of Maine. It is one of the few monitoring programs and the only one in the Gulf of Maine to be coordinated across international borders. Gulfwatch is coordinated and conducted by scientists and managers from agencies and universities around the Gulf. 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 U.S. Environmental Protection Agency and Environment Canada. Gulfwatch measures 12 low-molecular-weight PAHs and 12 high-molecular-weight 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.

Mussel Watch

Mussel Watch represents the longest-running continuous contaminant monitoring program in American 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 *Clostridium perfringens* (pathogen) concentrations. This project regularly quantifies PAHs, PCBs, DDTs and its metabolites, CHLs, other chlorinated pesticides, TBT and its metabolites and toxic trace elements at a total of 12 locations within the Gulf of Maine, of which 3 are located close to Gulfwatch sampling sites.

Environmental Protection Agency National Coastal Condition

The Environmental Protection Agency's National Coastal Condition program measured contaminants in sediments of the Gulf of Maine between 2000 and 2006 and in 2010 and reports the results regularly through their Coastal Condition reports (US EPA 2012b).

Environment Canada

Environment Canada has measured contaminants in eggs of nesting seabirds in the Bay of Fundy since 1972 as part of a Canada-wide program initiated in 1968

6. Indicator Summary

There are too many chemical indicators of contamination to practically list in a table so they have been grouped into a variety of contaminants, contaminant categories and combined effect of contaminants. There are several other approaches that could be taken, such as using environmental indicator categories, e.g., atmosphere, rain, seawater, sediments and biota. Contaminant concentrations in the air, rain and seawater are generally so low that the analytical detection becomes a challenge and too expensive for regular monitoring programs. Sediments and biota are more suitable for contaminant monitoring because concentrations are usually higher. Analyses of sediments provide an ideal indication of local pollution and can also provide a stratographic record of past discharges. Biota, particularly widespread species, are also excellent indicators of contamination. Higher trophic level organisms, such as the larger fish, seals and porpoises, are the preferred monitors for contaminants that bioaccumulate, such as methylmercury, organochlorines, organobromines, etc. However, these predators tend to be wide-ranging so a stationary organism, such as the mussel, will give a better spatial and temporal picture of local contaminant sources and overall environmental quality in the Gulf of Maine.

7. References

3M 2000. Phase out plan for PoSf-based products; US EPA Docket OPPT-2002-0043; Specialty Materials Markets Group. 3M: St. Paul, MN.

Addison RF and Smith TG. 1998. Trends in organochlorine residue concentrations in ringed seal (*Phoca hispida*) from Holman, Northwest Territories, 1972–91. Arctic 51: 253–261.

Alzieu C, Sanjuan J, Deltreil JP and Borel M. 1986. Tin contamination in Arcachon Bay: effects on oyster shell anomalies. Mar. Pollut. Bull. 17: 494–498.

Apeti DA, Lauenstein GG, Christensen JD, Kimbrough K, Johnson WE, Kennedy M and Grant KG. 2010. A historical assessment of coastal contamination in Birch Harbor, Maine based on the analysis of mussels collected in the 1940s and the Mussel Watch program. Mar. Pollut. Bull. 60: 732–742.

Armstrong SM, Hargrave BT and Haya K. 2005. Antibiotic use in finfish aquaculture: Modes of action, environmental fate, and microbial resistance. Hdb. Env. Chem. 5 (Part M): 341–357.

ATSDR (Agency for Toxic Substances and Disease Registry). 2000. Public health statement for polychlorinated biphenyls (PCBs). Atlanta, GA: US Department of Health and Human Service, Division of Toxicology and Environmental Medicine.

Barata C, Medina M, Telfer T and Baird DJ. 2002. Determining demographic effects of cypermethrin in the marine copepod *Acartia tonsa*: stage-specific short tests versus life-table tests. Arch. Environ. Contam. Toxicol. 43: 373–378.

Bargagli R, Monaci F, Sanchez-Hernandez JC and Cateni D. 1998. Biomagnification of mercury in an Antarctic marine coastal food web. Mar. Ecol. Prog. Ser. 169: 65–76.

Barkovskii AL, Green C and Hurley D. 2010. The occurrence, spatial and temporal distribution, and environmental routes of tetracycline resistance and integrase genes in *Crassostrea virginica* beds. Mar. Pollut. Bull. 60: 2215–2224.

Barnes KK, Kolpin DW, Meyer MT, Thurman EM, Furlong ET, Zaugg SD and Barber LB. 2002. Water-quality data for pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000. USGS Open File Report 02-94. http://toxics.usgs.gov/pubs/OFR-02-94/index.html#site.

Barrie LA, Gregor D, Hargrave B, Lake R, Muir D, Shearer R, Tracey B and Bidleman T. 1992. Arctic contaminants: Sources, occurrence and pathways. Sci. Total Environ. 122: 1–74.

Beleneva IA. 2011. Incidence and characteristics of *Staphylococcus aureus* and *Listeria monocytogenes* from the Japan and South China seas. Mar. Pollut. Bull. 62: 382–387.

Bidleman TF, Jantunen LMM, Helm PA, Brorstrom-Lunden E and Juntto S. 2002. Chlordane enantiomers and temporal trends of chlordane isomers in arctic air. Environ. Sci. Technol. 36: 539–544.

Bidleman TF, Kylin H, Jantunen LM, Helm PA and MacDonald RW. 2007. Hexachlorocyclohexanes in the Canadian Archipelago. Spatial distribution and pathways of α-, β- and γ-HCHs in surface water. Environ. Sci. Technol. 41: 2688–2695.

Bloom NS. 1992. On the chemical form of mercury in edible fish and marine invertebrate tissue. Can. J. Fish. Aquat. Sci. 49: 1010–1037.

Boehm PD and Hirtzer P. 1982. Gulf and Atlantic survey for selected organic pollutants in finfish. NOAA Tech. Mem. NMFS-F/NEC-13, 116p.

Bollmann UE, Moller A, Xie Z, Ebinghaus R and Einax JW. 2012. Occurrence and fate of organophosphorus flame retardants and plasticizers in coastal and marine waters. Water Res. 46: 531–538.

Bostrom C-E, Gerde P, Hanberg A, Jernstrom B, Johansson C, Kyrklund T, Rannug A, Tornqvist M, Victorin K, and Westerholm R. 2002. Cancer risk assessment, indicators, and guidelines for polycyclic aromatic hydrocarbons in the ambient air. Environ. Health Perspect. 110: 451–488.

Boxall AB, Kolpin DW, Halling-Sorensen B, and Tolls J. 2003. Are veterinary medicines causing environmental risks? Environ. Sci. Technol. 37: 286A–294A.

Branco V, Vale C, Canario J and Neves dos Santos M. 2007. Mercury and selenium in blue shark (*Prionace glauca*, L. 1758) and swordfish (*Xiphias gladius*, L. 1758) from two areas of the Atlantic Ocean. Environ. Pollut. 150: 373–380.

Braune BM. 1987a. Mercury accumulation in relation to size and age of herring (*Clupea harengus harengus*) from the southwestern Bay of Fundy, Canada. Arch. Environ. Contam. Toxicol. 16: 311–320.

Braune BM. 1987b. Comparison of total mercury levels in relation to diet and molt for nine species of marine birds. Arch. Environ. Contam. Toxicol. 16: 217–224.

Braune BM. 2007. Temporal trends of organochlorines and mercury in seabird eggs from the Canadian Arctic, 1975–2003. Environ. Pollut. 148: 599–613.

Braune BM, Mallory ML, Gilchrist HG, Letcher RJ and Drouillard KG. 2007. Levels and trends of organochlorines and brominated flame retardants in ivory gull eggs from the Canadian Arctic, 1976 to 2004. Sci. Total Environ. 378: 403–417.

Brooks CT. 1974. Chlorinated insecticides. Vol. 1. Technology and application. Cleveland, OH: CRC Press. 249pp.

Brun GL, Vaidya OMC and Leger MG. 2004. Atmospheric deposition of polycyclic aromatic hydrocarbons to Atlantic Canada: geographic and temporal distributions and trends 1980–2001. Environ. Sci. Technol. 38:1941–1948.

Buerge IJ, Buser H-R, Kahle M, Muller MD and Poiger T. 2009. Ubiquitous occurrence of the artificial sweetener acesulfame in the aquatic environment: an ideal chemical marker of domestic wastewater in groundwater. Environ. Sci. Technol. 43: 4381–4385.

Dearth MA and Hites RA. 1991. Complete analysis of technical chlordane using negative ionization mass spectrometry. Environ. Sci. Technol. 25: 245–254.

de Geus H-J, Basselink H, Brouwer A, Klungsoyr J, McHugh B, Nixon E, Rimkus GG, Wester PG and de Boer J. 1999. Environmental occurrence, analysis, and toxicology of toxaphene compounds. Environ. Health Perspect. 107 (Suppl. 1): 115–144.

Dimond JB and Owen RB. 1996. Long-term residue of DDT compounds in forest soils in Maine. Environ. Pollut. 92: 227–230.

Djomo JE, Dauta A, Ferrier V, Narbonne JF, Monkiedje A, Njine T and Garrigues P. 2004. Toxic effects of some major polyaromatiic hydrocarbons found in crude oil and aquatic sediments on *Scenedesmus subspicatus*. Water Res. 38: 1817–1821.

Dueri S, Dahllof I, Hjorth M, Marinov D and Zaldivar JM. 2009. Modeling the combined effect of nutrients and pyrene on the plankton population: validation using mesocosm experiment data and scenario analysis. Ecol. Modelling 220: 2060–2067.

Echeveste P, Augusti S and Dachs J. 2010a Cell size dependent toxicity thresholds of polycyclic aromatic hydrocarbons to natural and cultured phytoplankton populations. Environ. Pollut. 158: 299–307.

Echeveste P, Dachs j, Berrojalbiz N and Agusti S. 2010b. Decrease in the abundance and viability of oceanic phytoplankton due to trace levels of complex mixtures of organic pollutants. Chemosphere 81: 161–168.

Elfes CT, VanBlaricom GR, Boyd D, Calambokidis J, Clapham PJ, Pearce RW, Robbins J, Salinas JC, Straley JM, Wadw PR and Krahn MM. 2010. Geographic variation of persistent organic pollutant levels in humpback whale (*Megaptera novaeangliae*) feeding areas of the North Pacific and North Atlantic. Environ. Toxicol. Chem. 29: 824–834.

Elliott JE, Scheuhammer AM, Leighton FA, Pearce PA. 1992. Heavy metal and metallothionein concentrations in Atlantic Canadian seabirds. Arch. Environ. Contam. Toxicol. 22: 63-73.

Emlen JM and Springman KR. 2009. Developing methods to assess and predict the population level effects of environmental contaminants. Internat. Environ. Assess. Management 3: 157–165.

Environment Canada. 2003. Environmental signals: Canada's national environmental indicator series 2003. Ottawa: Environment Canada. 78 pp.

Ernst W, Jackman P, Doe K, Page F, Julien G, MacKay K and Sutherland T. 2001. Dispersion and toxicity to non-target aquatic organisms of pesticides used to treat sea lice on salmon in net encloures. Mar. Pollut. Bull. 42: 433–444.

ESIP (EcoSystem Indicators Partnership). 2012. ESIP Indicator Reporting Tool. Interactive Map. http://www2.gulfofmaine.org/esip/reporting/gmap.php

Fairchild WL, Doe KG, Jackman PM, Arsenault JT, Aube JG, Losier M and Cook AM. 2010. Acute and chronic toxicity of two formulations of the pyrethroid pesticide deltamethrin to an amphipod, sand shrimp and lobster larvae. Can. Tech. Rep. Fish. Aquat. Sci. 2876. 34 pp.

FDA (U.S. Food and Drug Administration). 2011. Fish and Fishery Products Hazards and Controls Guidance. Fourth Edition. U.S. Department of Health and Human Services, Food and Drug Administration. http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/Seafood/FishandFisheriesProductsHazardsandControlsGuide/default.htm

Fent K, Weston AA and Caminada D. 2006. Ecotoxicology of human pharmaceuticals. Aquat. Toxicol. 76: 122–159.

Fingerman M, Devi M, Reddy PS and Katyayani R. 1996. Impact of heavy metal exposure on the nervous system and endocrine-mediated processes in crustaceans. Zool. Studies 35: 1–8.

Fletcher CL and McKay WA. 1993. Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) in the aquatic environment – a literature review. Chemosphere 26: 1041–1069

Frame GM, Cochran JW, and Bowadt SS. 1996. Complete PCB congener distributions for 17 Aroclor mixtures determined by 3 HRGC systems optimized for comprehensive, quantitative, congener-specific analysis. J. High Resol. Chromatogr. 19: 657–668.

Friars F. 2002. Microbial resistance to oxytetracycline in sediments from salmon aquaculture sites in the Western Isles region of the Bay of Fundy. MSc thesis, Dalhousie University. 105 pp.

Fries E and Mihajlovic I. 2011. Pollution of soils with organophosphorus flame retardants and plasticizers. J. Environ. Monit. 13: 2692–2694.

Garrison AW, Wilkinson M and Boutilier R. 1976. Analysis of organic compounds in domestic wastewater. In: Keith CH (ed), Identification and analysis of organic pollutants in water. Ann Arbour, MI: Ann Arbor Science. pp. 517–566.

Gaskin DE, Frank R and Holdrinet M. 1983. Polychlorinated biphenyls in harbor porpoises *Phocoena phocoena* (L) from the Bay of Fundy, Canada and adjacent waters, with some information on chlordane and hexachlorobenzene levels. Environ. Contam. Toxicol. 12: 211–219.

Gaskin DE, Frank R, Holdrinet M, Ishida K, Walton CJ and Smith M. 1973. Mercury, DDT, and PCB in harbour seals (*Phoca vitulina*) from the Bay of Fundy and Gulf of Maine. J. Fish. Res. Board Can. 30: 471–475.

Gaskin DE, Holdrinet, M and Frank R. 1971. Organochlorine pesticide residues in harbour porpoises from the Bay of Fundy region. Nature 233: 499–500.

Gaskin DE, Holdrinet, M and Frank R. 1982. DDT residues in blubber of harbour porpoise,Phocoena phocoena (L), from Eastern Canadian waters during the five year period 1969–1973. In: Mammals in the seas. FAO Fish. Ser. (5) Vol. 4 : 135–143.

Gaskin DE, Stonefield KI, Suda P and Frank R. 1979. Changes in mercury levels in harbour porpoises from the Bay of Fundy, Canada, and adjacent waters during 1969–1977. Arch. Environ. Contam. Toxicol. 8: 733–762.

Gebbink WA, Letcher RJ, Burgess NM, Champoux L, Elliott JE, Hebert CE, Martin P, Wayland M., Weseloh DVC and Wilson L. 2011. Perfluoroalkyl carboxylates and sulfonates and precursors in relation to dietary source tracers in the eggs of four species of gulls (Larids) from breeding sites spanning Atlantic to Pacific Canada. Environ. Int. 37: 1175-1182

Jackson TJ, Wade TL, Sericano JL, Brooks JM, Wong JM, Garcia-Romero B and MacDonald Tj. 1998. Galveston Bay: temporal changes in the organic contaminant concentrations in NOAA National Status and Trends oysters (1986–1994). Estuaries 21: 718–730.

Johnson AC and Larsen PF. 1985. The distribution of polycyclic aromatic hydrocarbons in the surficial sediments of Penobscot Bay (Maine, USA) in relation to possible sources and to other sites worldwide. Mar. environ. Res. 15: 1–16.

Johnson-Restrepo B, Addink R, Wong C, Arcaro K and Kannan K. 2007. Polybrominated diphenyl ethers and organochlorine pesticides in breast milk from Massachusetts, USA. J. Environ. Monitor. 9: 1205–1212.

Johnson-Restrepo B, Kannan K, Rapaport D and Rodan B. 2005. Polybrominated diphenyl ethers and polychlorinated biphenyls in human adipose tissue from New York. Environ. Sci. Technol. 39: 8243–8250.

Johnston E and Roberts DA. 2009. Contaminants reduce the richness and evenness of marine communities: A review and meta-analysis. Environ. Pollut. 157: 1745–1752.

Jones S, Krahforst K and Harding G. 2010. Distribution of mercury and trace metals in shellfish and sediments in the Gulf of Maine. In: P Lassus (ed), Proceedings of the 7th International Conference on Molluscan Shellfish Safety, June 14–19, 2009, Nantes, France. Versailles, France: Quae Publishing. pp. 308–315.

Jones SH, Krahforst C, White L, Klassen G, Schwartz J, Wells P, Harding GCH, Brun GL, Hennigar P, Page D, Shaw SD, Trowbridge P, Taylor D and Aube J. In prep. The Gulfwatch Program 1993–2008. A review of scientific results. Final report. Gulf of Maine Council on the Marine Environment. Will be available at: http://www.gulfofmaine.org/council/publications/

Jurado E and Dachs J. 2008. Seasonality in the "grasshopping" and atmospheric residence times of persistent organic pollutants over the oceans. Geophys. Res. Letters 35, L17805,doi:10.1029/2008GL034698,2008.

Kannan K, Senthikumar K, Loganathan BG, Takahashi S, Odell DK and Tanabe S. 1997. Evaluated levels of tributyltin and its breakdown products in Bottlenose Dolphins (*Tursiops truncatus*) found stranded along the US Atlantic and Gulf coasts. Environ. Sci. Technol. 31: 296–301.

Kasprzyk-Hordern B, Dinsdale RM and Guwy AJ. 2008. The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. Water Res. 42: 3498–3518.

Kawano M, Inoue T, Wada T, Hidaka H and Tatsukawa R. 1988. Bioconcentration and residue patterns of chlordane compounds in marine animals: invertebrates, fish, mammals and seabirds. Environ. Sci. Technol. 22: 792–797.

Kayal S and Connell DW. 1995. Polycyclic Aromatic hydrocarbons in biota from the Brisbane River estuary, Australia. Estuarine Coast. Shelf Sci. 40: 475–493.

Kennicutt MC, Wade TL, Presley BJ, Requejo AG, Brooks JM and Denoux GJ. 1994. Sediment contaminants in Casco Bay, Maine: inventories, sources, and potential for biological impact. Environ. Sci. Technol. 28: 1–15.

Kidd KA, Blanchard PJ, Mills KH, Palace VP and Evans RE. 2007. Collapse of a fish population after exposure to a synthetic estrogen. Proc. Nat. Acad. Sci. 104: 8897–8901.

Kidd KA and Mercer A. 2012. Chemicals of emerging concern in the Bay of Fundy watershed. Bay of Fundy Ecosystem Partnership (BOFEP) report. 21 pp. + app.

Kidd KA, Schindler DW, Muir DCG, Lockhart WL and Hesslein RH. 1995. High concentrations of toxaphene in fishes from a subarctic lake. Science 269: 240–242.

Kimbrough KL, Johnson WE, Lauenstein GG, Christensen JD and Apeti DA. 2009. Mussel watch program. An assessment of polybrominated diphenyl ethers (PBDEs) in sediments and bivalves of the US coastal zone. Silver Spring, MD: Center for Coastal Monitoring and Assessment. http://ccma,nos.noaa.gov/about/coast/nsandt/pdf/PBDEreport.pdf

King TL, Haines BK and Uthe JF. 1996. Non-, mono-, and di-o-chlorobiphenyl concentrations and their toxic equivalents to 2,3,7,8-tetrachlorodibenzo[*p*]dioxin in Aroclors® and digestive glands from American lobster (*Homarus americanus*) captured in Atlantic Canada. Bull. Environ. Contam. Toxicol. 57: 465–472.

Klerks PL and Weis JS. 1987. Genetic adaptation to heavy metals in aquatic organisms: a review. Environ. Pollut. 45: 173–205.

Knowlton SW and Moran SB. 2010. Stable Pb isotope ratios in aerosols, precipitation, and size-fractioned particulate matter in the Gulf of Maine, Scotian Shelf, and Labrador Sea. Mar. Pollut. Bull. 60: 984–989.

Kolodziej EP, Gray JL and Sedlak DL. 2003. Quantification of steroid hormones with pheromonal properties in municipal wastewater effluent. Environ. Toxicol. Chem. 22: 2622–2629.

Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB and Buxton HT. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000: a national reconnaissance. Environ. Sci. Technol. 36: 1202–1211.

Korytar P, van Stee LLP, Leonards PEG, de Boer J and Brinkman UATh. 2003. Attempt to unravel the composition of toxaphene by comprehensive two-dimensional gas chromatography with selective detection. J. Chromatogr. A 994: 179–189.

Kraepiel AML, Keller K, Chin HB, Malcom EG and Morel FMM. 2003. Sources and variations of mercury in tuna. Environ. Sci. Technol. 37: 5551–5558.

Kuehl DW, Haebler R and Potter C. 1991. Chemical residues in dolphins from the U.S. Atlantic coast including Atlantic bottlenose obtained during the 1987/88 mass mortality. Chemosphere 22: 1071–1084.

Labare MP and Alexander M.1993. Biodegradation of sucralose in samples of natural environments. Environ. Toxicol. Chem. 12: 797–804.

Lake CA, Lake JL, Haebler R, McKinney R, Boothman WS, and Sadove SS. 1995. Contaminant levels in harbor seals from the northeastern United States. Arch. Environ. Contam. Toxicol. 29: 128–134.

Mayor DJ, Solan M, Martinez I, Murray L, McMillan H, Paton GI and Killham K. 2008. Acute toxicity of some treatments commonly used by the salmon aquaculture industry to *Corophium volutator* and *Hediste diversicolor*: whole sediment bioassay tests. Aquaculture 285: 102–108.

McCarty LS and D. MacKay. 1993. Enhancing ecotoxicological modeling and assessment. Environ. Sci. Technol. 27: 1719–1728.

Mead RN, Morgan JB, Brooks Avery Jr. G, Keiber RJ, Kirk AM, Skrabal SA and Willey JD. 2009. Occurrence of the articial sweetener sucralose in coastal and marine waters of the United States. Mar. Chem. 116: 13–17.

Medina M, Barata C, Telfer T and Baird DJ. 2002. Age- and sex-related variation in sensitivity to the pyrethroid cypermethrin in marine copepod *Acartia tonsa* Dana. Arch. Environ. Contam. Toxicol. 42: 17–22.

Medina M, Barata C, Telfer T and Baird DJ. 2004. Effects of cypermethrin on marine plankton communities: a simulated field study using mesocosms. Ecotoxicol. Environ. Safety 58: 236–245.

Metcalfe CD and Haffner GD. 1995. The ecotoxicology of coplanar polychlorinated biphenyls. Environ. Res. 3: 171–190.

Metcalfe C, Miao X-S, Hus W, Letcher R and Servos M. 2004. Pharmaceuticals in the Canadian environment. In: K Kummerer (ed), Pharmaceuticals in the Environment. Sources, Fate, Effects and Risks. 2nd Edition. Berlin: Springer. pp. 67–90.

Meyer J and Bester K. 2004. Organophosphorus flame retardants and plasticisers in wastewater treatment plants. J. Environ. Monit. 6: 599–605.

Miller GE, Grant PM, Kishore R, Steinkruger FJ, Rowland FS and Guinn VP. 1972. Mercury concentrations in museum specimens of tuna and swordfish. Science 175: 1121–1122.

Mills LJ and Chichester C. 2005. Review of evidence: are endocrine-disrupting chemicals in the aquatic environment impacting fish populations? Sci. Total Environ. 343: 1–34.

Monperrus M, Tessier E, Point D, Vidimova K, Amouroux D, Guyoneaud R, Leynaert A, Grall J, Chauvaud L, Thouzeau G and Donard OFZ. 2007. The biogeochemistry of mercury at the sediment-water interface in the Thau Lagooon. 2. Evaluation of mercury methylation potential in both surface sediment and the water column. Estuar. Coast Shelf Sci. 72: 485–496.

Moore A and Scott AP. 1991. Testosterone is a potent odorant in precocious male Atlantic salmon (*Salmo salar* L) parr. Proc. R Soc. London B 332: 241–244.

Muckle G, Aoyette P, Dewailly E, Jacobson SW and Jacobson JL. 2001. Prenatal exposure of the northern Quebec Inuit infants to environmental contaminants. Environ. Health Perspectives 109 :1291–1299.

Muir DCG and Howard PH. 2006. Are there other persistent organic pollutants? A challenge for environmental chemists. Environ. Sci. Technol. 40: 7157–7166.

Murata S, Takahashi S, Agusa T, Thomas NJ, Kannan K and Tanabe S. 2008. Contamination status and accumulation profiles of organotins in sea otters (*Enhydra lutris*) found dead along the coasts of California, Washington, Alaska (USA), and Kamchatka (Russia). Mar. Pollut. Bull. 56: 641–649.

Nakata H, Sakai Y, Miyawaki T and Takemura A. 2003. Bioaccumulation and toxic potencies of polychlorinated biphenyls and polycyclic aromatic hydrocarbons in tidal flat and coastal ecosystems of the Ariake Sea, Japan. Environ. Sci. Technol. 37: 3513–3521.

Nakata H, Sakakibara A, Kanoh M, Kudo S, Watanabe H, Nagai N, Miyazaki N, Asano Y and Tanabe S. 2002. Evaluation of mitogen-induced responces in marine mammal and human lymphocytes by in vitro exposure of butyltins and non-ortho coplanar PCBs. Environ. Pollut. 120: 245–253.

NESCAUM et al. 1998. Notheastern States for Coordinated Air Use Management (NESCAUM), Northeast Waste Management Association, New England Interstate Water Pollution Control Commission and the Canadian Ecological Monitoring and Assessment Network. Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action. Boston: NESCAUM.

Norstrom RJ, Simon M, Muir DCG and Schweinsburg RE. 1988. Organochlorine contaminants in Arctic marine food chains: identification, geographical distribution, and temporal trends in polar bears. Environ. Sci. Technol. 22: 1063–1071.

O'Connor TP. 1998. Mussel watch results from 1986 to 1996. Mar. Pollut. Bull. 37: 14–19.

O'Connor TP and Lauenstein GG 2006. Trends in chemical concentrations in mussels and oysters collected along the US coast: update to 2003. Mar. Environ. Res. 62: 261–285.

Oehme M, Schlabach M, Kallenborn R and Haugen JE. 1996. Sources and pathways of persistent polychlorinated pollutants to remote areas of the North Atlantic and levels in the marine food chain: a research update. Sci. Total Environ. 186: 13–24.

Palmer R, Rodger H, Drinan E, Dwyer C and Smith PR. 1987. Preliminary trials on the efficacy of ivermectin against parasitic copepods of Atlantic salmon. Bull. Eur. Ass. Fish Pathol. 7: 47–54.

Palmisano F, Cardellicchio N, and Zambonin PG. 1995. Speciation of mercury in dolphin liver: a two-stage mechanism for the demethylation accumulation process and role of selenium. Mar. Environ. Res. 40: 109–121.

Park J-S, Kalantzi OI, Kopec D and Petreas M. 2009. Polychlorinated biphenyls (PCBs) and their hydroxylated metabolites (OH-PCBs) in livers of harbor seals (*Phoca vitulina*) from San Francisco Bay, California, and Gulf of Maine. Mar. Environ. Res. 67: 129–135.

Pearce PA, DB Peakall and LM Reynolds. 1979. Shell thinning and residues of organochlorines and mercury in seabird eggs, Eastern Canada, 1970-1976. Pestic. Monit. J. 13: 61-68.

Peck AM, Pugh RS, Moors A, Ellisor MB, Porter BJ, Becker PR et al. 2008. Hexabromocyclododecane in white-sided dolphins. Temporal trend and stereo-isomer distribution in tissues. Environ. Sci. Technol. 42: 2650–2655.

Shaw S, Berger ML, Brenner D, Tao L, Wu Q and Kannan K. 2009. Specific accumulation of perfluorochemicals in harbor seals (*Phoca vitulina concolor*) from the northwest Atlantic. Chemosphere 74: 1037–1043.

Shaw SD, Brenner D, Berger ML, Carpenter DO, Hong C-S, and Kannan K. 2006. PCBs, PCDD/Fs, and organochlorine pesticides in farmed Atlantic salmon from Maine, eastern Canada, and Norway, and wild salmon from Alaska. Environ. Sci. Technol. 40: 5347–5354.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Storm R and O'Keefe P. 2007. Patterns and trends of PCBs and PCDD/Fs in northwestern Atlantic harbor seals: revisiting threshold levels using the new TEFs. Organohalogen Compounds 69: 1752–1756.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Addink R. 2008. Bioaccumulation of polybrominated diphenyl ethers in harbor seals from the northwest Atlantic. Chemosphere 73: 1773–1780.

Shaw SD, Brenner D, Bourakovsky A, Mahaffey CA and Perkins CR. 2005. Polychorinated biphenyls and chlorinated pesticides in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic coast. Marine Pollut. Bull. 50: 1069–1084.

Shaw SD and Kannan K. 2009. Polybrominated diphenyl ethers in marine ecosystems of the American continents: foresight from current knowledge. Rev. Environ. Health 24(3): 157–229.

Shigenaka G. 1990. Chlordane in the marine environment of the United States: review and results from the National Status and Trends program. NOAA OMA 55: 230p.

Siegener R and Chen RF. 2002. Caffeine in Boston Harbor seawater. Mar. Pollut. Bull. 44: 383–387.

Simcik MF, Hoff RM, Strachan WMJ, Sweet CW, Basu I and Hites RA. 2000. Temporal trends of semivolatile organic contaminants in Great Lakes precipitation. Environ. Sci. Technol. 34: 361–367.

Skarphedinsdottir H, Gunnarson K, Gudmundsson GA and Nfon E. 2010. Bioaccumulation and biomagnifications of organochlorines in a marine food web at a pristine site in Iceland. Arch. Environ. Contam. Toxicol. 58: 800–809.

Sobek A, McLachlan MS, Borga K, Asplund, L, Lundstedt-Enkel K, Polder A and Gustafsson O. 2010. A comparison of PCB bioaccumulation factors between an arctic and a temperate marine food web. Sci. Total Environ. 408: 2753–2760.

Stapleton HM, Klosterhaus S, Keller A, Ferguson PL, van Bergen S, Cooper E, Webster TF and Blum A. 2011. Identification of flame retardants in polyurethane foam collected from baby products. Environ. Sci. Technol. 45: 5323–5331.

Steffen W, Crutzen PJ and McNeill JR. 2007. The Anthropocene: are humans now overwhelming the great forces of nature? Ambio 36: 614–621.

Stein JE, Tilbury KL, Brown DW, Wigren CA, Meador JP, Robisch PA, Chan S-L and Varanasi U. 1992. Intraorgan distribution of chemical contaminants in tissues of harbor porpoises (*Phocoena phocoena*) from the northwest Atlantic. US Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-3. 76 pp.

Stewart AR, Luoma SN, Schlekat CE, Doblin MA and Hieb KA. 2004. Food web pathway determines how selenium affects aquatic ecosystems: A San Francisco Bay case study. Environ. Sci. Technol. 38: 4519–4526.

Stickle WB, Sharp-Dahl JL, Rice SD and Short JW. 1990. Imposex induction in *Nucella lima* (Gmelin) via mode of exposure to tributyltin. J. Exp. Mar. Biol. Ecol. 143: 165–180.

Stockholm Convention. 2012. Stockholm Convention. Protecting human health and the environment from persistent organic pollutants. http://www.pops.int

Street GT and Montagna PA. 1996. Loss of genetic diversity in Harpacticoida near offshore platforms. Mar. Biol. 126: 271–282.

Sunderland EM. 2007. Mercury exposure from domestic and imported estuarine and marine fish in the U.S. seafood market. Environ. Health Perspect. 115: 235–242.

Sunderland E, Amirbahman A, Burgess NM, Dalziel J, Harding G, Jones SH, Kamai E, Karagas MR, Shi X and Chen CY. 2012. Mercury sources and fate in the Gulf of Maine. Environ. Res. In press. http://dx.doi.org/10.1016/j.envres.2012.03.011

Sunderland EM and Chmura GL. 2000a. An inventory of historical mercury emissions in Maritime Canada: implications for present and future contamination. Sci. Total Environ. 256: 39–57.

Sunderland EM and Chmura GL. 2000b. The history of mercury emissions from fuel combustion in Maritime Canada. Environ. Pollut. 110: 29–306.

Sunderland EM, Dalziel J, Heyes A, Branfireun BA, Krabbenhoft DP and Gobas FAPC. 2010. Response of a macrotidal estuary to changes in anthropogenic mercury loading between 1850 and 2000. Environ. Sci. Technol. 44: 1698–1704.

Sunderland EM, Gobas FAPC, Heyes A, Branfireun BA, Bayer AK, Cranston RE and Parsons MB. 2004. Speciation and bioavailability of mercury in well-mixed estuarine sediments. Mar. Chem. 90: 91–105.

Sundkvist AM, Olofsson U and Haglund P. 2010. Organophosphorus flame retardants and plasticizers in marine and freshwater biota and in human milk, J. Environ. Monit. 12: 943–951.

Talsness CE. 2008. Overview of toxicological aspects of polybrominated diphenyl ethers: a flame-retardant additive in several consumer products. Environ. Res. 108: 158–167.

Tanabe, S. 1988. PCB problems in the future: foresight from current knowledge. Environ. Pollut. 50: 5–28.

Tanabe, S. 1999. Butyltin contamination in marine mammals – a review. Mar. Pollut. Bull. 39: 62–72.

Tao L, Kannan K, Wong CM, Arcaro KF and Butenhoff JL. 2008. Perfluorinated compounds in human milk from Massachusetts, U.S.A. Environ. Sci. Technol. 42: 3096–3101.

Taylor D, Maddock BG and Mance G. 1985. The acute toxicity of nine "grey list" metals (arsenic, boron, chromium, copper, lead, nickel, tin, vanadium and zinc) to two marine fish species: dab (*Limanda limanda*) and grey mullet (*Chelon labrosus*). Aquat. Toxicol. 7: 135–144.

Windsor JG and Hites RA. 1979. Polycyclic aromatic hydrocarbons in the Gulf of Maine sediments and Nova Scotia soils. Geochim. Cosmochim. Acta 43: 27–33.

Woodwell GM, Wurster Jr CF and Isaacson PA. 1967. DDT residues in an east coast estuary: a case of biological concentration of a persistent insecticide. Science 156: 821–824.

World Health Organization 1998. Flame retardants: tris(chloropropyl) phosphate and tris(2-chloroethyl)phosphate. Environmental Health Criteria 209; 94p.

Yamashita N, Kannan, K, Taniyasu S, Horii Y, Petrick G and Gamo T. 2005. A global survey of perfluorinated acids in oceans. Mar. Pollut. Bull. 51: 658–668.

Zitko V, Finlayson BJ, Wildish DJ, Anderson JM and Kohler AC. 1971. Methylmercury in freshwater and marine fishes in New Brunswick, in the Bay of Fundy, and on the Nova Scotia banks. J. Fish. Res. Bd. Canada: 28: 1285–1291.

Gulf of Maine Association
In support of the Gulf of Maine Council on the Marine Environment

Fisheries and Aquaculture Heritage

Fishing plays a vital role in the cultural and economic fabric of the Gulf of Maine region, with the identity and current-day economy of many of its coastal communities deeply tied to fishing and to iconic species such as cod and lobster. As one of the oldest European settlement areas in North America, the Gulf of Maine's fisheries have been historically important. The cod fisheries helped feed Europe's industrial revolution and were an important part of the 17th through early 19th Century's trade routes between Africa, the Caribbean, North America and Europe.

Over the past 20 years there has been reduced commercial fishing in this region due to stock depletion cause by a variety of factors, including over-fishing, migration, climate change, and water pollution. Groundfish stocks in the Gulf of Maine have become severely depleted and there is a greater reliance on the harvesting of lobster and other invertebrates. As a result, traditional maritime-oriented ways of life are in decline, changing the face and structure of many coastal communities.

Aquaculture as a form has been practiced in the Gulf of Maine region for over a century, including both finfish and shellfish culture. Marine aquaculture as an industry however, is relatively new and dates to the early 1970s. New Brunswick is the largest producer of aquaculture products, followed by Maine, Nova Scotia and Massachusetts. Aquaculture species include Atlantic salmon, oysters, clams, mussels, and more recently the culture of Atlantic halibut, Atlantic cod, Atlantic and shortnose sturgeon, bay scallop, the giant scallop, and kelp have been investigated.

Fisheries and Aquaculture Theme Papers

COMMERCIAL FISHERIES

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

November 2013

1. Issue in Brief

Commercial fisheries have a long history in the Gulf of Maine (Figure 1), beginning with the cod and haddock fishery that was established prior to colonization of North America by Europeans (Kurlansky 1997).[1] Various commercial fisheries developed in the region during early European colonization of North America and have remained economically and socially important. In 2009, commercial fisheries in the Gulf of Maine landed 505 thousand metric tons (mt)[2] of seafood with a dockside value of $114.5 million[3] (NMFS 2010, DFO landings data). These fisheries are dynamic, with the relative dominance of species changing over time in response to fishing pressure, environmental conditions, and unknown factors.

LINKAGES

This theme paper also links to the following theme papers:

- Climate Change and Its Effects on Ecosystems, Habitats and Biota
- Climate Change and Its Effects on Humans
- Species at Risk
- Invasive Species
- Coastal Land Use and Development

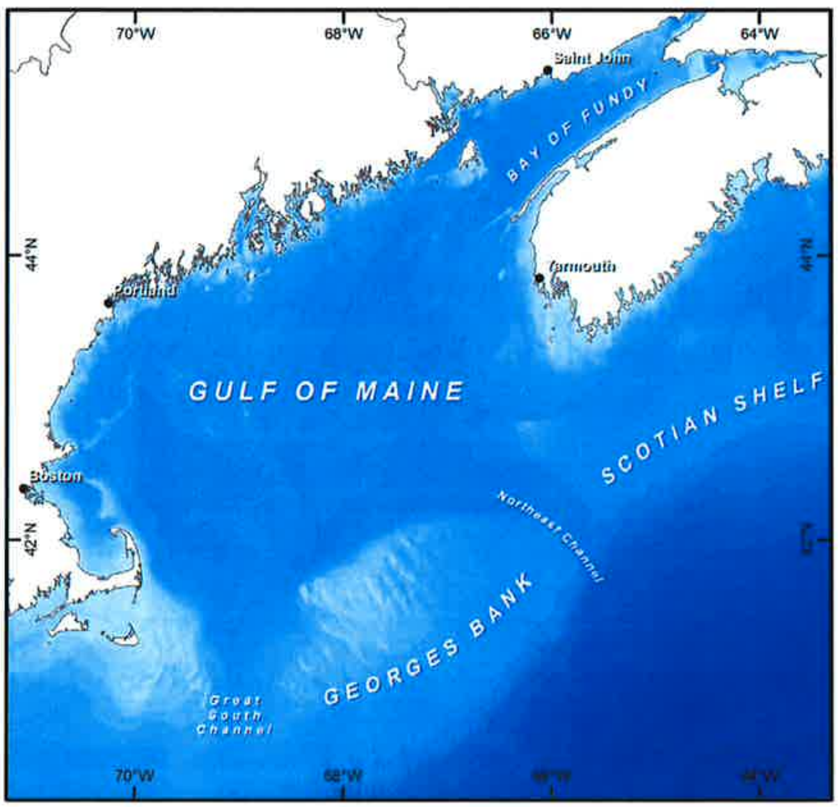


Figure 1: The Gulf of Maine.

[1] The Gulf of Maine area includes the Bay of Fundy, the Northeast Channel and Georges Bank. It is bounded to the northeast by the Scotian Shelf and is separated from the waters to the southwest (i.e., southern New England) by Georges Bank.

[2] 1 metric ton (mt) = 1000 kilograms (kg) = 2204 pounds.

[3] All dollar amounts in U.S. dollars, converted based on average annual exchange rate (Bank of Canada 2013).

2. Driving Forces and Pressures

DRIVING FORCES ARE BROAD-SCALE HUMAN-CAUSED AND NATURAL FORCES impacting, in this case, commercial fisheries. The driving forces cause pressures that affect commercial fisheries through landings, value, and distribution.

2.1 POPULATION GROWTH

Population growth in Canada, the United States, and the world have caused, and will continue to cause, direct and indirect pressures on Gulf of Maine commercial fisheries. The population of Canada is expected to increase from 35 million to 42.5 million by 2056 (Statistics Canada 2008; Statistics Canada 2013) and the population of the United States is projected to increase from 315.6 million to 399 million by 2050 (Ortman and Guarneri 2012; US Census 2013). The population of the world is projected to increase from the 7.07 billion to 8.99 billion by 2050 (United Nations 2004; US Census 2013). As human population grows, so too will the regional and global demand for food and other natural resources.

A disproportionate amount of population growth occurs in coastal areas, which puts additional pressure on coastal resources and nearshore and offshore fisheries. For example, 53 percent of the U.S. population lives in the coastal zone, which comprises only 17 percent of U.S. land area (NOAA 2013). Indirect effects of urban, residential, and agricultural development of coastal watersheds associated with burgeoning populations will cause continued degradation of nearshore and marine ecosystems (see Coastal Land Use and Development theme paper).

2.2 SEAFOOD DEMAND AND MARKET FORCES

Population growth in Canada, the United States, and the world has resulted in increased demand for fish products from the sea. As a result of projected increased demand, worldwide fisheries and aquaculture production is expected to increase 15 percent over 2009-2011 levels, reaching approximately 170 million mt in 2021 (OECD-FAO 2012). The increased demand for fish is expected to come with higher prices and production costs and an increasing globalized supply chain, with 34 percent of worldwide fishery production being exported to other countries (OECD-FAO 2012).

For Gulf of Maine commercial fisheries, global markets and demands will exert a significant and growing impact on the region's fishery resources and fisheries supply chains. Increased pressure on fishery resources will require timely management responses to restore, as needed, and maintain resource sustainability. Additionally, the bilateral trade between Canada and the United States is strong and will also exert pressure on Gulf of Maine resources. In 2010, the United States imported 304 thousand mt of seafood with a value of $2.31 billion from Canada being taken from the Gulf of Maine. The sea urchin fishery is a recent example of "boom and bust" fisheries, in which the fishery expanded very rapidly in the 1980s and then declined very rapidly because of resource depletion. Other fisheries, such as river herring, salmon, and sturgeon, were impacted by overharvest and habitat and environmental changes.

Up until the 1970s in Canada and 1980s and 1990s in the United States, Gulf of Maine commercial fisheries were largely open access, i.e., available to anyone who wanted to enter the fishery, with limited regulations. In contrast, today many fisheries are managed with limited access provisions and other regulations to ensure long-term resource sustainability and economic value. These regulatory changes have fundamentally altered commercial fishing in the Gulf of Maine. In the past, fish harvesters would switch among fisheries based on season, price, and resource availability. Limited entry in many fisheries has reduced fish harvesters' ability to switch among fisheries, resulting in reliance on fewer fisheries and vulnerability to price and resource variability. One response to limited access programs by harvesters is to retain licenses in multiple fisheries which allows them to adapt to changing market conditions and abundance in individual fisheries.

Throughout the regulatory, economic, cultural, and ecosystem changes that have occurred over the past 400 years, commercial fisheries have remained an important part of the social and economic fabric in the Gulf of Maine region, supporting thousands of jobs and families and contributing billions of dollars to the regional economy. Gulf of Maine fisheries are also iconic symbols that draw worldwide attention to the region.

2.4 CLIMATE CHANGE AND ECOSYSTEM INFLUENCES

Climate change will impact the Gulf of Maine area in many ways, including increasing sea level, increasing ocean temperature, ocean acidification, shifts in ocean currents, and altered abundance and distribution of plants and animals (Fogarty et al. 2007; Frumhoff et al. 2007; Schmitt 2011; see Climate Change and its Effects on Ecosystems, Habitats and Biota). System-wide impacts of climate change will be complex and may occur in unforeseen ways. For example, Fogarty et al. (2008) hypothesized that warm waters will cause cod populations to decline and lobster to decline in southern areas and potentially increase in more northern areas. In addition, blue crabs may become commercially exploitable in southern New England. Species at the southern limit of their range, such as northern shrimp (DFO 2012a; Richards et al. 2012) and Atlantic salmon, could decline or become locally extinct, commercially or biologically, from the Gulf of Maine. The movement of species historically associated with the mid-Atlantic into the Gulf of Maine, such as summer flounder, scup, and black sea bass, is also being observed in the Gulf of Maine. Ocean acidification could have very significant negative impacts on the lobster and clam fisheries through the effects of changes in

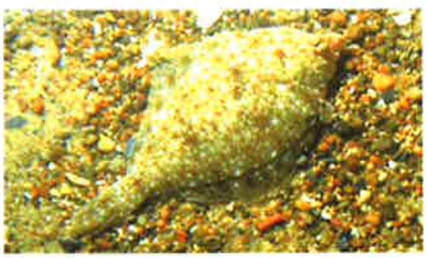
3. Status and Trends

THE GULF OF MAINE REGION IS HOME TO A DIVERSE COMMERCIAL FISHING industry that provides socio-economic benefits and well-being to many fish harvesters and communities. Some of these fisheries are valued in the millions of dollars, whereas others have much lower volume or individual value. Many fish harvesters make their living by participating in more than one fishery, making each fishery important to the region. The diversity of commercial fisheries in the Gulf of Maine is shown in Table 1, which lists all fisheries with recorded landings regardless of volume.[4]

3.1 MAJOR FISHERIES

Major fisheries in the Gulf of Maine include groundfish, herring, lobster, scallop, soft-shell clam, and tuna. These fisheries have long histories of contributing socially and economically to the region. The volume and value of these fisheries have varied through time with resource abundance, fishing pressure, and market demand, but some major trends are evident. A general characteristic of these fisheries is that they are dynamic, changing with variations in species abundance and distribution, market demand, vessels, gear, and regulations.

Groundfish



The groundfish fishery includes the catch of cod, haddock, pollock, hake, Acadian redfish, and a number of flounder species that are caught on or near the ocean floor (see box). This fishery was a founding industry in the Gulf of Maine, starting before European colonization. The early groundfish fishery was conducted with hook and line from small boats. These boats fished out of local harbors or were launched from larger sailing vessels to fish on offshore banks of shallow, productive waters. New gears were added to the fishery as technology changed from hooks to fish traps, gillnets, and otter trawls (FRCC 2011).

Historical landings of groundfish in the Gulf of Maine region are hard to compare with current landings because of poor historical reporting, different data sources, and different reporting areas. However, it is clear that landings in the past were very high relative to current levels, because of high fish abundance and a large number of vessels pursuing groundfish stocks (Figure 3). For example, cod catch on Georges Bank was estimated at greater than 60 thousand mt in the late 1890s (Serchuk et al. 1994), groundfish landings in the United States were estimated at 760 thousand mt in 1965 (NMFS 1999), and cod landings in the northwest

Species in Gulf of Maine Groundfish Fishery

- American plaice[a,b]
- Atlantic cod[a,b]
- Atlantic halibut[a,b]
- Haddock[a,b]
- Ocean pout[a,b]
- Offshore hake[a,b]
- Pollock[a,b]
- Red hake[b]
- Redfish[a,b]
- Silver hake[b]
- White hake[b]
- Windowpane flounder[a,b]
- Winter flounder[a,b]
- Witch flounder[a,b]
- Yellowtail flounder[a,b]
- Monkfish[a]

[a] Canada
[b] U.S.

[4] Statistics on species landed in New Brunswick and Nova Scotia from NAFO areas 4XP, 4XQ, 4XR, 4XS, 5YB, 5YC, 5YF, 5ZEH and 5ZEJ. Statistics on species landed in Maine, New Hampshire, and Massachusetts from NAFO areas 4X, 5Y and 5ZE.

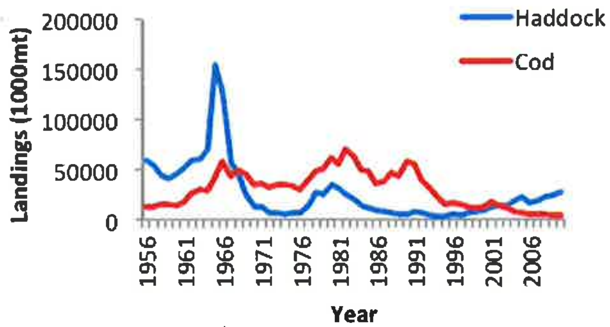


Figure 3: Cod and haddock landings, 1956-2010 (Source: Brodziak and Traver 2006; Mayo and O'Brien 2006; NEFSC 2008, 2012; Wang and O'Brien 2012; DFO landings data).

Atlantic were almost 2 million mt in the 1960s (DFO 2013b). Current catch levels are much lower because of reduced abundance and subsequent management restrictions. Other groundfish species show similar fishery trends of high landings followed by reduced abundance and landings (Sosebee et al. 2006).

Management of the groundfish fishery currently combines gear, area, and catch restrictions through quotas or allowable catch levels (DFO 2003; DFO 2008b; NEFMC 2009). The status of many groundfish stocks combined with the multi-species nature of the fishery has resulted in an extended period of conservative management actions with the goal of constraining catch to sustainable levels. This has resulted in fewer vessels, fewer participants, and fewer ports landing groundfish than in the past (Kitts et al. 2011). Quotas for some species or stocks is constrained to very low levels that impact the ability of the overall fishery to catch quotas of more abundant species as in the case of Eastern Georges Bank haddock catch being limited by very low cod quotas (TRAC 2012a). In the United States, stocks with very low quotas ("choke stocks") that limit catch of other more abundant stocks and overall low total allowable catch levels resulted in a fishery disaster declaration in 2012 for the U.S. northeast groundfish fishery (NMFS 2012a) because of cumulative impacts to the New England fishing industry and communities.

Atlantic Herring

The Atlantic herring is an economically and ecologically important fish in the Gulf of Maine. Herring are preyed upon by nearly all ocean predators, including fish, birds, and mammals, and their abundance and schooling behavior make them important to many predators (Collette and Klein-MacPhee 2002). Herring were caught by indigenous people prior to European colonization and were used as bait in the pre-colonial cod fishery (Collette and Klein-MacPhee 2002). The more recent history of the fishery has

Management Plan for Atlantic Herring by the New England Fishery Management Council, which established limited access to the fishery, an area in the inshore Gulf of Maine for seasonal purse seine and fixed gear only, and a process for setting three-year quotas (NEFMC 2007). The herring fishery in the Bay of Fundy is managed by quota, with 80 percent of the quota allocated to the purse seine fleet and 20 percent allocated to gillnets and weirs (DFO 2004).

Lobster

Lobsters symbolize the entire Gulf of Maine, with lobster fishing taking place out of almost every harbor from Cape Cod to Nova Scotia. The vast majority of the fishery in the United States, and all of the Canadian fishery, is a pot fishery, consisting primarily of vessels under 50 feet (15 meters) fishing up to 800 traps in the United States (ASMFC 1997) and up to 375 traps in Canadian portions of the Gulf of Maine (DFO 2011). Historically, lobsters were caught from sailing vessels fishing wooden traps. These catch methods and the relatively short distance that live product could be shipped restricted the demand for lobster to regional live markets and processing by canning. These inefficiencies and stock conditions limited lobster catch in the region to an average of 13 thousand mt from 1900 to 1990. Lobster gear, processing and shipping technologies, and resource abundance have changed significantly and, since 1990, catches have increased substantially, reaching 90 thousand mt in the Gulf of Maine region in 2011 (Figure 5). A portion of this increase is due to increased efficiency in the fishery through better vessels, traps, and other gear (ASMFC 1996), but overall productivity in the lobster population has also increased over past levels. Many hypotheses have been proposed to explain the increase including reduced predation from groundfish, conservation measures in the fishery,

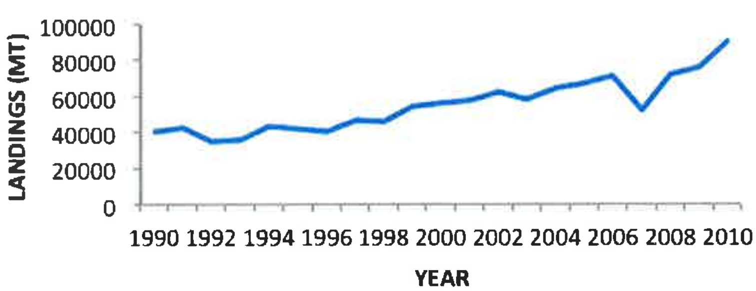


Figure 5: Gulf of Maine lobster landings, 1990-2011 (Source: DFO landings data; ACCSP data).

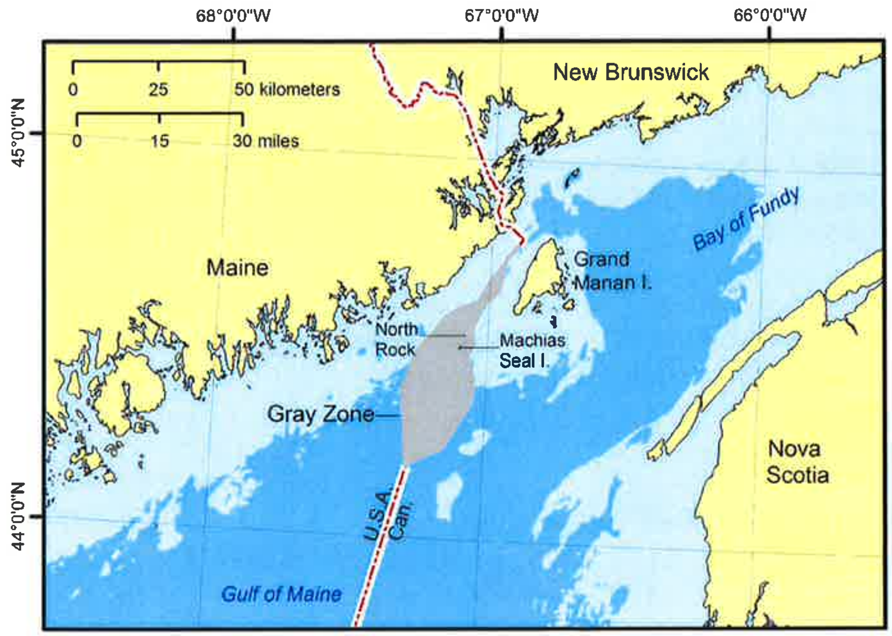


Figure 6: Area (gray zone) disputed between Canada and the United States (prepared by Oceans and Coastal Management Division, DFO).

Sea Scallop

The sea scallop fishery consists of a dredge or drag fishery in offshore and inshore areas and a dive fishery inshore in the United States. Dredges scrape scallops from the ocean floor; the scallops are then shucked, or cut open, to take the adductor muscle that is the edible portion of the scallop. There is growing interest in a whole scallop product.

The Canadian inshore scallop fishery in the Gulf of Maine/ Bay of Fundy is centered in Digby, Nova Scotia, where the bulk of scallops from the Canadian portion of the Gulf of Maine are landed. The Bay of Fundy scallop fishery is divided into Scallop Production Areas and Scallop Fishing Areas for stock assessment and management. The Bay of Fundy fishery is managed through a total allowable catch (TAC) which is accessed by Full Bay, Mid-Bay, and Upper Bay fleets, subarea quotas, meat count, and minimum shell height (DFO 2013c). The Full Bay TAC is allocated by percentage shares per license; Mid-Bay and Upper Bay fleets have a TAC that is fished competitively. The Canadian offshore fleet fishes Canada's offshore portions of the Gulf of Maine, including Georges Bank. The offshore fleet is managed with an enterprise allocation where each company receives a percentage share of the annual TAC for each scallop fishing area (DFO 2000).

waters and onshore winds. Public health authorities in Canada and in the United States manage extensive testing programs and area closures to ensure that soft-shell clams and other shellfish sold to dealers and consumers are safe for consumption. Closures of shellfish harvest areas can be lengthy and geographically broad, which significantly impacts harvesters and others in the clam fishery, as well as consumers. Additionally, the future harvest of soft-shell clams may be impacted by increased frequency of harmful algal bloom closures associated with climate change (NCCOS 2011).

The soft-shell clam resource and fishery can be impacted by predation by crustaceans, marine worms, mollusks, fish, and birds (Beal 2000). Soft-shell clams have evolved with native predators but are also impacted by invasive species. The prevalence of green crabs and Asian shore crabs has had significant impacts on local clam populations at various times. Soft-shell clams in the Gulf of Maine will likely be impacted by other species (e.g., blue crabs) as increasing ocean temperatures alter species distributions.

Soft-shell clam landings vary significantly in the Gulf of Maine (Figure 8) based on resource abundance and public health closures.

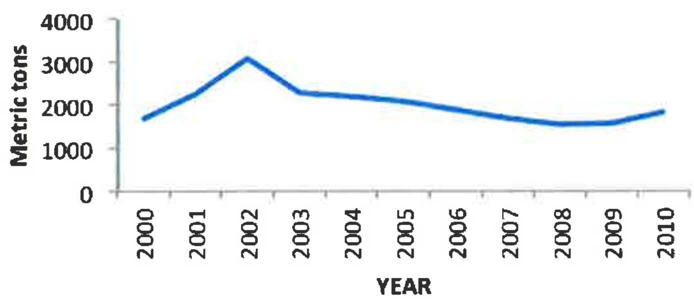


Figure 8: Reported Gulf of Maine soft-shell clam landings, 2000-2010 (Source: DFO landings data; ACCSP landings data).

Tuna

The tuna fishery in the Gulf of Maine consists of bluefin, albacore, bigeye, and yellowfin tuna, but the bluefin is the primary species because of abundance and price. Bluefin tuna is a widely distributed, valuable commercial species throughout the Gulf of Maine. Tuna are sold domestically for sushi and for cooking. They are also very valuable in the Japanese fish market where a single tuna was recently sold for $1.76 million (Revkin 2013). The high price for tuna has led to a significant fishery in the Gulf

Market Price for Selected Species

Market price is an indicator of the value of a particular species at point of first sale. Figures 10 and 11 show the gradual increase in the market price for selected species from 1970 to 2011. Atlantic herring is shown in a different figure because of the low value per pound relative to the other species listed in Figure 10. These figures are not adjusted for measures of inflation such as the consumer price index (CPI). Lobster prices in 2012 adjusted for CPI are lower than those in 1960 (Dayton and Sun 2012).

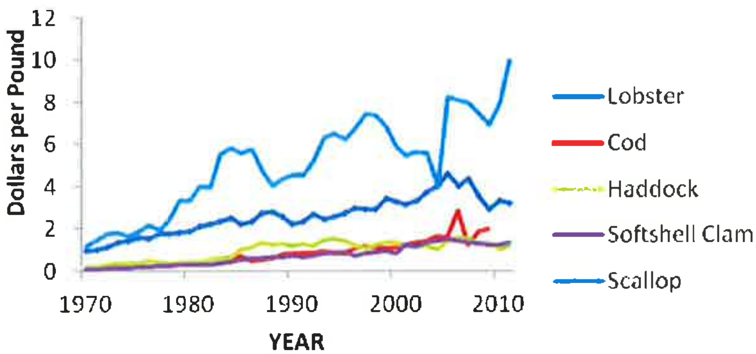


Figure 10: Price for selected Gulf of Maine fisheries, 1970-2011 (Source: DFO landings data; MEDMR landings data).

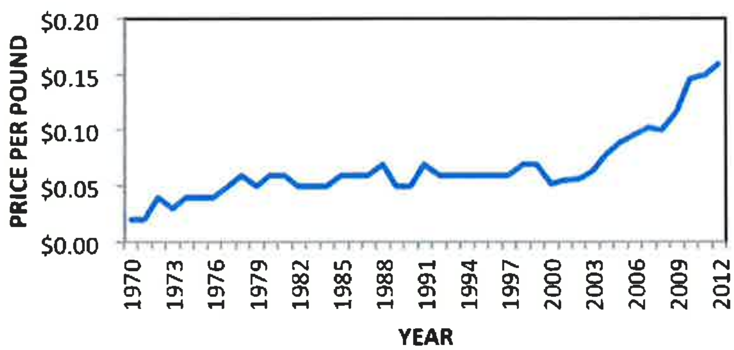


Figure 11: Atlantic herring price per pound, 1970-2012 (Source: DFO landings data; MEDMR landings data).

Total Landed Value

The overall value of landings (the sum of values at point of first sale) provides another indicator of the economic value of Gulf of Maine commercial fisheries. Figure 12 shows total Gulf of Maine landed value varying from $900 million to $1.3 billion between 2000 and 2010, with a peak in 2006. A longer term look at the total value of fisheries in Maine from 1970 through 2012 shows a long-term

The number of people licensed as fish harvesters has declined over time for many reasons, including limited entry programs, consolidations within fleets, changing fish availability, and alternative employment opportunities. Table 2 shows license trends over time for Gulf of Maine jurisdictions. Reductions in license numbers over time are likely the result of a combination of limited entry systems, management changes, and attrition.

Fish processing plants are an integral part of the marine fisheries economy. The number of processing plants in the Gulf of Maine has varied over time as shown in Table 3. Changes in processing capacity have varied due to world markets, labor and raw material prices, and changes in automation and efficiencies.

Table 2: Number of commercial fishing licenses/license holders issued in Gulf of Maine jurisdictions by year (Source: NMFS 2010; 2012b; DFO 2013d; state data). Data for Nova Scotia, New Brunswick and Maine show the number of license holders. Data for New Hampshire and Massachusetts show the number of licenses.

	1985	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
N.S.[a]	11,780	14,465	11,610	11,659	5,202	5,196	5,287	5,265	5,199	5,130	5,043	5,111
N.B.[a]	1,612	2,057	1,745	1,734	1,019	988	957	918	878	823	791	787
Maine	6,942	12,098	11,037	10,897	10,822	10,912	10,496	10,272	10,055	9,667	9,543	9,325
N.H.	[b]	[b]	608	635	697	685	691	693	654	630	634	609
Mass.	[b]	[b]	9,194	9,228	9,440	9,298	8,689	8,381	7,925	7,778	7,686	8,115

[a] License data for DFO Maritimes administrative region, which includes both the Scotian Shelf and Bay of Fundy/Gulf of Maine.
[b] Data not available.

Table 3: Fish processing plants in Gulf of Maine region (Source: Gardner Pinfold 2007; Gardner and Macaskill 2010; NMFS 2012b; NS Department of Fisheries and Aquaculture data; NB Department of Agriculture, Aquaculture, and Fisheries data).[a]

YEAR	2003	2004	2005	2006	2007	2008	2009	2010
Nova Scotia[b]	292	285	279	285	276	256	253	249
New Brunswick	132	129	143	139	134	126	122[c]	122[c]
Maine[d]	97	85	79	81	92	93	88	91
New Hampshire[d]	18	14	14	14	12	7	8	8
Massachusetts[d]	78	78	78	83	76	70	68	70

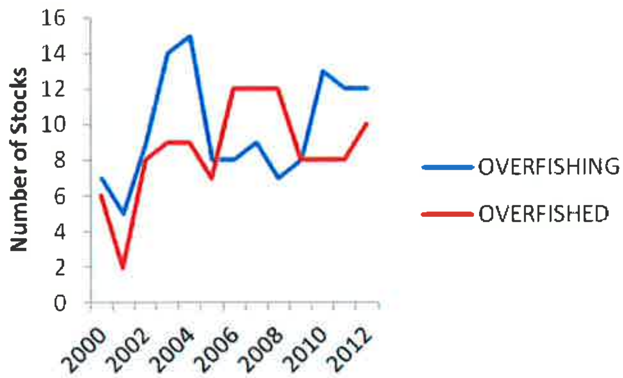
[a] Includes all processing plants in provinces and states, including areas outside the Gulf of Maine.
[b] Nova Scotia figures are the number of licenses. Not all licensed plants may be in operation.
[c] New Brunswick processing licenses changed in 2010 to primary (raw product from fishermen) and secondary (value added processing); these totals include both types of licensed processing plants.
[d] Includes employer establishments and non-employer firms (such as sole proprietorships).

Equally important to the commercial fishing industry is processing capacity. Fish processing in New Brunswick was valued at $399 million in 2008 (Gardner and MacAskill 2010). In the Bay of Fundy region, 34-40 processors employing 1,670-2,100 employees operated from 2003-2008. Nova Scotia had 182 operating processing plants in 2006, a decline of about 50 percent since the 1980s (Gardner Pinfold 2007). In the U.S. portion of the Gulf of Maine, 163-190 processing plants operated from 2000 to 2010 (NMFS 2012b).

Impacts on Fish Stocks

Two indicators of fish stock health used in fishery management are whether a stock is above fishing mortality reference points (called overfishing in the United States and above the removal reference in Canada) or below certain stock status reference points (called being overfished in the United States and below limit reference point in Canada). In the United States, the National Marine Fishery Service reports annually to the Congress on the status of U.S. fisheries (NMFS 2013a). Figure 14 shows the number of overfished stocks and the number of stocks where overfishing is occurring from 2000 to 2012.

Figure 14: Number of U.S. Gulf of Maine fisheries that are overfished or exhibit overfishing (Source: NMFS annual reports to Congress on status of fisheries).



In Canadian fisheries management, the harvest is guided by the status of a stock in relation to upper and limit reference points. The limit reference point (LRP) is the point below which serious harm is occurring to the stock, and stocks below the LRP are considered to be in a "critical" state. In 2012, two Gulf of Maine stocks were below their LRP: 4X5Y cod and 5Zjm cod. In addition, two Gulf of Maine stocks were fished above their removal reference: 5Zjm cod and 5Zhjm yellowtail flounder. While the harvest strategy for both 5Zjm cod and 5Zhjm yellowtail flounder is to maintain a low to neutral risk of exceeding the removal reference, fishing mortality has consistently been above, as reported in the Transboundary Status Report series. This may be attributed, at least in part, to weaknesses in the assessment model (S. Quigley, Fisheries Management, DFO Maritimes, pers. comm.).

The increase in these trends over time in the U.S. results both from changing stock status and changes in biological reference points, as well as increases in the number of stocks with quantitative assessments. Consequently, the upward trend in the number of stocks that are overfished or in which overfishing is occurring may be misleading. The multiple stocks in the groundfish fishery can also result in some species or stock components being overfished while others are not being overfished. Regardless of these data inadequacies, the increasing trend in this indicator demonstrates the ongoing need for sustainable fishery management and research into factors that influence the health of fish stocks in the Gulf of Maine.

5. Actions and Responses

GULF OF MAINE JURISDICTIONS AND INTERESTS TAKE MANY ACTIONS IN response to the threats and pressures being exerted on marine fisheries resources. This includes legislative and management action by federal governments, provincial governments, and state governments; bilateral management actions; shifts toward ecosystem based management; marketing and certification programs; and monitoring fisheries and the marine environment. Examples of actions and responses are listed below.

5.1 LEGISLATION

Governments in the Gulf of Maine regulate marine fisheries at national, provincial or state, and, in limited cases, local levels. Some fisheries are highly regulated, such as groundfish, scallops, and herring. Others have far fewer regulations because they are smaller fisheries geographically or economically, or because they simply have not received attention by fishery management authorities. Examples of less regulated fisheries include marine worms, hagfish, and sea urchin. The risk for fisheries with few regulations is that fishing effort will deplete the stock, as happened in the Gulf of Maine sea urchin fishery (Taylor 2004).

In Canada, marine fisheries are managed through the federal *Fisheries Act*, which applies to all fisheries and fishing areas. Canada also manages its oceans through the *Oceans Act*, which is a comprehensive approach to ocean management founded on sustainable development, integrated management, and the precautionary approach. Additionally, marine species at risk in Canada are protected through the *Species at Risk Act*, which protects marine mammals, fish, and mollusks and their habitats through a listing and management process. The provinces and territories manage most shoreside components of commercial fisheries.

In the United States, marine fisheries are managed by the states from the shore to three miles offshore and by the federal government from three miles offshore to the seaward limit of the Exclusive Economic Zone. Fisheries in federal waters are managed through the *Magnuson-Stevens Fishery Conservation and Management Act* for sustainable use and protection of fish habitat. Fisheries in state water are managed by regulations and statutes in individual states and by the Atlantic States Marine Fisheries Commission (ASMFC) for interjurisdictional fisheries through the *Atlantic Coastal Fisheries Cooperative Management Act* (ACFCMA). The federal and state fishery management systems use cooperative and sometimes joint planning to coordinate activities between state and federal waters.

Species at risk of extinction are protected and managed through the Endangered Species Act Regulations in the United States. Species at risk are those species for which there are concerns about population status and trends. Species at risk or

TRAC assessment stocks[a]

- Georges Bank Yellowtail Flounder
- Eastern Georges Bank Cod
- Eastern Georges Bank Haddock
- Atlantic Mackerel
- Spiny Dogfish
- Georges Bank / Gulf of Maine Herring Stock Complex

[a] Not all TRAC stocks are regularly assessed

TMGC stocks

- Georges Bank Yellowtail Flounder
- Eastern Georges Bank Cod
- Eastern Georges Bank Haddock

allow the United States-Canada Transboundary Resource Sharing Understanding to be considered an international agreement which allows some flexibility in setting the shared quotas through the TMGC process. This will provide some flexibility in setting quotas for the three shared stocks (GovTrackUS 2010).

Ecosystem-based Fisheries Management

Fisheries have traditionally been managed using a single species approach, such as herring regulations to address herring issues and lobster regulations to address lobster issues. A few fisheries, such as the scallop fishery, have cross-fishery provisions, which in this case minimize groundfish bycatch in the scallop fishery. Scientists and fishery managers increasingly recognize the need for management planning and actions that consider connections among many fisheries and with biological, oceanographic, and habitat components of an ecosystem. Canada and the United States have acknowledged the need to incorporate more and better ecosystem planning in marine fisheries (Pres. Exec. Order 2010; DFO 2013e).

The shift to ecosystem-based fishery management will take time, as multispecies stock assessments are developed and tested, multispecies management approaches are developed, and ecosystem-based concepts are understood and accepted by fishery management stakeholders.

5.3 INDUSTRY INITIATIVES/ECO-CERTIFICATION AND VERIFICATION

Product certification or verification programs allow producers, industry groups, governments, and consumers to determine if a product meets certain standards. Fisheries certification is the setting of standards for sustainability with assessments of individual fisheries being conducted by third parties, as is done through

5.4 RESEARCH AND MONITORING

Research and monitoring are necessary components in the sustainable management of Gulf of Maine commercial fisheries. Federal governments, state and provincial governments, and university and private research programs all play important roles in this arena. In Canada, Fisheries and Oceans Canada has a central, legislatively mandated responsibility for fisheries research and monitoring. In the United States, NOAA Fisheries, through their Northeast Regional Office and Northeast Fisheries Science Center, conducts much research and monitoring in the Gulf of Maine. State marine fisheries agencies have a complementary role in research and monitoring, concentrating on species in state-managed waters. Private research institutions and non-government organizations also have programs that are focused on specific areas of interest.

There are many monitoring and research programs throughout the Gulf of Maine ranging from local, single species efforts to large scale, comprehensive surveys. Research trawl surveys are conducted regularly in the Gulf of Maine by both DFO and NOAA Fisheries to assess the health of fish stocks in the region. In addition, inshore trawl surveys are conducted in state waters from Maine through North Carolina under the Northeast Area Monitoring and Assessment Program (NEAMAP) (NMFS 2013c). Scallop resources are monitored in Canada and the United States using dredge surveys as well as by drop camera surveys in the United States (SMAST 2013). Many smaller scale monitoring programs also take place in various portions of the Gulf of Maine region.

7. References

AP (Associated Press). 2012. New Brunswick union reaches pact on Maine lobsters. http://www.bostonglobe.com/metro/2012/08/11/new-brunswick-union-reaches-pact-maine-lobsters-protest-ends/sFeBtnwOSAWbrLfnc0lFqM/story.html (accessed January 2013)

ASMFC (Atlantic States Marine Fisheries Commission). 1996. A review of the population dynamics of the American lobster in the Northeast. ASMFC Special Report 61. Arlington VA: Atlantic States Marine Fisheries Commission. 48 pp.

ASMFC. 1997. Amendment 3 to the Interstate Fishery Management Plan for lobster. Arlington VA: Atlantic States Marine Fisheries Commission. 36 pp.

ASMFC. 2006. Amendment 2 to the Interstate Fishery Management Plan For Atlantic Herring. Arlington VA: Atlantic States Marine Fisheries Commission. 97 pp.

ASMFC. 2009. American Lobster Stock Assessment Report for Peer Review. Stock Assessment Report No. 09-01 (Supplement). Arlington VA: Atlantic States Marine Fisheries Commission. 298 pp.

Bank of Canada. 2013. Monthly and annual average exchange rates. http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf (accessed March 2013).

Beal B. 2000. Predation and soft-shell clams. http://www.maine.gov/dmr/research/soft_shell_clams.htm#attach.%20D (accessed January 2013).

Brodziak J and Traver M. 2006. Status of fishery resources off the Northeastern US: Haddock. http://www.nefsc.noaa.gov/sos/spsyn/pg/haddock/ (accessed January 2013).

CBC (Canadian Broadcasting Corporation). 2012. Lobster fishermen block N.B. Processing Plant. http://www.cbc.ca/news/canada/new-brunswick/story/2012/08/02/nb-lobster-fishermen-protest-shediac.html (accessed January 2013).

Cheung WL, Lang WWY, Sarmiento JL, Kearney K, and Pauly D. 2008. Projecting global marine biodiversity impacts under climate change. Fish and Fisheries 2009(10): 235-257.

Collette B and Klein-MacPhee G. 2002. Bigelow and Schroeders's fishes of the Gulf of Maine. 3rd ed. Washingon DC: Smithsonian Institution Press. 746 pp.

Curran K and Azetsu-Scott K. 2012. Ocean acidification. State of the Scotian Shelf Report. http://coinatlantic.ca/docs/ocean-acidification.pdf (accessed April 2013).

Dayton A and Sun J. 2012. An independent evaluation of the Maine limited entry licensing system for lobster and crab. Portland, Maine: Gulf of Maine Research Institute. 82 pp.

DFO (Department of Fisheries and Oceans). 2000. 2000 Scotia-Fundy Offshore Scallop Integrated Fisheries Management Plan: Maritimes Region. http://www2.mar.dfo-mpo.gc.ca/fisheries/res/imp/2000Offscal.htm (accessed April 2013).

DFO 2003. Groundfish Integrated Fisheries Management Plan, Scotia-Fundy Fisheries, Maritimes Region, April 1, 2000 – March 31, 2002. http://www2.mar.dfo-mpo.gc.ca/fisheries/res/imp/2000grndfish.htm (accessed February 2013).

DFO. 2004. Herring management—Martimes Region. http://www.dfo-mpo.gc.ca/media/infocus-alaune/2004/20040325/sheet-feuillet2-eng.htm (accessed January 2013).

DFO. 2008a. Transboundary Resources Assessment Committee (TRAC). http://www2.mar.dfo-mpo.gc.ca/science/trac/TRAC.html (accessed January 2013).

DFO. 2008b. Transboundary Management Guidance Committee (TMGC). http://www2.mar.dfo-mpo.gc.ca/science/tmgc/TMGC-e.html (accessed January 2013).

DFO. 2009. Underwater world: Green crab. http://www.dfo-mpo.gc.ca/Science/publications/uww-msm/articles/greencrab-crabevert-eng.html (accessed January 2013).

DFO. 2011. Integrated Fishery Management Plan (Summary) Lobster Fishing Areas 27 - 38 Scotia-Fundy Sector Maritimes Region 2011. http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/maritimes/insholob-2011-eng.htm (accessed January 2013).

DFO. 2012a. Assessment of Northern Shrimp on the Eastern Scotian Shelf (SFAs 13-15). DFO Canadian Science Advisory Secretariat Science Advisory Report 2012/001.

DFO. 2012b. List of Harbours and Harbour Activities. http://www.dfo-mpo.gc.ca/sch-ppb/list-liste-eng.htm (accessed February 2013).

DFO. 2013a. Canadian fisheries statistics: International trade. http://www.dfo-mpo.gc.ca/stats/trade-commerce/can/export/xmkt12-eng.htm (accessed February 2013).

DFO. 2013b. Atlantic cod. http://www.dfo-mpo.gc.ca/science/publications/uww-msm/articles/atlanticcod-morueatlantique-eng.htm (accessed March 2013).

DFO. 2013c. Scallop Fishing Area 28 (Bay of Fundy). www.dfo-mpo.gc.ca/decisions/fm-2012-gp/atl-041-eng.htm (accessed April 2013).

DFO. 2013d. Commercial fisheries: Licences. http://www.dfo-mpo.gc.ca/stats/commercial/licences-permis/licences-permis-atl-eng.htm (accessed March 2013).

DFO. 2013e. Sustainable Fisheries Framework. http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/overview-cadre-eng.htm (accessed April 2013).

Fogarty M, Incze L, Hayhoe K, Mountain D and Manning J. 2008. Potential climate change impacts on Atlantic cod (*Gadus morhua*) off the northeastern USA. Mitigation and Adaptation Strategies for Global Change 13: 453–466

NMFS. 2010. Fisheries economics of the U.S. http://www.st.nmfs.noaa.gov/st5/publication/fisheries_economics_2009.html (accessed January 2013).
NMFS. 2011. Fisheries of the United States 2010. Current Fisheries Statistics No. 2010. Washington, DC. 102 pp.
NMFS. 2012a. Secretary of Commerce declares disaster in Northeast groundfish fishery. http://www.nmfs.noaa.gov/mediacenter/2012/09/13_secretary_of_commerce_declares_disaster_in_northeast_groundfish_fishery.html (accessed April 2013).
NMFS. 2012b. Fisheries economics of the United States, 2011. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-F/SPO-118, 175p. https://www.st.nmfs.noaa.gov/st5/publication/index.html. (accessed April 2013).
NMFS. 2013a. Status of US Fisheries. http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm (accessed January 2013).
NMFS. 2013b. Proactive Conservation Programs: Species of Concern. http://www.nmfs.noaa.gov/pr/species/concern/ (accessed April 2013).
NMFS. 2013c. What is NEAMAP? http://www.nefsc.noaa.gov/groundfish/meetings/neamap.pdf (accessed March 2013).
NOAA (National Oceanic and Atmospheric Administration). 2013. Ocean Facts. http://oceanservice.noaa.gov/facts/population.html (accessed January 2013).
NSGLC (National Sea Grant Law Center). 2012. Starting and Maintaining Community Supported Fisheries (CSF) Programs. National Sea Grant Law Center. University, MS. 16pp.
OECD-FAO (Organization for Economic Co-operation and Development and UN Food and Agriculture Organization). 2012. OECD-FAO Agricultural Outlook 2012–2021. http://www.oecd.org/site/oecd-faoagriculturaloutlook/fish-oecd-faoagriculturaloutlook2012-2021.htm (accessed January 2013).
Ortman JM and Guarneri CE. 2012. United States population projections: 2000 to 2050. http://www.census.gov/population/projections/files/analytical-document09.pdf (accessed January 2013).
Overholz W. 2006. Status of fishery resources off the Northeastern US: Atlantic Herring. http://www.nefsc.noaa.gov/sos/spsyn/pp/herring (accessed January 2013).
Parkes G, Walmsey S, Cambridge T, Trumble R, Clarke S, Lamberts D, Souter D and White C. 2009. Review of fish sustainability information schemes. Kingston, RI: University of Rhode Island. 180 pp.
Pauly D, Christensen V, Dalsgaard J, Froese R, and Torres Jr F. 1998. Fishing down marine food webs. Science 279: 860-863.
PRRT (Penobscot River Restoration Trust). 2013. About the Project. http://www.penobscotriver.org/content/4003/the-project (accessed January 2013).
Pezzack D, Tremblay J, Claytor R, Frail C and Smith S. 2006. Stock status and indicators for the lobster fishery in Lobster Fishing Area 34. Canadian Science Advisory Secretariat Research Document 2006/010. 141 pp.
Pres. Executive Order. 2010. Stewardship of the oceans, our coasts, and the Great Lakes. Executive Order 13547. The White House, Washington, DC.
Revkin A. 2013. Bluefin Tuna Sold for Record $1.76 million in Tokyo "Auction." http://dotearth.blogs.nytimes.com/2013/01/04/bluefin-tuna-poised-for-new-record-sale-in-tokyo-auction-more-pressure-at-sea (accessed January 2013).
Richards A, Whitmore K, Fischer J, Hunter M, Waine M and Drew K. 2012. Assessment report for Gulf of Maine northern shrimp–2012. Washington DC: Atlantic States Marine Fisheries Commission. 81 pp.
Rose G, Bradbury I, deYoung B, Fudge S, Lawson G, Mello L, Rideout R, Robichaud D, Sherwood G, Snelgrove P and Windle M. 2008. Rebuilding Atlantic cod: Lessons from a spawning ground in coastal Newfoundland. In: G Kruse, K Drinkwater, J Ianelli, J Link, D Stram, V Wespedsad and D Woodby (eds), Resiliency of gadid stocks to fishing and climate change. Alaska Sea Grant Program. pp 197-220.
Schmitt C. 2011. Maine's climate future and Maine's seafood supply. University of Maine Climate News. http://umaine.edu/maineclimatenews/archives/spring-2011/ocean-acidification (accessed January 2013).
Serchuk FM, Grosslein MD, Lough RG, Mountain DG and O'Brien L. 1994. Fishery and environmental factors affecting trends and fluctuation in the Georges Bank and Gulf of Maine Atlantic cod stocks: an overview. ICES Marine Science Symposium 198: 77-109
SMAST (School of Marine Science and Technology, University of Massachusetts, Dartmouth). 2013. Marine Fisheries Field Research Group. http://webserver.smast.umassd.edu/lab_stokesbury (accessed April 2013).
Statistics Canada. 2008. Population Growth in Canada. http://www.statcan.gc.ca/pub/91-003-x/2007001/4129907-eng.htm (accessed February 2013).
Statistics Canada. 2013. Statistics Canada: latest estimates. http://www.statcan.gc.ca/start-debut-eng.html (accessed April 2013).
Steneck R, Hughes T, Cinner J, Adger W, Arnold S, Berkes F, Boudreau S, Brown K, Folke C, Gunderson L et al. 2011. Creation of a gilded trap by the high economic value of the Maine lobster fishery. Conservation Biology 25: 904-912.
Steneck RS, Vavrinec J, and Leland A. 2004. Accelerating trophic-level dysfunction in kelp forest ecosystems of the western North Atlantic. Ecosystems 7: 323-332.
Sosebee K, Traver M and Mayo R. 2006. Status of fishery resources off the Northeastern United States: Aggregate and resource and landings trends. http://www.nefsc.noaa.gov/sos/agtt (accessed January 2013).
Taylor P. 2004. Green Gold: Scientific findings for management of Maine's sea urchin fishery. Boothbay Harbor: Maine Department of Marine Resources. 33 pp.
Thayer P and Stahlnecker J. 2006. Non-native marine species in Maine. Report to Maine State Legislature, Marine Resources Committee and Natural Resources Committee. 22 pp.

Gulf of Maine Association
In support of the Gulf of Maine Council on the Marine Environment

EUTROPHICATION

Nutrients

Eutrophication is an increase in the concentration of nutrients (primarily nitrogen and phosphorus) in an ecosystem to the extent that an excessive increase in primary productivity occurs. It is most often the result of anthropogenic pollution, particularly the release of sewage effluent and agricultural run-off carrying fertilizers into natural waters. Eutrophication generally promotes excessive plant growth and decay, favours simple algae and plankton over other more complicated plants, and causes a severe reduction in water quality. It can lead to dense blooms of phytoplankton, including "red tides" or harmful algal blooms, and changes in seagrass beds and other submerged aquatic vegetation. It also increases zooplankton productivity, and causes changes in coral reefs. Negative effects include: decreased water clarity; depletion of dissolved oxygen in the water; reductions in fish and shellfish harvests; fish kills; problems with water odour; and decreases in the resource value of coastal and marine habitats such that recreation, fishing, hunting, and aesthetic enjoyment are hindered.

Eutrophication is a common phenomenon in marine and coastal waters. Nitrogen is more commonly the key limiting nutrient of marine waters and is of greater importance in marine waters than phosphorus. Estuaries tend to be naturally eutrophic (nutrient rich) because land-derived nutrients are concentrated where run-off enters the marine environment. Upwelling in coastal systems also promotes increased productivity by conveying deep, nutrient-rich waters to the surface, where the nutrients can be taken up by algae. The National Estuarine Eutrophication

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NOVA SCOTIA CANADA

MASSACHUSETTS OFFICE OF COASTAL ZONE MANAGEMENT

NOAA
National Oceanic and Atmospheric Administration

EUTROPHICATION

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2012

1. Issue in Brief

Cultural eutrophication is an ecosystem response to increases in nutrient (primarily nitrogen and phosphorus) inputs from human sources. Estuaries, bays and nearshore coastal waters in the Gulf of Maine receive nutrient inputs from land-based sources via rivers and streams, directly from human activities adjacent to and within marine environments, atmospheric deposition, and oceanic upwelling and circulation. These inputs result in predictable consequences once they enter the waterbody (Cloern 2001; Bricker et al. 2007, Figure 2). First, nutrient loading to the water column increases, which then stimulates growth and production of both phytoplankton and larger algal species such as floating mats of macroalgae, such as *Ulva* or sea lettuce. Although a certain amount of phytoplankton and macroalgae are needed to support upper trophic levels (i.e., fish), excessive algal growth can lead to other more serious water quality consequences. For example, high concentrations of phytoplankton may cloud the water and cause die-off of seagrasses (submerged aquatic vegetation), which are considered important habitat for juvenile fish. Macroalgal growth can smother seagrasses and bottom-dwelling organisms such as clams, leading to die-offs of both. In addition, episodes of low bottom water dissolved oxygen (i.e., hypoxia or anoxia) may occur if algae sink to the bottom and deplete oxygen levels during decomposition. The phytoplankton community may also shift to favor more toxic and nuisance species, or harmful algal blooms (red tides) that may also result in public health concerns. The eutrophication process, however, is more complex than portrayed here. Estuaries are part of larger systems and the development of eutrophic symptoms is influenced by both "bottom-up" (e.g., nutrient inputs) and "top-down" (e.g., phytoplankton grazers such as shellfish) effects. It is important to stress that eutrophication has potential negative impacts on our coastal habitat and recreational values that are so important to the Gulf of Maine communities.

This theme paper describes how population increases and development have altered the hydrological and biogeochemical cycles in our watersheds, resulting in more potential export of carbon, nitrogen, and phosphorus to the Gulf of Maine's estuaries and coastal waters. Urbanization has led to channelization and damming of rivers and other waterbodies, water withdrawals, loss of vegetation in riparian areas, more impervious surfaces, less infiltration of water into the ground. Because of these multifarious effects of development on water quality, reducing nutrient pollution requires action by all levels of the government and the public (Figure 1).

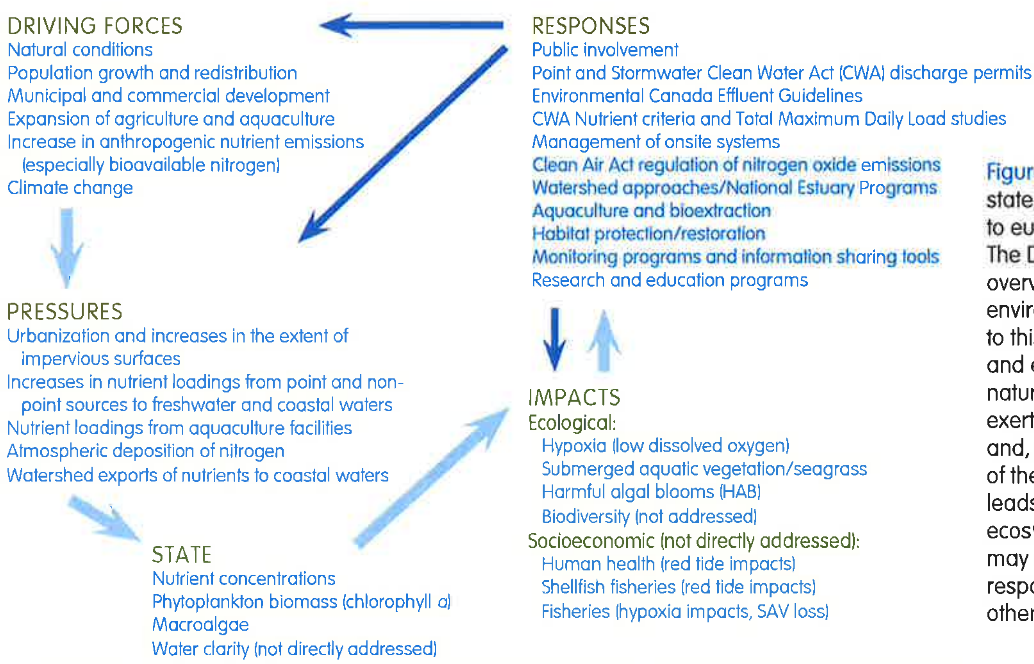


Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to eutrophication in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions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

physical characteristics of the waterbody determine the likelihood of a eutrophic response. Coastal bays, estuaries and tidal rivers with a longer residence time (and more restricted exchange of water with the ocean) are expected to be more sensitive to land-based nutrient inputs (Kelly 1997; Cloern 2001; Bricker et al. 2007; Glibert et al. 2008). This is particularly important with regard to harmful algal blooms, since they have slower growth rates and are less likely to occur if water residence time is short (Ferreira et al. 2005).

Circulation patterns in the Gulf of Maine have been described in *The Gulf of Maine in Context*. Three attributes of the Gulf's physical and chemical oceanography are worth highlighting here because of their importance in stimulating biological production. First, the Gulf of Maine is biologically productive due to the upwelling of nutrient-rich, deep continental slope water from the Northeast Channel and inputs from the Scotian Shelf (Townsend 1998). This is the primary source of nutrients to Gulf of Maine waters and contributes over 90% of the inventory of nitrogen in the Gulf of Maine. Upwelled waters mix with Scotian Shelf waters and with runoff from Maine and New Brunswick to form the Maine Coastal Current, which is important in transporting harmful algal blooms. Second, the Maine Coastal Current is supplemented with nutrient-rich freshwater sources (the largest of which are the St. John, Penobscot, Kennebec, and Merrimack rivers), which creates a "freshwater plume" along the coast and influences productivity of important coastal habitats such as salt marshes and seagrass habitats. Fortunately, the third attribute, a large tidal range in the Gulf, reduces sensitivity of estuarine and coastal waters to nutrient enrichment. These conditions combine to make the Gulf of Maine and Georges Bank one of the most productive coastal seas in the world.

2.2 HUMAN POPULATION DEMOGRAPHICS AND MIGRATIONS

Cultural (human-induced) eutrophication has been shown to be a problem in many coastal areas due primarily to the high density of population along the shoreline (Bricker et al. 2007).Though the overall population of the Gulf of Maine region continues to grow (static in Canada; growth in the US), the major demographic trends are migration from rural to metropolitan centers along the coast and a sprawl-like expansion of these metropolitan areas (Collins 2004; see *The Gulf of Maine in Context*). Urbanization in the coastal zone has also expanded because the coast attracts retirement and seasonal residences, especially in the United States. This increase in coastal development has shortened and altered the time-of-travel and flow pathways for nutrients from their sources to coastal waters in several ways. First, nutrients that may have once entered groundwater from septic systems scattered across the landscape are increasingly being routed through municipal facilities, processed, and released as point source effluents directly to rivers or estuaries. Second, formerly rural coastal communities (e.g., on Cape Cod, Massachusetts) served primarily by septic systems increase the demand for better treatment of nitrogen and phosphorus with municipal or decentralized wastewater treatment facilities. And finally, the application of

Table 1: Watershed-based sources of nitrogen and phosphorus from select Gulf of Maine river basins. Estimates derived from Moore et al. (2011) and G.A. Benoy (Environment Canada, unpublished data).

RIVER BASIN	DRAINAGE AREA (km^2)	TOTAL NITROGEN (metric tons)	PREDICTED PERCENT OF NITROGEN LOAD FROM			
			Atmospheric Deposition	Agricultural Sources	Developed Lands	Municipal Wastewater
Charles	749	539	15	7	64	15
Merrimack	12950	8229	25	8	29	38
Piscataqua	2574	1084	29	13	41	17
Saco	4389	1208	50	11	32	7
Androscoggin	9129	2511	52	9	24	15
Kennebec	15348	4218	55	14	23	8
Penobscot	21908	4912	66	12	18	4
Saint John	55100	16020[a]	-	-	-	-

[a] Estimated sum of agricultural land, forested land, food processing plants and pulp and paper mills, and rural and urban inhabitants (G.A. Benoy, Environment Canada, unpublished data).

RIVER BASIN	DRAINAGE AREA (km^2)	TOTAL PHOSPHORUS (metric tons)	PREDICTED PERCENT OF PHOSPHORUS LOAD FROM			
			Forested Lands	Agricultural Sources	Developed Lands	Municipal Wastewater
Charles	749	26	5	6	47	42
Merrimack	12950	524	14	5	21	60
Piscataqua	2574	71	15	9	42	33
Saco	4389	70	43	15	27	15
Androscoggin	9129	138	37	15	18	30
Kennebec	15348	245	34	20	18	28
Penobscot	21908	270	48	29	16	7
Saint John	55100	2242	34	24	16[b]	26

[b] Not estimated, assumed to be equivalent to neighboring watersheds in Maine.

gradient in the Gulf of Maine region, the contribution of nitrogen from urban areas (e.g., from wastewater treatment facilities and urban runoff) is about 75% in the most southern watersheds of the Gulf of Maine (e.g., Charles and Merrimack river basins) with upland forests (represented by the atmospheric contribution) contributing as little as 15%. Similar variation in source contributions is observed for phosphorus. In comparison with nitrogen, relatively greater contributions of phosphorus are derived from agricultural sources and municipal wastewater and relatively less from forested lands.

Non-point sources of nitrogen and phosphorus to estuaries and coastal waters tivity of coastal waters to nutrient enrichment. Specifically, warmer waters may increase algal productivity—leading to expanded ranges or growing seasons of some undesirable species. Warmer waters might also increase stratification, and since warmer waters also hold less dissolved oxygen, the potential for hypoxic events might increase. Climate change impacts on the distribution of rainfall and snowfall and the intensity of storm events may alter hydrologic cycles and the timing and delivery rates of nutrients to the Gulf of Maine from rivers. Indirectly, alteration of global circulation patterns may actually decrease delivery rates of nutrients from offshore upwelling sources (Townsend et al. 2010). On land, warmer temperatures may affect the phenology (the timing and seasonality of life cycle events) of floral and faunal communities, potentially altering biogeochemical cycling of nutrients. Similarly, changes in mean annual temperatures may affect river freeze-up in the fall and the timing of spring melt and ice break-up in the spring.

Sea level rise may gradually inundate coastal lands, causing increased erosion and sediment delivery to waterbodies, and potentially flooding wetlands. The increased sediment load and subsequent turbidity increase may cause submerged aquatic vegetation loss. The positive feedback between increased erosion and algal growth (as erosion increases, sediment associated nutrients also increase, stimulating growth) may also increase turbidity. The loss of wetlands, which act as nutrient sinks, will further increase nutrient delivery to estuaries.

Some recent research internationally and in Casco Bay shows that eutrophication increases the susceptibility of coastal waters to ocean acidification impacts (Green et al. 2009). The decomposition of organic material from algal mats in estuarine and coastal waters has already enhanced the acid content of coastal subsurface waters. With the expected increases of atmospheric carbon dioxide, further increases in acidification of coastal waters are predicted. This acidification is likely to impact shell formation in shellfish (such as clams) with concomitant losses in commercial shellfish yields.

Figure 3: Indicators (except nutrients) that are used in the evaluation of eutrophication (adapted from Bricker et al. 2007). The NEEA and NCA use the same thresholds for chlorophyll *a* and dissolved oxygen.

	Description of State Indicators	Thresholds
Chlorophyll *a* (Phytoplankton)	A measure used to indicate the amount of microscopic algae (phytoplankton) growing in a water body. High concentrations can lead to low dissolved oxygen levels as a result of decomposition.	High: >20 µg Chl *a* l^{-1} Medium: >5, ≤20 µg Chl *a* l^{-1} Low: ≤5 µg Chl *a* l^{-1}
Macroalgal blooms	Large algae commonly referred to as "seaweed". Blooms can cause losses of submerged aquatic vegetation by blocking sunlight. Additionally, blooms may smother immobile shellfish, corals or other habitat. The unsightly nature of some blooms may impact tourism due to the declining value of swimming, fishing, and boating.	(e.g., dieoff of submerged plants (SAV) – see Submerged aquatic vegetation in symptoms below left.) No problems: no problems are indicated when there are no apparent impacts on biological resources.
	Description of Impact Indicators	**Thresholds**
Dissolved oxygen	Low dissolved oxygen is a eutrophic symptom because it occurs as a result of decomposing organic matter (from dense algal blooms), which sinks to the bottom and uses oxygen during decay. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic values, resulting in the loss of tourism and recreational water use.	Anoxia: 0 mg l^{-1} Hypoxia: >0, ≤2 mg l^{-1} Biologically Stressful: >2, ≤5 mg l^{-1}
Submerged aquatic vegetation	Loss of submerged aquatic vegetation (SAV) occurs when dense algal blooms caused by excess nutrient additions (and absence of grazers) decrease water clarity and light penetration. Turbidity caused by other factors (e.g., wave energy, color) similarly affects SAV. The loss of SAV can have negative effects on an estuary's functionality and may impact some fisheries due to loss of a critical nursery habitat.	High Loss: >50% of seagrass area Medium Loss: ≥25%, <50% of seagrass area Low Loss: <25% of seagrass area
Nuisance blooms	Thought to be caused by a change in the natural mixture of nutrients that occurs when nutrient inputs increase over a long period of time. These blooms may release toxins that kill fish and shellfish. Human health problems may also occur due to the consumption of contaminated shellfish or from inhalation of airborne toxins. Many nuisance/toxic blooms occur naturally, some are advected into estuaries from the ocean; the role of nutrient enrichment is unclear.	Problem: a problem is indicated if there is a detrimental impact to any biological resource (e.g., dieoff of filter feeding bivalves and fish, respiratory irritation). No problem: no problems are indicated when there are no apparent impacts on biological resources

3.1 NUTRIENTS

Nutrients are considered primary indicators and are typically measured in two ways; as Total Nitrogen (TN) and Total Phosphorus (TP), or in the dissolved state (DIN is Dissolved Inorganic Nitrogen, DIP is Dissolved Inorganic Phosphorus). There is a debate in the scientific community over which are the better indicators, TN and TP or DIN and DIP. The dissolved forms of nutrients (DIN and DIP) are used for this discussion because they are relatively easy to measure, and are suitable for evaluating patterns over large spatial scales.

Table 2: Thresholds, ranges (mg/L), and ratings for DIN and DIP for the National Estuarine Eutrophication Assessment (NEEA) and the National Coastal Assessment (NCA) methods (from Bricker et al. 1997; US EPA NCA 2008).

	HIGH* POOR+	MODERATE* FAIR+	LOW* GOOD+
DIN (mg/L)			
NEEA	>1.0	0.1–1.0	<0.1
NCA	>0.5	0.1–0.5	<0.1
DIP (mg/L)			
NEEA	>0.10	0.01–0.10	<0.01
NCA	>0.05	0.01–0.05	<0.01

The name of the ratings for NEEA are indicated with * and for NCA are indicated as +. Note that the thresholds for ratings of the worst case conditions (High and Poor) are higher for the NEEA method than the NCA. DIN is Dissolved Inorganic Nitrogen. DIP is Dissolved Inorganic Phosphorous.

Results from summertime sampling for the National Coastal Assessment (EPA NCA 2008 data as summarized by John Kiddon, EPA, pers. comm.) show that 96% of the United States portion of the Gulf of Maine region is considered good quality for DIN, and 99% of the region shows fair-to-good DIP when they sink and decay in bottom waters. Macroalgal biomass or abundance is a status indicator, but they are difficult to evaluate quantitatively because of their mobility and variation in thickness. The NEEA results show that one third of the systems exhibit moderate-to-high-level problems from macroalgae and the spatial extent of macroalgae has increased in Great Bay, New Hampshire, Hampton Harbor, New Hampshire and Cape Cod Bay, Massachusetts since the early 1990s (Figures 5 and 6). In Great Bay, macroalgae have replaced 6% of seagrass meadows between 1996 and 2007 specifically in areas of high nitrogen concentrations (NHDES 2009). Unfortunately, for many of the estuaries there are no data with which to make an evaluation; assessing the abundance of macroalgae is an important need due to the potential for macroalgal proliferation to reduce habitat and recreational uses (see *Coastal Ecosystems and Habitats* theme paper).

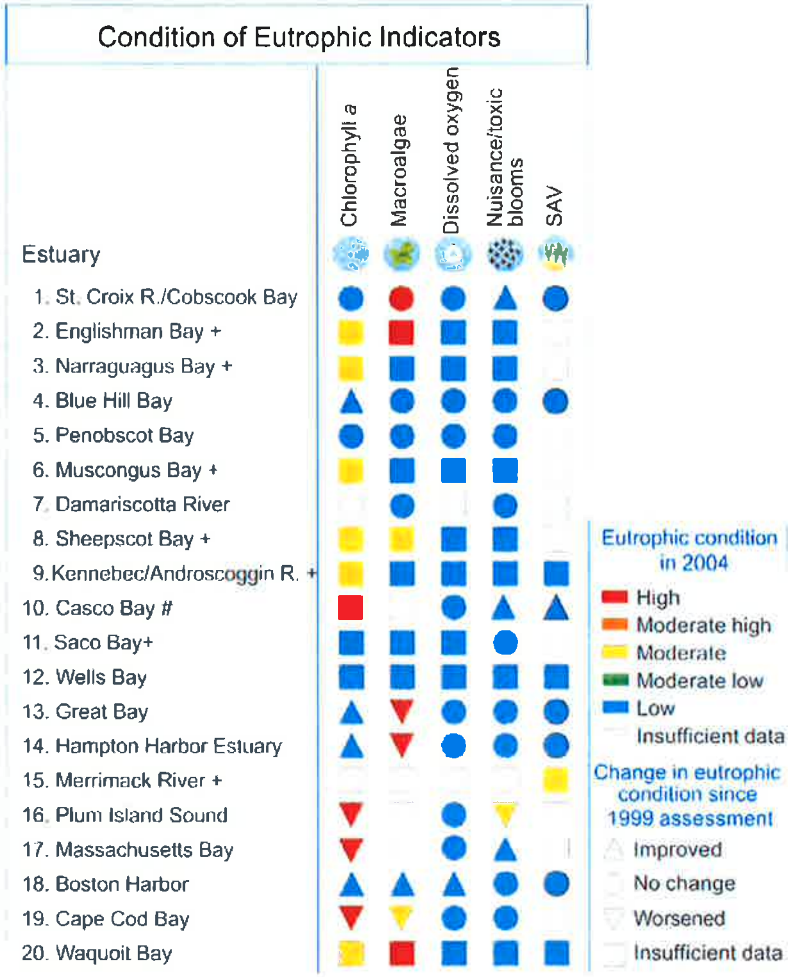
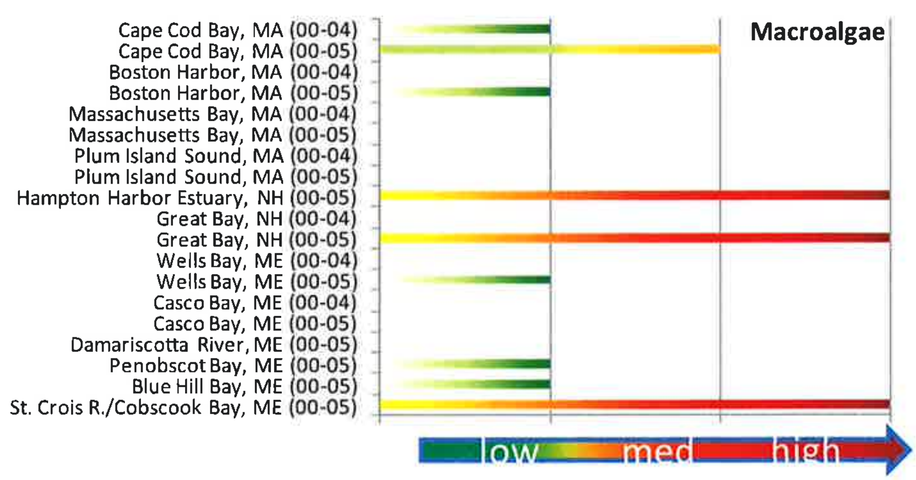


Figure 5: National Estuarine Eutrophication Assessment results for individual indicators of eutrophication (adapted from Bricker et al. 1999 (indicated with +), 2006 (indicated with #), 2007 (all others).

Figure 6: Summary of combined information from the NOAA assessments for macroalgae bloom frequency. Green indicate no problems, red indicates periodic or persistent problems; assessment periods are in parentheses by each estuary name. Estuaries with no bars indicate unknown status. Sources: Bricker et al. 2006; Bricker et al. 2007.



the region is considered in the good category (EPA NCA 2008 data as summarized by John Kiddon EPA, pers. comm.). This is not unexpected since the estuaries in this region are strongly flushed due to the large tidal range, and except for coastal cities with high populations, nutrient loads are considered to be relatively low. Boston Harbor is an exception to the general trend among coastal population centers—the improved sewage treatment and relocation of the metropolitan Boston wastewater outfall from Boston Harbor to 15 km offshore into Massachusetts Bay resulted in improved oxygen levels in Boston Harbor (Taylor 2005, 2006; see box in Responses section).

4.2 SEAGRASS

Seagrasses provide important ecological services, including: fish, shellfish, and shore-bird feeding habitats; nutrient and carbon cycling; sediment stabilization; and biodiversity throughout the world (Duarte et al. 2008; Orth et al. 2006; see *Coastal Ecosystems and Habitats*). Loss of seagrasses (primarily *Zostera marina*) in the northeast is often associated with light limitation due to algae-associated turbidity, smothering by phytoplankton or macroalgae, or epiphytic shading (Duarte 1995; Hauxwell et al. 2003; Leschen et al. 2010), as well as from sediment sulfides (which are toxic to plants) that occur with high sediment organic matter levels in greatly enriched estuaries (Figure 8).

Observed losses in the Gulf of Maine are consistent with losses of more than half of the seagrass beds within North Atlantic region estuaries during the past century (GOMCME 2004, 2009; Gustavson 2010) and are also consistent with global patterns; nearly 20% of seagrass species are threatened and are decreasing in abundance (Short et al. 2011). Importantly, the response of seagrass appears to be non-linear, above a specific nitrogen loading threshold; seagrass loss is precipitous (Figure 9). Evidence from southern New England estuaries combined with global data reveal that nitrogen loading must be kept well below 50 kg N ha^{-1} yr^{-1} to prevent eelgrass loss (Latimer and Rego 2010). As noted above, Great Bay shows a loss of 6% of seagrass area due to macroalgal growth between 1996

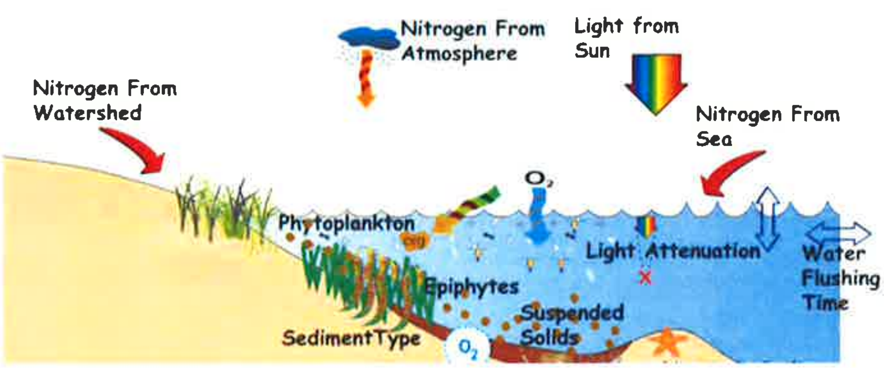


Figure 8: Threats to seagrasses derived from nutrient enrichment. Source: J. Latimer, U.S. EPA, pers. comm., 2012.

5. Actions and Responses

REDUCING NUTRIENT POLLUTION TO PROTECT EXISTING USES, OR TO ENSURE that emerging problems do not get worse, is a major challenge. It requires voluntary actions, individual actions by homeowners and developers, as well as governmental regulation and initiatives at local, regional, state, and federal levels. Importantly, citizen advocacy is a critical motivator to ensure that coastal water quality can be restored, or that they are not polluted in the first place. Many of the responses described below have been discussed at many fora and workshops, including one co-sponsored by the Gulf of Maine Council and the National Oceanic and Atmospheric Administration (NOAA)/University of New Hampshire Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET 2001). An overarching response to eutrophication, as well as to all threats to the coastal ocean, is improved regional management. Coordination among federal, state/provincial, and local governance structures is critical to protect and restore the coastal ocean in the Gulf of Maine. The United States National Ocean Policy, which was established in 2010, calls for improvements to manage the ocean, including coastal and marine spatial planning, regional ecosystem protection and restoration, and improved scientific data sharing capabilities, among others. Organizations such as the Gulf of Maine Council, the Northeast Regional Ocean Council (NROC), and the Northeast Regional Association of Coastal Ocean Observing Systems (NERACOOS) provide tools and information to coastal scientists and managers to reduce the stresses and impacts associated with eutrophication. Described below are regulatory tools (such as establishment of nutrient criteria) as well as other actions that promote information sharing or stewardship to help restore and protect the Gulf of Maine from eutrophication, specifically in the nearshore or estuarine areas, where eutrophication effects are most apparent. Although most of these examples are from the United States, the approaches described may also be applicable to Atlantic Canada.

Boston Harbor Cleanup

An example of how combined federal, state, and local activities can reduce nutrient pollution is the successful cleanup of Boston Harbor (Massachusetts). This cleanup got a major push in the 1980s when Boston Harbor was considered among the dirtiest harbors in the country. The Deer Island and Nut Island treatment plants performed primary treatment only and therefore discharged sewage effluent and sludge, rich in nutrients, organic matter, and other pollutants, into Boston Harbor. Algal blooms were frequent, water clarity was poor, and dissolved oxygen in the water and the sediments was below standards for the protection of aquatic life. With a combination of citizen advocacy, federal enforcement of the Clean Water Act (and an aggressive and vigilant judge), reorganization of a state agency, federal and local financing, and continued public interest (from both the water quality and harbor access perspectives), sewage discharge into Boston Harbor was dramatically improved.

After significant environmental assessment, transfer of the discharge location out of the harbor was approved by both the state and federal governments. Part of this review included a consultation with the National Marine Fisheries Service, which was concerned about the potential for nutrient enrichment in Massachusetts Bay to affect protected marine mammals. Ultimately this review concluded that there would be no harm to the marine mammals, but required establishment of a monitoring plan to determine whether nutrients discharged to Massachusetts Bay might alter the ecosystem.

Today, thanks to improved treatment levels and the new outfall pipe, Boston Harbor is cleaner and both nutrient and chlorophyll levels have decreased to acceptable levels (Taylor et al. 2011). Because of dilution and the vigorous mixing in Massachusetts Bay at the outfall site, there does not seem to be significant harm to marine life caused by the discharge of 350 Million Gallons a Day (MGD) of treated sewage. The message here is that solutions take a mosaic of local, state, and federal controls, along with support from the legislature, the public, and, in some cases, the judiciary, which is especially critical for obtaining project financing.

can be discharged from a given facility and set limits in the permit to ensure that water quality standards will be met.

Most municipal WWTPs discharge to rivers or to tributaries of estuaries, or directly into the coastal ocean. Due to increased concern about nutrient enrichment in estuaries, more attention is being paid to whether nitrogen discharged from WWTPs is causing or contributing to violations of water quality standards in the receiving waters. Most secondary treatment facilities do not effectively remove nitrogen from the effluent (most of which is usually in the form of ammonia). Typical effluent concentrations range from 10 to 25 mg/L total nitrogen and efforts are underway in many communities to reduce nitrogen discharges to levels protective of water quality or aquatic resources (D. Pincumbe, EPA Region 1 environmental engineer, pers. comm., April 2011).

In a recent example of efforts to address this problem, EPA issued a draft permit to the town of Exeter in New Hampshire (EPA 2011b). The town's sewage treatment plant discharges into the Squamscott River which is exhibiting signs of eutrophication, and is a tributary to the Great Bay estuary which has lost much of its eelgrass habitat. The New Hampshire Department of Environmental Services identified violations of water quality standards in the tributaries to the estuary, and EPA determined that the estuary could not assimilate any additional nutrients. The draft permit requires a reduction of total nitrogen in the effluent from an annual average of 14.4 mg/L to 3 mg/L during the growing season of April through October and optimized removal of nitrogen using all available equipment at the facility from November through March. To comply with the effluent limitation of 3 mg/L, Exeter and a number of other communities within the watershed (there are 17 other WWTP in the Great Bay watershed) may require significant upgrades to their wastewater treatment facilities to include denitrification.[2]

Point sources in Atlantic Canada

There is no federal Canadian legislation that specifically regulates discharge of sewage from municipal WWTPs. The *Canadian Environmental Protection Act* of 1999 (supplemented by the *Fisheries Act*, 1985), however, which is implemented by Environmental Canada with Provincial agencies and municipal authorities' input, governs the release of potentially toxic contaminants into the environment. Atlantic Canada appears to be lagging behind the United States in terms of sewage treatment. For example, as of 2002, only about 60% of sewage from New Brunswick's largest city (Saint John, population 74,000) was treated – the remainder was discharged raw (Hinch et al. 2002). Recently, however, the *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* strengthened and clarified performance standards for discharges and reinforced efforts to provide financing for upgrading WWTPs (CCME 2009).

Non-point sources and the U.S. Clean Water Act NPDES stormwater permits

As described in Section 2.3, non-point sources are major contributors to nutrient enrichment in many estuaries in the Gulf of Maine. State and federal agencies are

[2] The Exeter permit is under review and the permittee and a coalition of communities in the watershed may object to the limits on the grounds that other pollutants, and not nitrogen discharged from the WWTPs, are causing eutrophication in the estuary or loss of eelgrass habitat.

Management of onsite sewage disposal systems

In general, most environmental protection is addressed or implemented at the local level. This is especially true in the Gulf of Maine where enforcement and oversight of small residential on-site sewage disposal systems ("OSDS" or "septic systems") is often managed by local health officials using regulations developed by state or provincial environmental or health agencies. A well maintained and functioning septic system will remove significant loads of phosphorus, but only about 25% of nitrogen in the leach field (Costa et al. 2002). Further attenuation occurs within the watershed, but less if septic systems are located more directly near tributaries or estuaries. Septic systems are the preferred sewage treatment approach in areas of low residential density because of cost considerations, but poorly maintained systems are a threat to estuaries. Thus, regional decentralized wastewater treatment districts, which ensure ongoing monitoring, are highly recommended. Alternative treatment systems, which are designed to remove additional nitrogen, are proven technologies and are now recommended for siting in areas of sensitive resources (e.g., estuaries) or in retrofitting failing systems.

U.S. Clean Water Act regulatory tools: Nutrient criteria and TMDLs

Water quality standards are an important tool to protect coastal waters from nutrient enrichment, however, most states employ a narrative, or descriptive, standard, which is difficult to enforce or employ because it is not always objectively determined. In the United States, EPA and state environmental agencies have been working for many years on determining appropriate numeric levels of causal (nutrient) and response variables (chlorophyll *a*, macroalgae, dissolved oxygen, and transparency) that protect aquatic life, such as submerged aquatic vegetation, or prevent hypoxia. Numeric criteria are important targets that can be used in setting permit limits, preventing degradation of unimpaired waterbodies, and determining whether waterbodies are meeting designated uses, and if not, in setting targets for a Total Maximum Daily Load (TMDL) study.

As an example, the New Hampshire Department of Environmental Services has developed numeric nitrogen criteria for Great Bay that was used for determining attainment of water quality standards and was one of many scientific factors in determining appropriate nitrogen limits for the Exeter WWTP draft permit (NHDES 2009). Maine is also making progress and the United States EPA Region 1 office has conducted a significant level of sampling (2009 to 2011) to establish coastal nutrient criteria for the Gulf of Maine. Although developing numeric nutrient criteria may take several years, EPA recommends that while criteria are being developed, it is important to "prioritize watersheds on a statewide basis for nitrogen and phosphorus loading reductions … and set watershed load reduction goals based upon best available information" (Stoner 2011).

TMDLs are restoration plans designed to address a specific pollutant(s) to return a waterbody to a condition where it meets water quality standards. They

5.3 WATERSHED AND RESTORATION APPROACHES

United States National Estuary Programs (NEPs)

The United States NEPs are ecosystem-based and geographic-based management programs established in 1987 as part of the *Clean Water Act* to protect and restore the water quality and ecological integrity of significant estuaries. NEPs utilize management conferences—partnerships among government and non-government organizations—to develop and implement a Comprehensive Conservation and Management Plan, or CCMP. The goal of each plan is to identify actions designed to improve water quality and protect and restore habitat and living resources in the estuary, and the watershed. There are three NEPs in the Gulf of Maine—the Casco Bay Estuary Partnership, the Piscataqua Region Estuaries Partnership, and the Massachusetts Bays Program. Here are two examples of how the NEPs implement approaches to address sources nutrients.

Much progress has been made toward managing stormwater through a regional, or watershed, approach. The Casco Bay Estuary Partnership (CBEP), for example, assists communities by providing technical information, mapping tools, and citizen advocacy to encourage municipalities and individual citizens to reduce nutrient pollution (CBEP 2011). In an urban environment, most stormwater is not effectively treated before discharge to tributaries or estuaries. To address this challenge, the CBEP provides training and technical assistance in stormwater best management practices (BMPs) including LID, promotes subwatershed management planning and implementation, and monitors progress in reducing stormwater discharges.

The Massachusetts Bays Program (MBP) in 2011 established a dedicated grant program to assist communities implementing projects consistent with their management plan, including prevention of nutrient enrichment. For example, in 2011 and 2012 the MBP funded projects to design stormwater best management practices in Kingston Bay, assess turbidity in Salem Harbor, and evaluate sites for eelgrass restoration in Plum Island Sound.

A watershed receiving major attention is the Long Creek Watershed in Portland, Maine, and three surrounding towns. CBEP, along with the Cumberland County Soil and Water Conservation District, were key organizations that led the development of a plan to restore water quality and habitat in both urban and rural parts of this watershed.[3] This plan is funded and implemented through an innovative public-private partnership, the Long Creek Watershed Management District. Already, the District has installed more than $2 million worth of BMPs with funding from the State Revolving Loan (SRF). A comprehensive stormwater BMP maintenance and inspection database has been developed to assist landowners and environmental managers in Maine to monitor the progress of the plan.

[3] Year 16 CBEP workplan, 2011.

5.4 MONITORING, RESEARCH AND INFORMATION PROGRAMS

There are several water quality monitoring programs in the Gulf of Maine estuaries, coastal bays, and offshore, some of which are significant long-term programs. These monitoring programs typically provide information to managers and the public on water quality, identify spatial and temporal trends, and determine whether water quality is responding to management actions, such as reductions in nutrient loads from WWTPs. For example, the Massachusetts Water Resource Authority (MWRA) outfall monitoring program is a permit requirement (and a long-term investment) that ties results directly to the operation of the sewage treatment plant and to model predictions. The ESIP program has catalogued many of these programs and has made strong efforts to ensure that ecosystem indicators based on data collection efforts allow decision makers to understand the connection between ecosystem health and environmental actions (ESIP 2011c).

In the United States, government agencies (such as the EPA and NOAA), National Estuary Programs (such as the Piscataqua Region Estuaries Partnership and the Casco Bay Estuary Partnership), and marine "stewardship" organizations (such as the Friends of Casco Bay in Maine) and other community based initiatives make regular measurements of a set of eutrophication indicators to assess the condition of their aquatic resources. The indicators are based on conceptual models of eutrophication in coastal waters (e.g., Bricker et al.1999, 2003, 2006, 2007; CICEET 2001; Figures 2 and 3) and are measured at programmatically dependent spatial and temporal intervals (i.e., monthly, seasonally, etc). Some indicators are used to evaluate the status of the estuary (i.e., chlorophyll *a*, macroalgal abundance, and nutrient concentrations; see section 3: Status and Trends) and others are used to evaluate the impacts of eutrophication (i.e., dissolved oxygen, changes in seagrass distribution, and occurrences of nuisance and toxic blooms; see section 4: Impacts). Although some programs monitor year round, most measures are taken during the summer, the presumed optimum growing period, and a period when symptoms are worst (e.g., low dissolved oxygen is typically observed in the late summer).

In the Atlantic provinces, Fisheries and Oceans Canada (DFO) operates the Atlantic Zone Monitoring Program (DFO 2011) which is aimed at increasing the Department's understanding of the marine environment to better forecast the state of the environment and to quantify the changes in ocean physical, chemical and biological properties and predator-prey relationships of marine resources (DFO 2009a). This long term monitoring program was implemented in 1998.

There are several programs in the Gulf of Maine that combine research efforts with communicating results to the public focusing on assessing and evaluating loads of nutrients to the coastal zone. The results of this research usually are (or hopefully are) incorporated into science based action plans for restoration. These

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	TREND*	ASSESSMENT
Nutrients	Relates to nutrient loading	State	-	Fair to Good
Chlorophyll *a*	Symptom of eutrophication	State	-	Fair to Good
Macroalgae	Potential negative impact on aesthetic use and fish and shellfish habitat	State	-	Fair to Good
Dissolved oxygen	Potential negative impact on fish and shellfish habitat	Impact	/	Good
Loss of seagrass	Potential negative impact on fish and shellfish habitat	Impact	-	Poor
Harmful Algal Blooms	Possible connection to nutrient enrichment	Impact	-	Poor

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

Data Confidence

Results in this report for the various driver, pressure, state and impact indicators are derived from published papers, reports, and databases; the degree of confidence of each indicator is dependent on the confidence of data use which is contained in the published documents themselves or in the metadata files of the databases utilized. For example, the confidence of NEEA state and impact indicators is based on the representativeness of spatial and temporal sampling, as well as the confidence in the analytical method used to measure the specific parameter. Methods for parameters such as chlorophyll *a* and dissolved oxygen are standardized and thus the confidence in the data for these indicators is typically very high. For other parameters such as macroalgae, for which there is no standard measure, and for nuisance and toxic blooms, for which there are not much data available, there is not as high a level of confidence in the results.

Data Gaps

- There is a paucity of data and information from the Canadian portion of the Gulf of Maine for all components (drivers, pressures, state, impacts) of the assessment.
- Although there are data for the estuarine areas of the Gulf of Maine, more data are needed for central Gulf waters. While there are adequate data in many estuarine and near coastal areas to determine the impact of human related nutrient inputs, due to the lack of data, is not possible to say what the impacts are to waters that are further offshore.
- Data on the conditions of estuaries from the time period of this assessment to the present and into the future.
- Quantification of the linkages between watershed activities, nutrient loading, and ecological responses
- With the exception of a few estuaries within the Gulf (e.g. Great Bay, Boston Harbor) there is no adequate data to develop numeric nutrient criteria to guide management measures. Additionally, there are only adequate data in a few places (e.g. Boston Harbor) for performance evaluation of management measures.

EPA. 2011c. Nitrogen Dioxide. http://www.epa.gov/airquality/nitrogenoxides/index.html

ESIP (Ecosystem Indicator Partnership). 2011a. Aquaculture in the Gulf of Maine. Fact Sheet. http://www.gulfofmaine.org/esip/ESIPFactSheetAquacultureversion3.pdf

ESIP. 2011b. Aquatic habitats in the Gulf of Maine. Fact Sheet. http://www.gulfofmaine.org/esip/ESIPFactSheetAquaticHabitatsFinal.pdf

ESIP. 2011c. Overview. http://www.gulfofmaine.org/new-site/committees-and-programs/ecosystem-indicator-partnership

Ferreira JG, Wolff WJ, Simas TC and Bricker SB. 2005. Does biodiversity of estuarine phytoplankton depend on hydrology? Ecological Modeling 187: 513–523.

Galloway JN, Schlesinger WH, Levy C, Michaels A and Schnoor JL. 1995. Nitrogen fixation: anthropogenic enhancement environmental response. Global Biogeochemical Cycles 9: 235-252.

Galloway JN, Aber JD, Erisman JW, Seitzinger SP, Howarth RW, Cowling EB and Cosby BJ. 2003. The nitrogen cascade. Bioscience 53: 341–356

Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, Martinelli JA, Seitzinger SP and Sutton MA. 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320: 889-892.

Glibert PM, Madden C, Boyton W, Flemer D, Heil D and Sharp J (eds). 2008. Estuarine nutrient criteria development: state of the science. U.S. Environmental Protection Agency.

GOMCME (Gulf of Maine Council on the Marine Environment. 2004. Northeast Coastal Indicators Workshop. Workshop held January 6-8, 2004, Durham, New Hampshire. Gulf of Maine Council on the Marine Environment. 15 pp.

GOMCME. 2005. Marine Habitats in the Gulf of Maine: Assessing Human Impacts and Developing Management Strategies. Workshop Proceedings. September 21-22, 2005, Walpole, Maine. Gulf of Maine Council on the Marine Environment. 17 pp.

GOMCME. 2009. Status, Trends, and Conservation of Eelgrass in Atlantic Canada and the Northeastern United States. Report of a workshop held February 24-25, 2009, Portland, Maine. Gulf of Maine Council on the Marine Environment (GOMCME), Friends of Casco Bay, Casco Bay Estuary Partnership, Bay of Fundy Ecosystem Partnership. http://www.cascobay.usm.maine.edu/pdfs/eelgrass_workshop_report.pdf

Gustavson, K. 2010. Coastal ecosystems and habitats. State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment. 18 pp. http://www.gulfofmaine.org/new-site/resources/state-of-the-gulf-of-maine-report/

Hauxwell J, Cebrian J and Valiela I. 2003. Eelgrass *Zostera marina* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. Marine Ecology Progress Series 247: 59-73.

Heisler J, Glibert PM, Burkholder JM, Anderson DM, Cochlan W, Dennison WC, Dortch Q, Gobler CJ, Heil CA, Humphries E, Lewitus A, Magnien R, Marshallm HG, Sellner K, Stockwell DA, Stoecker DK and Suddleson M. 2008. Eutrophication and harmful algal blooms: a scientific consensus. Harmful Algae 8: 8-13.

Hinch PR, Bryon S, Hughes K and Wells PG (eds). 2002. Sewage management in the Gulf of Maine. Workshop Proceedings. April 11–12, 2002, Halifax, NS. Gulf of Maine Council on the Marine Environment. http://www.gulfofmaine.org/council/committees/eqmc/SewageWorkshopReport.pdf

Howarth RW. 1998. An assessment of human influences on nutrient fluxes of nitrogen from the terrestrial landscape to the estuaries and continental shelves of the North Atlantic Ocean. Nutrient Cycling in Agroecosystems 52: 213–223.

Howarth RW. 2008. Coastal nitrogen pollution: a review of sources and trends globally and regionally. Harmful Algae 8(1): 14-20.

HydroQual. 2009. Applying the system wide eutrophication model (SWEM) for a preliminary quantitative evaluation of biomass harvesting as a nutrient control strategy for Long Island Sound. Report prepared for the Hudson River Foundation on behalf of the Long Island Sound Study.

Jewett EB, Lopez CB, Kidwell DM, Bricker SB, Burke MK, Walbridge MR, Eldridge PM, Greene RM, Hagy JD, Buxton HT and Diaz RJ. 2010. Scientific assessment of hypoxia in U.S. coastal waters. Washington, DC: Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology. 154 pp.

Johnson PTJ, Townsend AR, Cleveland CC, Glibert PM, Howarth RW, McKenzie VJ, Rejmankova E and Ward MH. 2010. Linking environmental nutrient enrichment and disease emergence in humans and wildlife. Ecological Applications 20:16-29.

Kelly JR. 1997. Nutrients and human-induced change in the Gulf of Maine—One if by land, and two if by sea. In: GT Wallace and EF Braasch (eds), Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop. RARGOM Report 97-1. Hanover, NH: RARGOM. pp. 169-181

Latimer JS and Rego SA. 2010. Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuarine Coastal and Shelf Science 90: 231-240.

Leschen A, Ford K and Tay Evans N. 2010. Successful eelgrass (*Zostera marina*) restoration in a formerly eutrophic estuary (Boston Harbor) supports the use of a multifaceted watershed approach to mitigating eelgrass loss. Estuaries and Coasts 33: 1340-1354.

Lindahl O, Hart R, Henroth B, Koliberg S, Loo L, Olrog L, Rehnstam-Holm A, Svensson J, Svesson S and Syversen U. 2005. Improving marine water quality by mussel farming: a profitable solution for Swedish society. Ambio 34: 131-138.

McGillicuddy DJ, Anderson DM, Lynch DR and Townsend DW. 2005. Mechanisms regulating large-scale seasonal fluctuations in *Alexandrium fundyense* populations in the Gulf of Maine: Results from a physical–biological model. Deep-Sea

Walmsley D. 2010. Climate change and its effects on humans: state of the Gulf of Maine report. Gulf of Maine Council on the Marine Environment, 14 pp. http://www.gulfofmaine.org/new-site/resources/state-of-the-gulf-of-maine-report/

Whitall D, Bricker S, Ferreira J, Nobre AM, Simas T and Silva M. 2007. Assessment of eutrophication in estuaries: pressure-state-response and nitrogen source apportionment. Environmental Management 40: 678-690.

characterization, restoration, protection and monitoring of aquatic habitats in the Gulf:

- Habitat Restoration: Developing a Gulf-wide coastal and marine habitat restoration plan; assisting in implementation of the Council/NMFS restoration partnership grant program; and pursing land protection initiatives.

Aquatic Habitat Theme Papers

Three theme papers been identified that will be developed for the State of the Gulf of Maine Report:

- Coastal Ecosystems and Habitats (PDF, 1.6 mb)
- Offshore Ecosystems and Habitats (PDF, 1.9 mb)
- Watershed Status (PDF, 2 mb – hi-res version, 21 mb, is here) NEW!

Actions and Responses

In addition to the Actions and Responses described in each theme paper, many different organizations have developed guidelines, codes of conduct, best management practices, or other types of advice aimed at addressing the issues described in the theme papers. Some of the guidelines related to Aquatic Habitats can be found here. These links are maintained by outside agencies and are provided for information purposes. The linked documents are not endorsed by the Gulf of Maine Council on the Marine Environment.

Search

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Fisheries and Oceans Canada Pêches et Océans Canada

Quick Links

COASTAL ECOSYSTEMS AND HABITATS

STATE OF THE GULF OF MAINE REPORT

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Gulf of Maine Council on the Marine Environment

USGS science for a changing world

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This publication was made possible through the support of the Gulf of Maine Council on the Marine Environment and grants from Environment Canada and the United States Geological Survey.

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.

Cover photo by Peter Taylor/Waterview Consulting
Cover map (background) courtesy of Census of Marine Life/Gulf of Maine Area Program

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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2. Driving Forces and Pressures

THE PRIMARY DRIVING FORCES RESULTING IN PRESSURES ON COASTAL ECOSYSTEMS and habitats include climate change, population growth, economic growth and coastal development. The characteristics of these forces are dealt with in more detail in other theme papers and, thus, are not addressed further here (see also The Gulf of Maine in Context). The resulting pressures lead to the physical, chemical and biological alteration of habitat that, independently and cumulatively, can change both the structure and function of coastal ecosystems. Key biophysical changes of concern are: site energetics (wave and tidal action); nutrient loading; oxygen demand and availability; water turbidity (and availability of light); habitat fragmentation, and pollution and contamination with toxic chemicals.

The pressures of most concern are dependent on the type of coastal ecosystem and habitat, but many threats are pervasive. Overall, coastal ecosystems are particularly susceptible to: effluent from wastewater treatment and outfalls; runoff and sedimentation from coastal development, forestry and agricultural activities; contamination from aquaculture facilities, and direct destruction of habitat through infilling and other activities that remove habitat from production. Contamination by pathogens (bacterial and viral) and heavy metals is a persistent threat, particularly as it restricts the use of coastal waters and the harvest of species such as blue mussels, clams and oysters by humans (GOMC 2005). Habitat degradation due to fishing (dredging, trawling), the commercial and recreational overfishing of species, the introduction of invasive species, shoreline armouring, coastal infilling and waterfront development threaten several different habitats across the region (GOMC 2005). Key pressures to coastal habitats are summarized in Table 1.


Photo: Woodley Wonderworks

For salt marshes, coastal development and habitat alteration, resulting in tidal restrictions, dykes, draining and infilling, can have a substantial effect on hydrology and, thus, the viability of the habitat (GOMC 2004; Taylor 2008; CBCL Limited 2009). The alteration of habitat by tidal restrictions is of particular concern because of the effects on site energetics and water flows. Marsh-building processes may not be able to keep pace with accelerated rates of sea level rise, resulting in degraded salt marsh ecosystems and a loss of function (Titus and Richman 2001); the migration of salt marshes inland in response to sea level rise may also be hindered by coastal development, leading to a loss of habitat due to a lack of available space (Bozek and Burdick 2003).

Mudflats are particularly susceptible to pollution and contamination from coastal development (sewage and stormwater discharge), agriculture and industrial activity because they are depositional environments where organic pollutants and metals can accumulate. Dredging of mudflats and overharvesting of clams and worms from mudflats are known to have a substantial effect on the physical habitat (GOMC 2005).


Photo: Bodhisoma

persistent organic pollutants and metals, which may affect shellfish health and marketability; changes in water temperature and hydrographic regimes due to climate change will result in changes to the distribution of shellfish communities and may increase the prevalence of disease causing organisms and phytotoxins (GOMC 2005).

Overharvesting of intertidal seaweeds on the rocky shore can have a negative effect on these diverse ecosystems. Turbidity and sedimentation can smother sessile filer-feeding species. With respect to sandy shore, major threats include sand extraction, the installation of marine infrastructure (seawalls and jetties), inappropriate placement of buildings and roads, and human use (beach vehicles, trampling) (GOMC 2004; CBCL Limited 2009).

3. Status and Trends

THE GULF OF MAINE HAS ABOUT 12,000 KM (7,500 MILES) OF COASTLINE (Horton and McKenzie 2009). Coastal habitats are typically distinguished based on substrate type, water depth, physical properties of the water (e.g., salinity, temperature, current regime), and the specific structure-forming plants and animals that are present (Tyrrell 2005). The status of these habitats can be described by their distribution and geographical extent across the Gulf of Maine. A more comprehensive assessment of the health of coastal ecosystems, including species composition, trophic relationships and ecosystem functioning (e.g., productivity), is not possible within the constraints of this paper, but the status and trends of certain key species can be used as indicators of coastal ecosystem health.

3.1 SALT MARSHES

Salt marshes are grass-dominated habitats that can extend across the intertidal zone (Taylor 2008; Tyrrell 2005). They are influenced by gradients associated with the duration of tidal flooding and the extent of freshwater influx. Different species become dominant along different parts of these gradients. There is a gradient from fringing marshes to salt marsh meadows along the Gulf of Maine coast (Taylor 2008). Fringing marshes form narrow bands along the shoreline, and are dominated by tall forms of salt marsh cordgrass. Salt marsh meadows form in well-protected areas and have a greater diversity of communities, including high-marsh plants, border plants, marsh pannes and pools, low-marsh plants, and intertidal and subtidal creeks with muddy bottoms (Tyrrell 2005). Key salt marsh plant species include: salt marsh cordgrass (*Spartina alterniflora*); tall cordgrass (Spartina pectinata); saltmeadow hay (*Spartina patens*); black grass (*Juncus gerardii*); sea lavender (*Limonium nashii*); spike grass (*Distichlis spicata*); marsh elder

The total area of seagrass bed habitat along coastal areas is currently estimated to be approximately 12,000 ha in Maine, 1,040 ha in New Hampshire, and 12,610 ha in Massachusetts.[1] In the Bay of Fundy within Canada, the distribution of eelgrass is very limited, occurring only along the outer portions of the bay (Fisheries and Oceans Canada 2009). Data on the spatial extent and distribution of eelgrass beds in the US have been collected by ESIP and are available at www2.gulfofmaine.org/esip/reporting/. Seagrass habitat throughout the Gulf of Maine is believed to be in significant decline. Green and Short (2003) estimated overall eelgrass loss in the region to be approximately 20% since European settlement, although much greater localized declines have been documented (Neckles et al. 2009).

3.4 KELP BEDS

Photo: Adrienne Pappal

Kelps attach to hard substrates in the subtidal zone and can form tall "forests" extending upward in the water column, with the dominant species varying according to water depth and wave exposure regime. Kelp requires relatively clear water and a suitably firm substrate for attachment (Tyrrell 2005). The most common species include: sugar kelp (*Laminaria saccharina*), oarweed (*Laminaria digitata*), edible kelp (*Alaria esculenta*), and shotgun kelp (*Agarum clathratum*) (Tyrrell 2005; East Coast Aquatics 2009). For the Gulf of Maine as a whole, information is not readily available on the distribution and spatial extent of kelp beds or changes over time, although there are site-specific studies. The "deforestation" of kelp beds is a general concern, but a comprehensive habitat inventory has yet to be completed. An initial baseline study is required before changes in status and trends can be established over time.

3.5 SHELLFISH BEDS

Bivalves can form large, dense aggregations, which in turn provide a refuge for smaller species and a surface for attachment for certain sessile organisms (GOMC 2005; Tyrrell 2005). Shellfish beds are found in intertidal and subtidal zones, although the species composition varies according to biological requirements. Within the Gulf of Maine, the main shellfish-bed forming species are mussel, oyster and scallop (GOMC 2005; Tyrrell 2005). Blue mussels and oysters occur in the intertidal to shallow subtidal; scallops and horse mussels occur in the deep subtidal (Tyrrell 2005). Shellfish beds are often associated with rocky bottoms, which provide a substrate for attachment; however, scallops neither attach to each other nor the bottom, but nonetheless occur in dense aggregations.

Shellfish beds are widely found throughout the Gulf of Maine, mussels and oysters less so in the reaches of the Bay of Fundy where suitable rocky shore habitat is not as predominant. Information is not readily available on the distribution and spatial extent of shellfish beds throughout the Gulf of Maine.

[1] Data obtained by the Aquatic Habitats Subcommittee, Ecosystem Indicator Partnership (ESIP), Gulf of Maine Council on the Marine Environment (http://www.gulfofmaine.org/esip/).

Photo: Joshua Bousel

nated by annelids and arthropods, while molluscs become more dominant in the softer (sand-silt and silt clay) bottoms (East Coast Aquatics 2009). Common subtidal epifauna species, living on the surface of the sand, include moon snails, welks, sand dollar, and American sand lance (Tyrrell 2005).

Information of the spatial distribution and extent of sandy shore within the Gulf of Maine is not readily available. There are prominent and extensive beach areas along the shorelines of the Bay of Fundy (CBCL Limited 2009). It is unknown how these habitats are changing, specifically as measured by beach erosion and deposition rates. But sandy shore habitat has been documented to be in decline (e.g., Natural Resources Canada 2006). In a study of five locations in southeastern New Brunswick between 1944 and 2001, beach and dune habitat was reduced in area from between ~8% and ~40% (O'Carroll et al. 2010).

3.8 INDICATOR SPECIES

The distribution and spatial extent of coastal habitats, and patterns of change in the distribution of those habitats resulting from alteration and destruction, provides a measure of their status; however, a deeper understanding of the health of coastal ecosystems can be obtained by looking at the status of key indicator species (Rapport et al. 1998), which reflect the condition of an ecosystem. For the purposes of this report, shorebirds are examined as indicators for the broad range of coastal ecosystems on which they depend.

The coastal areas of the Gulf of Maine provide important habitat for migrating and breeding shorebirds. The upper Bay of Fundy is particularly important as a stopover area. Although migrating birds are negatively affected by habitat changes throughout their range and there are potentially other limiting factors outside of the Gulf of Maine, they have undoubtedly been adversely affected by impacts on local coastal habitats. A comparison of changes in the populations of 16 different species of migrating shorebirds from the 1970s through the 1990s in the Maritimes showed a strong and significant negative trend in most species (Morrison and Hicklin 2001). This overall negative trend in abundance has continuing through the 2000s.

Pressures on the functions listed in Table 2 result in biophysical and socio-economic impacts. The main biophysical impacts include: seawater intrusion and flooding; coastal erosion; impacts on species distribution and abundance; and impacts on habitat distribution and extent. Socio-economic impacts occur indirectly as a result of the occurrence of biophysical impacts on coastal ecosystems and habitats. The most notably affected include outdoor recreation values, production of species fished or harvested, and protection of coastal properties from erosion, among other ecosystem goods and services. These are described below as they vary by habitat type.

4.1 SALT MARSHES

Photo: Ashleigh Bennett

Historically, salt marshes have been drained and dyked for agriculture, filled for development, transected by roads and rail lines, and drained or dredged for the perceived benefit of controlling mosquito numbers (Tyrrell 2005; Taylor 2008). Although some of these practices have been halted, or greatly curtailed, climate change and coastal development-related pressures continue to affect these habitats. Upland development serves as a barrier to the natural migration of salt marshes in response to sea level rise (Bozek and Burdick 2003). Coastal infrastructure (ports, seawalls, etc.) may displace habitat, alter water flows, and increase sedimentation. These pressures result in negative impacts on the ability of salt marshes to provide refuge and nursery areas for fish and shellfish species, food for a number of animal (e.g., rodents, snails, crustaceans), bird and insect species, as well as resting, feeding and breeding areas for migratory birds. Salt marshes are also important in removing contaminants, nutrients and sediments as water enters the marine environment from upland activities (Taylor 2008). A reduction in the amount and quality of fish rearing grounds has a negative impact on commercial and recreational fisheries. Protection of coastal properties from erosion, recreational values (bird watching, hunting), and education values may also be affected.

4.2 MUDFLATS

The filter-feeding organisms (e.g., clams, worms) and other invertebrates found in mudflats, provide an important trophic link between primary coastal productivity and higher tropic levels in the marine food chain. The pressures on mudflats also hinder their ability to provide important shorebird feeding areas. Coastal foraging mammals also feed on mudflats, including racoon and mink, and they provide important spawning habitat for spider crabs and horseshoe crabs (Tyrrell 2005). Mudflats support important commercial fisheries for softshell clams, quahogs, bloodworms and sandworms (Roman et al. 2000). The deposition and accumulation of contaminants in mudflats has an impact on harvests of these species. Inputs of nutrients from agricultural and sewage sources can lead to massive growth of bottom algae, and the subsequent biological oxygen demand (use of oxygen to decompose organic materials) can further stress the infaunal community and have a negative impact on harvested species (Tyrrell 2005).

4.5 SHELLFISH BEDS

Fishing has a direct impact on the size, community structure and habitat structure of shellfish beds. This is particularly evident with the use of more destructive fishing gear, such as dredges (GOMC 2005). The installation of coastal infrastructure, such as wharfs and marinas, also results in the direct removal and alteration of shellfish bed habitat. Persistent organic pollution and metal contamination are also a particular concern with respect to shellfish, which as filter feeders concentrate these pollutants within their flesh (GOMC 2005; Tyrrell 2005). A number of ecological functions are adversely impacted. Shellfish beds provide habitat for many species (e.g., fish, molluscs, polychaete worms and various crustaceans; Tyrrell 2005). Broadly, the habitat provides support for biodiversity and as a direct source of food for fish, lobster, predatory snails, and seabirds. Shellfish also play an important role as filter feeders in the food chain. With respect to socio-economic impacts, oyster and mussel reefs offer protection to shorelines from erosion. Shellfish have substantial value directly as a fishery, as well as indirectly supporting the biological production of other fished species.


Photo: Jessica Langlois

Monitoring of concentrations of metal and organic contaminants in the blue mussel (*Mytilus edulis*) is conducted by the GulfWatch Program for the Gulf of Maine Council (LeBlanc et al. 2009). Many of these contaminants have been shown to bioaccumulate and biomagnify throughout the food web, and can adversely affect the growth, reproduction, and survival of marine organisms; thus, contaminant levels in marine organisms serves as a useful indicator of ecosystem health. LeBlanc et al. (2009) concluded that the status of contaminants in near shore areas around the Gulf of Maine suggests that the more heavily developed areas have higher contaminant levels compared to locations with smaller communities and less industrial activity. They further note that lead and mercury levels in 2008 exceeded the 85th percentile of the NOAA national dataset at several sites. Overall, organic contaminants were highest in Massachusetts and Maine (LeBlanc et al. 2009). Further information of contaminants in the blue mussel around the Gulf of Maine is available through the GulfWatch Program (www.gulfofmaine.org/gulfwatch/data/files.php) and ESIP (www2.gulfofmaine.org/esip/reporting/).

4.6 ROCKY AND COBBLE SHORE

Biophysical impacts on rocky and cobble shore habitat include reduced habitat complexity for the protection and development of a number of species (e.g., fish, molluscs, polychaetes, crustaceans), and reduced food for animals that occur along the shore, including many birds and mammals (e.g., foraging rats and mink). Bivalves living on rocky and cobble shore play an important role in the trophic food web, as a link between phytoplankton and zooplankton productivity to fish, shellfish and birds. Subtidal areas are key spawning habitat for fish species that include herring and capelin, as well as providing substrate for kelp forests. These important ecological functions are affected by resource harvesting and increases in sedimentation, water turbidity and temperature.

5. Actions and Responses

Actions and responses to impacts on coastal ecosystems and habitats include: regulatory control of development, pollution and direct habitat disturbance; habitat protection and the creation of conservation areas; habitat restoration initiatives; and environmental mapping and monitoring to inform adaptive management. These responses all provide different avenues to conserve coastal areas, in order to maintain or enhance ecological function and ensure the provision of ecosystem goods and services.

5.1 CONTROL OF DEVELOPMENT, POLLUTION AND HABITAT DISTURBANCE


Photo: Dale Calder

The regulation of development is primarily addressed at the municipal, county and, to a lesser extent, state and provincial levels. Provisions of land use plans and municipal development plans can reduce or mitigate impacts on coastal habitats by regulating development practices. Regulatory approaches and levels of control vary substantially across jurisdictions. Pollution discharge and habitat disturbance associated with human activity is also directly controlled by federal and provincial/state legislation, policies and guidelines. For example, Section 404 of the Clean Water Act in the United States regulates discharge of dredge or fill in wetlands and unvegetated and vegetated shallows in the general waters of the US, while in Canada the Fisheries Act prohibits the harmful alteration, disruption or destruction of fish habitat. Again, there are numerous tools in place across all five provinces and states bordering the Gulf of Maine that focus on regulating a range of pollutants and wide variety of activities that can result in pollutants entering the environment or in the alteration or destruction of coastal habitat.

5.2 HABITAT PROTECTION AND CONSERVATION AREAS

The conservation of marine habitat by restricting human activities in specific geographic areas can occur through several different legal mechanisms, such as the formal designation of parks or protected areas, conservation areas, fisheries closure areas, or through the use of zoning as enabled by marine management legislation (e.g. see Courtney and Wiggin 2003). This is facilitated by various pieces of legislation at the federal, provincial/state and municipal levels. At a more local level, habitat protection programs include the designation of easements and purchase of key habitat areas.

Legislation can be targeted at species groups in coastal environments (e.g., the State of Maine shorebird habitat protection regulations) or at specific species of concern (e.g., the Canadian Species at Risk Act that allows for the designation and protection of critical habitat). At the international level, the Ramsar Convention facilitates the designation of wetlands of international importance. Table 4 lists the existing prominent conservation areas within the coastal areas of the Gulf of Maine.

TIDAL RESTRICTIONS

The Bridge Creek Salt Marsh Restoration Project, within the Town of Barnstable, was one of the most complex salt marsh restorations ever undertaken in Massachusetts. The overall project consisted of replacing an existing 36-inch culvert beneath an active railroad line with a large concrete box culvert, and an existing smaller box culvert beneath a state road with a larger concrete box culvert. The completed project restored tidal flushing to approximately 40 acres of degraded salt marsh, which lies within a designated Area of Critical Environmental Concern. The total cost of the project was approximately $1.5 million, with funds provided by various private, state and federal sources, including the GOMC-NOAA Habitat Restoration Partnership.

Source: http://restoration.gulfofmaine.org/projects/

The primary activity of the Habitat Restoration Committee of the Gulf of Maine Council is through the GOMC-NOAA Habitat Restoration Partnership, which oversees restoration projects supported by that fund in the Gulf of Maine watershed (i.e., the Habitat Restoration Partnership Grants). The Gulf of Maine Habitat Restoration Web Portal serves as a central repository of information, including a restoration project inventory, guidance on project planning, and links to key background information sources. There are numerous local-level restoration programs and individual projects throughout the Gulf of Maine, the Habitat Restoration Web Portal listing over 80 project funded by Habitat Restoration Partnership Grants alone.

5.4 ENVIRONMENTAL MAPPING AND MONITORING

Environmental mapping and monitoring is important to both understand both the current state of coastal habitats within the Gulf of Maine and changes to those habitats over time. For many of the habitats discussed in this theme paper, this critical information is lacking. To help address this gap, there are several initiatives underway. ESIP, as a committee of the Gulf of Maine Council, is developing indicators for the Gulf of Maine and integrating regional data for an internet-based reporting system to support marine ecosystem monitoring. ESIP has identified six indicator areas for study: coastal development, contaminants and pathogens, eutrophication, aquatic habitat, fisheries and aquaculture, and climate change. The Habitat Monitoring Sub-committee of the Gulf of Maine Council is developing a regional strategy for monitoring coastal and marine habitats, as well as regional monitoring plans for specific habitat types. For aquatic habitats, indicators have been proposed for the monitoring and assessment of salt marsh, seagrass and subtidal soft-bottom habitats. Guidelines for restoration monitoring and long-term change analysis of salt marshes are included in Taylor (2008).

6. References

Bertness MD. 1999. The Ecology of Atlantic Shorelines. Sinauer Associates, Sunderland MA. 417 pp.

Bozek CM and Burdick DM. 2005. Impacts of seawalls on saltmarsh plant communities in the Great Bay Estuary, New Hampshire, USA. Wetlands Ecology and Management 13(5): 553-568.

CBCL Limited. 2009. 2009 State of Nova Scotia's Coast Technical Report. Prepared for the Department of Fisheries and Agriculture, Province of Nova Scotia, Halifax, NS. 245pp plus appendices.

Courtney F and Wiggin J. 2003. Ocean Zoning for the Gulf of Maine: A Background Paper. Prepared for the Gulf of Maine Council for the Marine Environment. 35 pp.

Dionne M, Burdick D, Cook R, Buchsbaum R and Fuller S. 1998. Scoping Paper 5: Physical Alterations to Waterflow and Salt Marshes. Commission for Environmental Cooperation, Montreal, QE.

East Coast Aquatics. 2009. Gulf of Maine Ecosystem Overview Report. Report prepared for the Ocean and Coastal Management Division, Fisheries and Oceans Canada, Dartmouth, NS. 199pp.

Fisheries and Oceans Canada (DFO). 2009. Does Eelgrass (Zostera marina) Meet the Criteria as an Ecologically Significant Species? Science Advisory report 2009/018. Canadian Science Advisory Secretariat, Fisheries and Oceans Canada, Ottawa, ON.

Gulf of Maine Council on the Marine Environment (GOMC). 2004. Gulf of Maine Habitat Restoration Strategy: Restoring Coastal Habitat in the Gulf of Maine Region. GOMC Habitat Committee, Restoration Subcommittee. 25 pp.

Gulf of Maine Council on the Marine Environment (GOMC). 2005. Marine Habitats in the Gulf of Maine: Assessing Human Impacts and Developing Management Strategies. Workshop Proceedings. September 21-22, 2005, Walpole, ME. 17 pp.

Green EP and Short FT. 2003. World Atlas of Seagrasses. Prepared by the UNEP World Conservation Monitoring Centre, University of California Press, Berkeley, CA.

Horton S and McKenzie K. 2009. Identifying Coastal Habitats at Risk from Climate Change Impacts in the Gulf of Maine. Report prepared by Climate Change Network for the Gulf of Maine Council on the Marine Environment. 34 pp.

LeBlanc L, Christian Krahforst K, Aube J, Roach S, Brun G, Harding G, Hennigar P, Page D, Jones S, Shaw S, Stahlnecker J, Schwartz J, Taylor D, Thorpe B and Wells P. 2009. GulfWatch 2008 Data Report: Eighteenth Year of the Gulf of Maine Environmental Monitoring Program. Prepared for the Gulf of Maine Council on the Marine Environment. 82 pp.

McDougall PT, Janowicz M and Taylor RF. 2007. Habitat Classification in the Gulf of Maine: A Review of Schemes and a Discussion of Related Regional Issues. Gulf of Maine Council on the Marine Environment, Habitat Conservation Subcommittee. 15 pp.

Morrison RIG and Hicklin P. 2001. Recent Trends in Shorebird Populations in the Atlantic Provinces. Bird Trends 8: 16-19.

Natural Resources Canada. 2006. Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick. Natural Resources Canada, Ottawa, ON.

Neckles HA, Hanson AR, Colarusso P, Buchsbaum RN and Short FT (eds.). 2009. Status, Trends, and Conservation of Eelgrass in Atlantic Canada and the Northeastern United States. Report of a Workshop Held February 24-25, 2009, Portland, Maine. http://gulfofmaine.org/council/committees/habitat_mon/ (accessed June 2010).

Nova Scotia Museum of Natural History. 1996. Natural History of Nova Scotia, Volume 1: Topics and Habitats. http://museum.gov.ns.ca/mnh/nature/nhns/about.htm (accessed August 2010).

O'Carroll S, Berube D, Hanson A, Forbes D, Ollerhead J and Olsen L. 2010. Temporal changes in beach and dune habitat in southeastern New Brunswick, 1944-2001. In: Environment Canada, Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick. Environment Canada, Ottawa, ON. pp. 421-426.

Rapport D, Costanza R, Epstein PR, Gaudet C and Levins R. 1998. Ecosystem Health. Blackwell Science, Oxford, UK.

Roman CT, Jaworski N, Short FT, Findlay S and Warren RS. 2000. Estuaries of the northeastern United States: Habitat and land use signatures. Estuaries 23(6): 743-764.

Taylor PH. 2008. Salt Marshes in the Gulf of Maine: Human Impacts, Habitat Restoration, and Long-term Change Analysis. Gulf of Maine Council on the Marine Environment. 42 pp.

Taylor PH and Atkinson J. 2008. Seascapes: Getting to Know the Sea Around Us. A Guide to Characterizing Marine and Coastal Areas. Quebec-Labrador Foundation, Inc. 80 pp.

Titus JG and Richman C. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf Coasts. Climate Research 18: 205-228.

Tyrrell MC. 2005. Gulf of Maine Marine Habitat Primer. Gulf of Maine Council on the Marine Environment. 54 pp.

Wiken E, Smith WGB, Cinq-Mars J, Latsch C, and Gauthier D. 2003. Habitat Integrity: Wildlife Conservation in Canada. Background paper for the national conference on Guidelines and Tools for the Evaluation of Natura 200 Sites in France, Montpellier, March 3-5, 2003. http://www.whc.org/files/habitat_integrity_france_mar24_03_000.pdf (accessed June 2010).

OFFSHORE ECOSYSTEMS AND HABITATS

STATE OF THE GULF OF MAINE REPORT

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Gulf of Maine Council on the Marine Environment

Fisheries and Oceans Canada / Pêches et Océans Canada

This publication was made possible through the support of the Gulf of Maine Council on the Marine Environment and a grant from Fisheries and Oceans Canada.

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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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Cover photo: Diverse community of sponges, anemones and other attached marine animals discovered on rocky outcrops in Jordan Basin, 2005. Canadian scientists have since revisited this area and other offshore regions in the northern Gulf of Maine, investigating seabed diversity patterns as part of the Canadian Healthy Oceans network, www.chone.ca (Photo credit: Fisheries and Oceans Canada, Bedford Institute of Oceanography).

Cover map (background): Courtesy of Census of Marine Life/Gulf of Maine Area Program

LINKAGES

This theme paper also links to the following theme papers:

- Coastal Ecosystems and Habitats
- Watershed Status
- Marine Invasive Species
- Climate Change and its Effects on Ecosystems, Habitats, and Biota

Although many people think of "habitat" as being a physical structure, in the open ocean it is just as much about the different water masses created by variable depths, salinities, temperatures, and currents as it is about features such as sand, canyons, and vegetation. Water masses are sometimes referred to as the pelagic (within the water column) habitats, whereas substrates and ocean floor features are key components of benthic (nearest the sea floor) habitat in the marine environment. In contrast to habitats, ecosystems are not just habitats, but also the vegetation and animals found within those habitats and all of the complex relationships that exist both among living organisms and between living organisms and their habitats. In providing this offshore ecosystem overview, focus has been given to the driving forces/pressures, current status and trends, and impacts on the benthic and pelagic components of a group of three broad key physical habitats. These habitats are:

- Shallow banks (Jeffreys, Stellwagen),
- Deep basins (Georges, Wilkinson, Jordan), and
- Channels (Northeast, Great South).

Two additional habitats have been dealt with separately because of both their uniqueness within the Gulf of Maine and the relatively greater scientific study and knowledge of these habitats. They are:

- Georges Bank, and
- Bay of Fundy.

2. Driving Forces and Pressures

WITHIN THE GULF OF MAINE'S OFFSHORE ECOSYSTEM – AREAS DEEPER THAN about 50 m (164 ft) in depth – the drivers and resulting pressures are complex. Drivers are of both anthropogenic and natural origin. These "driving forces" are human influences and activities as well as the natural conditions that underpin environmental change. "Pressures" are direct or indirect pressures on the functioning and quality of the environment resulting from driving forces.

2.1 NATURAL DRIVERS: PHYSICAL AND CHEMICAL OCEANOGRAPHY

The physical and chemical oceanography of the Gulf of Maine strongly influence where particular species can survive and thrive, what time of year they will reproduce and grow, and spatially where their eggs and food gets transported. The surface waters of the Gulf of Maine are strongly influenced by waters from the Scotian Shelf, while deep water from the continental slope enters the Gulf through the Northeast Channel, modulating temperatures and providing a source of nutrients to portions of the Gulf of Maine. The Eastern Maine Coastal Current carries low-salinity, nutrient-rich water along the coast of Maine, influencing the ecosystems found in that region. The Gulf Stream and associated gyres bring warmer, more saline water into the region and tend to have most influence in the fall. Frontal zones – areas where there are sudden changes in temperature and salinity of the water – occur regularly in the Gulf of Maine and tend to be areas of high biological activity. More details on the region's oceanography can be found in the *Gulf of Maine Ecosystem Overview Report* (East Coast Aquatics 2011) and *The Gulf of Maine in Context* (Thompson 2010).

The influence of various natural drivers on the Gulf of Maine, such as air temperature, freshwater inputs, and the North Atlantic Oscillation (NAO), is extremely variable both in terms of time (seasonally, or over a period of years) and space (deep water relative to surface water, Georges Bank relative to Wilkinson Basin). For example, the year to year water temperatures in the Gulf of Maine are among the most variable in the entire North Atlantic Ocean (DFO 2008), and during the year range from more than 20°C (68°F) in August to 2-3°C (35-37°F) in February–March (Friedland and Hare 2007). The seasonal patterns of light and temperature affect the stratification (layering) of the Gulf of Maine waters, nutrient availability, and thus productivity and patterns of species distribution. Whether at the scale of months or decades, the drivers that alter the physical (i.e., currents, temperature, salinity) and chemical (i.e., nutrients, dissolved oxygen) oceanography of the Gulf tend to have the greatest influence on the living organisms.

North Atlantic Oscillation (NAO)

The NAO is a fluctuation in atmospheric pressure at the surface of the North Atlantic Ocean that is influenced by movements in a southern high pressure zone near the islands of the Azores Archipelago and a northern low pressure area the water column is already highly stratified (Friedland and Hare 2007). Based on data for the period of 1979 to 1987, it has been found that the interannual variability of surface water temperature in the western Gulf of Maine is significantly correlated with the changes in the rate of heat exchange between the Gulf waters and the atmosphere. However, in the eastern Gulf, no relationship is found in the exchange of heat between the water and the air, and instead water temperature is more greatly influenced by the different water sources entering the eastern Gulf (Mountain et al. 1996). These differences highlight the spatial variability of driving forces (in this case atmospheric temperature) influence on the Gulf of Maine. In short, the same driver may not have the same effect across all areas of the Gulf at the same time.

Freshwater Inputs

Along with the NAO and atmosphere-ocean heat exchange, freshwater inputs are a significant natural driver of environmental change in the offshore Gulf of Maine ecosystem. The combined discharge of the four largest rivers (Saint John, Penobscot, Kennebec, and Merrimack) entering the Gulf of Maine has been estimated at about 60 billion cubic metres (78.5 billion cubic yards) of freshwater per year. This freshwater "plume," by which it is often referred, has a profound influence on water properties and dynamics not just in the estuaries close to land, but also all along the Gulf of Maine coast (Xue et al. 2000). The Saint John River in New Brunswick, Canada, remains the largest river entering the Gulf of Maine, and discharges a comparable amount to the sum of the three American rivers (Geyer et al. 2004). Although the salinity variability of the western Gulf and Georges Bank appears to be more greatly influenced by local precipitation and this coastal river runoff (Mountain and Taylor 1998), the overall freshwater budget for the Gulf of Maine is dominated not by river inflow, but by the inflow to the Gulf of relatively cold, low-salinity ocean water from the north, off the Scotian Shelf (Smith 1983; Brown and Irish 1993 cited by Pettigrew et al. 1998). This inflowing current brings fresh water from the St. Lawrence River and from melting sea ice to the north (Houghton and Fairbanks 2001).

In summary, many natural drivers modify the environmental conditions associated with the physical and chemical oceanography of the Gulf of Maine. The North Atlantic Oscillation, atmospheric heat exchange, and freshwater inputs are but a few, and the spatial and temporal range of their influence can be extremely varied across the Gulf. Along with these natural drivers, economic and anthropogenic drivers also influence changes in the habitat and biota of the Gulf of Maine.

2.2 ECONOMIC/ANTHROPOGENIC DRIVERS

The ocean economy includes sectors such as fishing, aquaculture, offshore oil and gas, shipping, and coastal tourism. It also captures government services, including national defence (ocean based), fisheries management, coast guard, and marine

Other

The Gulf of Maine, with its significant resources of marine life and offshore oil and gas, is linked through exploitation to a number of social, economic, and cultural values. These values can drive how much, how quickly, and in what manner humans exploit resources. The result of this exploitation is the socioeconomic impact, both positive and negative, on the Gulf of Maine ecosystem. Although Georges Bank is known world-wide as a productive and diverse fishing ground, it also has significant petroleum resource potential beneath its seafloor. On the Canadian portion of Georges Bank, there are an estimated 60 million barrels of oil and 1.3 trillion cubic feet of natural gas, although exact amounts remain uncertain (Procter et al. 1984 cited in DFO 2011). The U.S. Bureau of Environmental Management estimates that the entire Atlantic Outer Continental Shelf, which includes the American portion of Georges Bank, has 3.82 billion barrels of oil (CLF 2012). The size and value of this potential resources has made Georges Bank an area of interest for offshore petroleum exploration and development for more than four decades (NRCan and NSPD 1999). Both the governments of Canada and the United States issued their first permits for offshore petroleum exploration on the Bank in the 1960s, and eight wells were drilled on the Bank, but were not developed because they did not yield significant product (DFO 2011). The potential interactions between the ecosystem and offshore petroleum activities have been assessed as part of a recent moratorium review on the Canadian portion of Georges Bank. Potential impacts have generally been categorized as seismic noise, drill muds, spills, blowouts and malfunctions, and produced water (DFO 2011).

Some anthropogenic impacts, such as climate change, originate far away from the Gulf waters. Yet, climate change has the potential to affect marine habitats. Atmospheric warming and melting of sea ice are altering the physical oceanography of the Gulf of Maine, while higher levels of atmospheric carbon dioxide (CO_2) may alter ocean chemistry, both of which will have effects on the ecosystem (Nye 2010, see *Climate Change and its Effects on Ecosystems, Habitats, and Biota*). For example, by changing water temperature and salinity, two key habitat components that help determine the spatial distribution of individual species, climate change will impact species distribution.

Other human activities with the potential of having ecosystem impacts are naval operations, government research, ocean disposal, submarine cables, and pipelines. Within the Gulf, the demand for aquaculture sites has led to examination of open ocean aquaculture, at least within the Bay of Fundy, as the number of viable coastal sites becomes limited. Physical constraints of water temperature and waves, the need for technology advancement, and conflicts with other uses and values, such as traditional fishing, shipping, and species at risk, are challenges to expanding the aquaculture industry to open ocean areas (Chang et al. 2005).

es Bank, are vertically well mixed by vigorous tidal activity. The western portion of the Gulf of Maine, including Wilkinson Basin, is less well mixed as cold fresh riverine water enters the Gulf along the Maine Coastal Current and rests on top of the more dense marine water in the western Gulf. The result is a tidally mixed eastern region separated from the stratified western region by a tidal front (Xue et al. 2000).

There are three primary sources of water to the Gulf of Maine, each with its own temperature, salinity, and nutrient regime. Concentrations of each of these flows create identifiable water masses. The marine inflow to the Gulf of Maine is the sum of two of the primary water sources receiving both relatively shallow northern inflow from the Scotian Shelf around Cape Sable and deep oceanic inflow through the Northeast Channel (Mountain 1991). These waters move predominantly in a counter-clockwise direction around the perimeter of the Gulf of Maine (see Figure 3). It has been estimated that it takes about three months for water to circulate around the periphery of the Gulf (Van Dusen and Hayden 1989). These source waters are a significant influence on marine water temperature in the Gulf of Maine (DFO 2008). Atlantic temperate slope water from the open Atlantic is warmer and saltier, while Labrador Current water is cooler, less saline, less dense, and has lower nutrients (Fogarty and Trollan 2006). Temperature, salinity, and nutrients are key water characteristics that influence what marine species will live where, and changes in the biological communities within the Gulf of Maine are expected when there are changes in the NAO.

As these offshore water sources enter the Gulf of Maine along the Northeast Channel, they appear to drive the eastern portion of the counter-clockwise Gulf of Maine gyre, one of two main gyres (prevailing circular currents) in the Gulf, and initiate the overall counter-clockwise direction of flow around the Gulf of Maine. The majority of the inflow turns southwestward near Grand Manan Island and the mouth of the Bay of Fundy, but part flows cyclonically into the Bay of Fundy before eventually leaving the Bay to move along the New England coastline (Xue et al. 2000). The Gulf of Maine gyre is influenced not only by the inflow around southwest Nova Scotia and by the inflow of dense, deep water through the Northeast Channel, but also by the spring runoff from the region's rivers and daily tides (Van Dusen and Hayden 1989). Water circulates in the Gulf gyre counter-clockwise around Jordan Basin, located at the mouth of the Bay of Fundy, and around Georges Basin, located at the head of the Northeast Channel. Vigorous tidal stirring keeps the water vertically well mixed in this eastern portion of the Gulf of Maine and the Gulf gyre (Pettigrew et al. 1998).

The third primary source of water to the Gulf of Maine is the relatively fresh water of the Maine Coastal Current. This current is driven by inputs originating from the four largest rivers entering the Gulf of Maine coastline. The Saint John River, Kennebec River, Penobscot River, and Merrimack River, along with freshwater

GYRES – A PHYSICAL BIOLOGICAL LINKAGE

An oceanic gyre is a prevailing circular current. Although spatially one of the smaller gyres in the Gulf of Maine, the Bay of Fundy gyre has large vertical tidal velocities which are thought to be a major factor in the nutrient pump that brings deep water nutrients to the surface water. When nutrients reach sunlight in the photic zone close to the surface, they contribute to phytoplankton growth. The physical shape of the Bay of Fundy promotes the formation of a gyre that is linked to exceptionally high biological productivity at the mouth of the Bay of Fundy.

haddock have been noted to drift within the gyre around Georges Bank. This current both helps keep them on the Bank where conditions for young fish are favourable, and distributed around the Bank until they grow large enough to swim to other habitats within the Gulf of Maine (Lough et al. 1989).

As demonstrated in the preceding paragraphs, there are a number of water masses within the Gulf of Maine that have particular characteristics of movement, salinity, and temperature, and that may represent preferred habitats for a community of species. There have also been some widespread observable trends in some of these characteristics. For example, there has been a long-term trend in sea surface temperature range (the difference between the coldest and warmest temperature of the year). A decreasing range was observed at the beginning of the twentieth century, followed by an increase in range from 1920 to the late 1980s. The range has remained high through to the present. Although the mean annual sea surface temperature in the Gulf of Maine is currently trending below historical levels (1854–2005), the intensity of summer warming is at or near its highest levels, and winter sea surface temperatures are remaining relatively constant and cool (Friedland and Hare 2007). Spring warming rate has increased during the last half of the twentieth century on the order of 0.5°C per month. A regime shift in spring warming rate was identified around 1940 in the eastern Gulf of Maine, although not in the western Gulf or on Georges Bank. Conversely, autumn cooling rates have decreased over the time series (1854–2005) on the order of 0.5°C per month. Notably, a shift to more rapid fall cooling occurred around 1987 in five regions of the northeastern continental shelf, including the western Gulf, suggesting a relatively widespread phenomenon (Friedland and Hare 2007).

WHAT LIVES IN THE GULF?

Some 3317 species of flora and fauna have been inventoried from the Gulf of Maine (Valigra 2006). Approximately 2350 of those are also found in the Bay of Fundy (Census of Marine Life 2007). More than 652 species of fish have been documented living in, or migrating through, the Gulf of Maine. It is estimated that 87 (13%) of these fish species are resident (live their whole lives) within the Gulf of Maine (Valigra 2006). At least 14 species of coral live in the Gulf of Maine (Mortensen et al. 2006).

Along with observed temperature trends, there have been salinity trends documented in the Gulf of Maine. Salinity measurements have been taken since 1924 at a fixed station near St. Andrews, New Brunswick, adjacent to the entrance of the Bay of Fundy. For surface salinity, there appears to have been a decrease in salinity from the mid-1970s to the mid-1990s (low in 1996), followed by an increase to 2002. This was followed again by a decline (DFO 2008). This pattern is consistent with the pattern of salinities measured by the Northeast Fisheries Science Center on the continental shelf (Gulf of Maine) since the 1970s (Ecosystem Assessment Program 2009).

Table 2: Four "community" groups have been identified from a 35-year time series study of 24 demersal fish species within the Gulf of Maine. These groupings indicate a seasonal preference for temperature and depth over substrate type. Adapted from Methratta and Link (2006).

	SEASONAL HABITAT KEYS	DEMERSAL SPECIES
Community 1	• Remained in relatively deep waters in both autumn and spring. • Experienced the relatively cooler portion of the region in the autumn and the relatively warmer portion of the region in the spring.	White hake, silver hake, Acadian redfish, goosefish, witch flounder, thorny skate, and pollock.
Community 2	• Remained in relatively shallow habitats in both seasons. • Experienced wide temperature fluctuations.	Winter flounder, yellowtail flounder, winter skate, little skate, windowpane, longhorn sculpin, and sea raven.
Community 3	• Moved from shallow areas in the autumn to deep areas in the spring. • Maintained relatively warm waters.	Spiny dogfish, summer flounder, fourspot flounder, barndoor skate, and red hake.
Community 4	• Travelled from the deep portion of the region in the autumn to the shallow portion of the region in the spring. • Maintained relatively cool waters.	Atlantic cod, haddock, American plaice and ocean pout.

Shallow Banks and Associated Communities

The Gulf of Maine banks are shallow, offshore areas. There are a number of these offshore bank areas around the Gulf of Maine, including Stellwagen Bank and Jeffreys Bank. Unlike Georges Bank of the outer continental shelf, most of these shallow bathymetric features are found on the central continental shelf, and are located a short distance offshore in the western Gulf of Maine. Stellwagen Bank, for example, is located some 40 km (25 miles) from the coast, and is a glacial deposit of sand, gravel, and rock that today lies a mere 20 m (65 ft) below the surface (NOAA 2012b). Light typically penetrates to the sea floor through the water column, above these shallow geological features. Waves and currents tend to keep the water over the banks well mixed, at least for certain periods of the year.

Even now, surface sediments and features of the banks are being reworked and reshaped by tidal and storm-generated currents. Over time, the shallow areas affected by these processes have become coarser as sand and mud are removed and gravel remains (Butman et al. 2004). Ocean substrate grain size influences the size of benthic organisms and infauna, as well as which species might attach to, forage over, and spawn on the surface of the substrate (Etter and Grassle 1992). Surficial geology of the banks, which form a variety of habitats, is a result of the basic geological structure of the banks and their interaction with ocean processes. Like basins and channels, the Gulf of Maine banks attract their own community of living organisms. One group within that community is the demersal fish living at or near the bottom of the ocean. Based on depth alone, Mahon et al. (1998)

temperatures are colder (and vice versa), and the likelihood of deep winter mixing in the western Gulf of Maine is greater when cold saline coastal waters drop deep into the basin (Taylor and Mountain 2009).

Mud accumulates where still-water conditions favour the slow settling of small particles or their entrapment by sessile (slow-moving) organisms, such as polychaete worms. For this reason, a thick layer of mud sediments has been deposited in Georges Basin (Backus and Bourne 1987). In fact, present day tidal and storm-generated currents continue to erode and transport sediments from the shallow areas of the Gulf of Maine into the deeper basins. This process means the deeper basins have been built up as they receive the eroded sand and mud (Maine Geological Survey 2005; Butman et al. 2004), although thick deposition of postglacial mud (King and Fader 1986) in the relatively deep basins has created proportionally small changes in bathymetry. These muddy regions are the most common areas on the continental shelf in waters deeper than 100 m (330 ft) (Barnhardt et al. 1996), and poorly sorted silt (mud) can be found in most Gulf of Maine basins (Backus and Bourne 1987).

Scientists have identified a demersal fish community within the Gulf of Maine that tends to remain in relatively deep waters (>200m or 655 ft) in both autumn and spring. In such areas, demersal fish experience a relatively cooler portion of the region in the autumn and a relatively warmer portion of the region in the spring. This deep-water community includes white hake, silver hake, Acadian redfish, goosefish, witch flounder, thorny skate, and pollock (Methratta and Link 2006). As shown in Table 3, two assemblages of demersal fish have been identified by Mahon et al. (1998) based on depth and temperature that spend a portion of the year in deepwater. Although fish and shellfish tend to be the marine organisms for which the most spatial data are available within the Gulf of Maine, a host of other algae, plants and animals also occupy deep water habitats. For example, at least 14 species of coral live in the Gulf of Maine, and several have been found in the deep basins such as Jordan Basin (DFO 2006; Mortensen et al. 2006).

Table 3: Two deep water assemblages of demersal fish identified by Mahon et al. (1998) based on data from between 1975 and 1994. The assemblages were derived from the 108 most abundant demersal species in the North Atlantic and were based, in part, on the depth of water in which they were found.

DEPTH CLASS	DEMERSAL FISH ASSEMBLAGE	BOUNDARY RELEVANCE TO THE GULF OF MAINE	PRIMARY ASSEMBLAGE SPECIES	
>200m	Temperate deepwater	From the Gulf of Maine northwards; the Gulf of Maine is the approximate southern extent.	Marlin - spike Black dogfish Atlantic argentine	Longfin hake Barracudinas Roughnose grenadier
>200m	Southern deepwater	From the Gulf of Maine southwards; the Gulf of Maine is the approximate northern extent.	Blackbelly rosefish Offshore hake Shortnose greeneye Shortfin squid	Buckler dory Beardfish Slackjaw cutthroat eel Armoured searobin

3.2 GEORGES BANK

Georges Bank is a prominent marine habitat within the Gulf of Maine, and as such is discussed separately from, and less generically than the previous shallow banks habitat section. The features and organisms of Georges Bank are some of the most studied in the offshore Gulf of Maine. Georges Bank is a bedrock cuesta: an area of gently tilted sedimentary rocks that have a steep slope on one side exposed as a cliff or escarpment. It is similar in this regard to other outer continental shelf banks off Nova Scotia (Davis and Browne 1996a). The 28 800 km^2 (11 120 square mile) offshore bank is often considered its own biogeographic area within the Gulf of Maine because of its relatively unique characteristics (Wolff and Incze 1998). With its ovoid shape, the most southwesterly point of Georges Bank is bounded by the Great South Channel and its northeasterly tip is bounded by the Northeast Channel.

Georges Bank is the shallowest part of the offshore Gulf of Maine, with approximately 50% of its area being shallower than 60 m (200 ft) (Backus and Bourne 1987). It rises to within 30 m (100 ft) of the ocean's surface on the northern edge at a location called Georges Shoal (Backus and Bourne 1987). The shoal is a series of sand ridges that run in a northwest-southeast trending direction. In addition to the shoals, there are overlying sand waves patterns (Twichell et al. 1987 cited in Lynch and Naimie 1993). Gravel dominates the remainder of the Bank (Todd et al. 2001), and a series of eleven incisions exist between the outer edge of the Bank and the open Atlantic. Oceanographer Canyon and Lydonia Canyon are but two of the incisions, known as submarine canyons, that can be up to 1 km (0.62 miles) deep (Backus and Bourne 1987).

On Georges Bank, sediment type has been found to have significant effect on the diversity, total abundance, and total biomass of species living both within and on top of the seafloor. The greatest number of different species has been found in biogenic sands, while minimum richness was observed in underwater mineral sand dunes (Thouzeau et al. 1991). Biogenic sands contain skeletal material of marine plants and animals such as clams and sea snails. According to Thouzeau et al. (1991), six communities of organisms are associated with two major substrates (biogenic sand-gravel and sand-shell fauna) on Georges Bank. The biogenic sand-gravel assemblage of the northeastern bank area includes an abundance of suspension-feeding organisms that stay in one place (i.e., barnacles, tunicates, sponges, non-burrowing bivalves, and tube-dwelling polychaete worms). A number of species are exclusive to the biogenic substrate, such as the brittle star *Ophiura sarsi*, Icelandic scallop, Arctic salt water clam *Hiatella arctica*, Arctic moonsnail, the arctic mollusc *Margarites costalis*, boreal topsnail, the tunicate sea peach, pink shrimp, and spiny lebbeid shrimp. The typical fauna of the sand-shell substrate is found on most of the southern half of Georges Bank. Ocean quahog and common sand dollar are the common species of this community, while the sea anemone *Actinothoe gracillima*, sand coral, the hermit crab *Pagurus arcuatus*, Atlantic surf clam, bamboo worm, and sea mouse worms are also typical

1987; Meise and O'Reilly 1996 cited in Bisagni 2000). If the physical stratification of the Georges Bank water column promotes a concentration of phytoplankton and small zooplankton (plankton blooms), such a linkage is likely an important factor controlling growth and survival of larger zooplankton and larval fish at lower trophic levels of the food chain. While many of the biological processes occurring on Georges Bank appear to be linked in some way to physical processes and hydrography, much more work needs to be completed before exact mechanisms can be proven (Mavor and Bisagni 2001). However, changes in stratification trends, with increased stratification in the eastern Gulf of Maine and Georges Bank since the mid-1980s (Figure 4), are likely to drive biological changes.

3.3 BAY OF FUNDY

Like Georges Bank, the Bay of Fundy is a prominent marine habitat within the Gulf of Maine, and as such is discussed separately from, and less generically than other marine habitats. The Bay of Fundy is a narrow, funnel-shaped body of water that lies between Nova Scotia and New Brunswick. This large, macro-tidal (having tides greater than 4 m or 13 ft) embayment and its oceanography are closely linked to the greater Gulf of Maine (Aretxabaleta et al. 2008; Chang et al. 2005; Desplanque and Mossman 2001; Xue et al. 2000). It is 270 km (168 miles) long and 60 km (37 miles) wide at its widest point, and encompasses offshore oceanic features such as shallow banks and deep channels (Willcocks-Musselman 2003). The Bay can be divided into two large regions, the inner Bay and the outer Bay, based on oceanographic parameters and biotic assemblages (Hunter and Associates 1982). The outer-Bay component is considered part of the offshore Gulf of Maine. Also called the "mouth" of the Bay of Fundy, this area is more oceanic than the inner Bay of Fundy, with cold summer and warm winter temperatures, high current velocities, and high salinity. The sea floor of the outer Bay consists of exposed bedrock and a coarse sand-and-gravel substrate sorted by tidal currents (Davis and Browne 1996b).

The defining characteristic of the Bay of Fundy is its gigantic tides, ranging from a mean height of 5 m (16 ft) in the outer Bay to a maximum 16 m (52 ft) in the

THE LIVING REEF

A biogenic (composed of living and dead marine organisms) type of reef that is found in the Gulf of Maine is the horse mussel reef. Bivalve reefs are an important linkage between pelagic (mid to upper water column) and benthic (near bottom) environments. Preliminary studies show that horse mussels are mostly limited to harder, more stable gravel/cobble, gravel/scallop bed, and mottled gravel substrates, but also to sand with bioherms. Bioherms are raised features formed by the horse mussels growing on megarippled sand. The mussels grow faster or slower depending on which type of substrate they grow on (Wildish et al. 1998). Although horse mussel reefs have been identified throughout the Bay of Fundy, little is known about their status at this time (Wildish and Fader 1998).

4. Ecosystem Impacts

Ecosystem impacts are generally very challenging to fully quantify and understand because of the complex linkages and biological interactions that exist within an ecosystem. Impacts to an ecosystem can be natural or anthropogenic, and result from alteration of one or more ecosystem drivers. By altering one of the driving forces, pressure is placed on the functionality or quality of the environment that may result in measurable or observable changes. This section presents a sampling of known ecosystem impacts in the Gulf of Maine. Impacts have been categorized as natural or anthropogenic, although it is not always possible to clearly attribute them to a single category.

4.1 NATURAL IMPACTS

Given the magnitude of human influence on the natural ecosystem of the Gulf of Maine, from centuries of fishing to global climate change, it becomes difficult to determine what impacts are natural in the strictest meaning of the word. However, the following are observed impacts and changes that seem to be predominantly influenced by natural drivers, or at least are not directly linked to anthropogenic drivers.

Food Web Changes

Atlantic herring has long been a key forage fish, as well as a commercial fish species within the Gulf of Maine. Herring biomass fluctuated greatly during the period 1977–2002, primarily because of chronic overfishing in the 1970s followed by a recovery in the 1990s (Overholtz and Link 2006). Along with the herring recovery there has been a change in food web interactions between species. Marine mammals increased their consumption of herring in the Gulf of Maine to the point where they consumed a roughly equal amount as demersal piscivorous fish (fish that eat fish) (Figure 5). Consumption of herring by these natural predators is now potentially larger than that of the commercial fishery in some areas of the Gulf of Maine. This is a significant change from the early 1990s when fish were the dominant natural predator of herring, accounting for approximately 70% of predation, and nearly three times that eaten by marine mammals. The change is likely to have impacts on energy flow through the ecosystem, and a failure to consider these changes may lead to an over-optimistic picture of how many fish the commercial herring fishery can harvest. If herring were overfished, important trophic interactions would be disturbed, and an important link in the Gulf of Maine food web significantly altered (Overholtz and Link 2006).

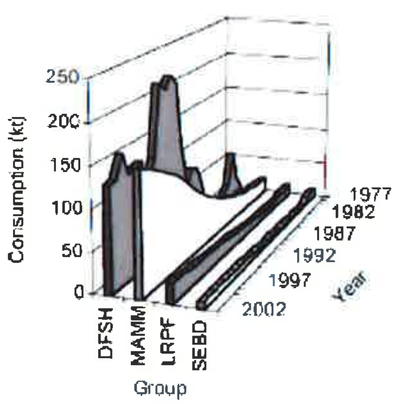

Figure 5. Consumption of Gulf of Maine-Georges Bank herring by the four groups of predators (DFSH - demersal fish; MAMM - marine mammals; LRPF - large pelagic fish; SEBD - seabirds) during the years 1977–2002 (Overholtz and Link 2006).

Although the previous example involves food web impacts at higher trophic levels, impacts at the base of the trophic structure can have potentially far reaching implications for the entire ecosystem. Ottersen et al. (2001) have shown that the North Atlantic and surrounding regions display a biological response not just at the species level, but also at the population and community levels, to NAO-

Since herring is a keystone prey species not just for predator fish species like the bluefin tuna, but also mammals and birds within the Gulf of Maine ecosystem (Overholtz and Link 2006), the variable energy density of Atlantic herring has significant potential to have broad fitness consequences throughout the food web, for example, a number of seabird species feed on herring within the Gulf (Overholtz 2006). During periods when herring have been the dominant prey, the breeding success of both Arctic and Common Tern at the mouth of the Bay of Fundy has been positively correlated with the energy density of juvenile herring (Diamond and Devlin 2003). Younger age classes of herring are also an important food source for Bonaparte's Gull, and have made up >80% of the diet of Razorbills and Puffins in the outer Bay of Fundy (Clarke et al. 2008). Therefore changes in the herring population could be expected to affect not just fish populations, but also a number of seabird populations within the Gulf of Maine.

Spatial Changes

The following example indicates how natural impacts to physical-biological ecosystem linkages can influence spatial changes in where certain organisms are found. Petrie and Yeats (2000) noted that a potentially major influence of decadal variability on marine populations may occur through associated changes in chemical oceanographic properties (an ecosystem driver). Significant changes in nutrients (decreased nitrate) and dissolved oxygen (increased) occurred in the Gulf of Maine region when colder/fresher water entered the Gulf during the 1960s, with potentially important biological implications, some of which were spatial. Such implications included changes in distributions and migrations of various species (Loder et al. 2001). The driving forces that effect such changes in the biological communities of the Gulf of Maine do not have to originate within the Gulf. For example, the NAO and a number of associated physical oceanographic changes have significant biological influence within the Gulf of Maine. Straile and Stenseth (2007) have outlined a wide array of known ecological relationships with the NAO, including the spatial characteristics of location and abundance of different temperature habitats in oceanic waters for Atlantic salmon.

Natural drivers also affect more local spatial changes within the ecosystem. The Gulf of Maine has distinct temperature and salinity characteristics from the adjacent offshore Atlantic Ocean, and a "front" that delineates these differences generally lies along the continental slope east of Georges Bank (Page et al. 2001). An oceanic front is the interface between two water masses of different physical characteristics. There is usually a strong horizontal change of temperature and salinity across a front, and some associated current shear that may mix nutrients and capture and concentrate numbers of small living organisms that are food for other animals. Fronts are important for organisms such as plankton and jellyfish, which tend to collect at a front, and their congregation attracts predators such as sea turtles, whales, and pelagic seabirds (Worcester and Parker 2010). Although other fronts exist in the Gulf of Maine, the most persistent frontal region is at the conti-

4.2 ANTHROPOGENIC IMPACTS

Pressures from changing ocean activities such as shipping and fishing result in a number of important impacts to the Gulf of Maine ecosystem. These impacts are anthropogenic—caused by human activities—and may be intentional or unintentional. Because human activity in the offshore marine environment is primarily the result of social and economic drivers such as the need to provide food and acquire financial stability, anthropogenic impacts may be refered to as socio-economic impacts. The following section describes impacts from human activities to the food web structure of the Gulf of Maine and some of the physical habitats found on the ocean floor.

Trophic Structure Changes

Trophic structure is a term used to capture the idea that each organism has a place within the food web. There are several ways in which human activities can alter the trophic structure of an ecosystem. One way is by introducing a species that becomes a dominant predator or prey within the ecosystem, upsetting the natural balance of interactions that previously existed. Commercial shipping has led to the introduction of at least 14 of the 64 marine invasive species identified in the Gulf of Maine through two primary mechanisms: transport by ballast water and fouling on ship surfaces (see *Marine Invasive Species* theme paper; Pappal 2010). However, invasives can also naturally migrate to new areas as changing environmental conditions permit. Although a body of knowledge has been collected on marine introductions in the Gulf of Maine, most of it is for the shallower coastal and estuarine systems rather than the offshore ecosystem. Logistical constraints and identification difficulties, generally associated with the extremely small size of many introduced organisms or their tendency to live within soft sediments, mean only some habitats and groups of organisms have been adequately identified (Pappal 2010). Twenty-two new plankton species have been observed in the Bay of Fundy alone during the last 15 years, although it is unclear whether all of these records represent true introductions (Martine and LeGresley 2008 cited in Pappal 2010). However, these low trophic level organisms have the potential to alter the food web because of the number of higher level organisms that feed on or are supported by plankton.

Introductions of new organisms into the food web can also have an economic impact on the people living and working around the Gulf of Maine. It is believed that the colonial tunicates *Botrylloides violaceus* and *Diplosoma listerianum* were fouling (attached to ships' hulls) introductions to the Gulf of Maine. These tunicate species can displace a wide array of native species by smothering their habitat, growing prolifically over large areas. Some of the displaced species are fished commercially, resulting in an economic impact/loss. The tunicates also coat aquaculture equipment, hulls of vessels, and harbour infrastructure requiring maintenance costs for removal and cleaning. Because modern vessels are faster, have shorter times in port, and are more frequently maintained, the role of hull fouling ally during the same period (Auster et al. 1996). Studies at three sites in the Gulf showed that mobile fishing gear altered the physical structure of benthic habitats, reduced habitat complexity by direct removal of biogenic (e.g., sponges, hydrozoans, bryozoans, amphipod tubes, holothurians, shell aggregates) and sedimentary (e.g., sand waves, depressions) structures and by removal of organisms such as crabs and scallops that create structures. Reduction in habitat complexity is thought to lead to increased predation on juveniles of some commercial harvested species and ultimately reduce the harvestable stock (Auster et al. 1996). As such, direct benthic impacts from trawl fishing on the ecosystem may also have an indirect economic impact on a variety of commercial fisheries. Further unquantified negative pressure is placed on small fish such as Atlantic herring, silver hake, juvenile cod, haddock, red hake and flounder which are often caught in various quantities as bycatch in shrimp trawls within the Gulf of Maine (He et al. 2007).

As noted previously, a significant decline in adult cod biomass on Georges Bank occurred around 1990, and has remained relatively low since (Wang et al. 2011). Over a 25-year time series study (1973-1998), the majority of North Atlantic cod could be found in three areas: the Gulf of Maine (excluding Georges Bank), Georges Bank, and the Scotian Shelf. This indicates the historic importance of the Gulf of Maine habitat to the entire North Atlantic cod population. During this current period of low abundance on the U.S. continental shelf, fewer cod have been found south of the Gulf of Maine, implying an effective contraction of the distribution of cod over the three decades from the 1970s to the 1990s (Link and Garrison 2002). The contraction of species range for the cod from areas south of the Gulf is indicative of a changing ecosystem even though the driver is not entirely clear.

Another example of a human activity causing impacts on the Gulf of Maine ecosystem is the introduction of an invasive tunicate on Georges Bank. It is thought that the invasive colonial tunicate *Didemnum* sp. was brought to the Gulf of Maine on oysters transferred for aquaculture (Pappal 2010). The tunicate was first noted in an area of gravel habitat on Georges Bank in 2002. Since its discovery there the infested area has spread to an area of 230 km^2 (89 $miles^2$) in two adjacent gravel areas, and at some locations covers nearly 75% of the seabed. *Didemnum* sp. has had a significant impact on the species composition of the benthic community. In particular, the abundance of two polychaete species has increased significantly in areas infested by the tunicate compared to areas not infested. The polychaetes live beneath the tunicate mats, and the increased abundance of these species suggests they are avoiding predation by fish by being under the mats (Lengyel et al. 2012). Although the implications of such changes are not yet understood, there is a direct link between the anthropogenic impact and the biological response.

petroleum activities in the U.S. North Atlantic region, which includes the U.S. portion of Georges Bank, would not be considered for leasing until 2017 (DFO 2011). Numerous potential interactions between the marine environment and offshore petroleum activities exist, but concern over the potential environmental impacts from offshore petroleum development and production is largely linked to the possible exposure of marine organisms to seismic noise, operational waste discharges (e.g., drill wastes, produced water, and other associated wastes), and accidental oil spills and/or blowouts (DFO 2011).The current moratoria have been established to protect the ecosystem from perceived risk of impacts, rather than existing or created impacts.

Legislation and policy have also been used as a response to help minimize known impacts to individual species of conservation concern within the Gulf of Maine, for example the North Atlantic right whale. The abundance of the endangered right whale is critically low (DFO 2007, DFO 2012a). These whales have been provided legislative protection under the Canadian *Species at Risk Act* and the U.S. *Endangered Species Act*. Within the Gulf of Maine, Grand Manan Basin is an important feeding and aggregation area for the right whale (DFO 2007). It was identified as a Right Whale Conservation Area in 1993 and as critical habitat in the 2009 North Atlantic Right Whale Recovery Strategy (Brown et al. 2009). Activities in these areas are not enforced pursuant to legislation, but rather have been managed through voluntary measures published in the Canadian Coast Guard Annual Notices to Mariners and through government-industry cooperation (DFO 2011). The Great South Channel has also been identified as critical habitat (WWF 2000), limiting certain fishing and shipping activities in that area.

Study and observation have confirmed a significant percentage of right whale mortalities have resulted from ship strikes (IMO 2002). In 2003, the International Maritime Organization (IMO) amended and implemented the Bay of Fundy Traffic Separation Scheme to reduce ship strikes of the highly endangered North Atlantic right whale by shifting the ship traffic lanes from an area with the highest density of right whales to an area where there is a lower whale density (IMO 2002), as shown in Figure 6. The new shipping lanes have had an effect on commercial activities in the region as fishermen now do some of their fishing in the lanes instead of east of them, and ships' passages are longer to ports in Saint John, New Brunswick, and Eastport, Maine. Despite these inconveniences, both industries supported the proposal and their stewardship has contributed to recovery efforts for the species in the Bay of Fundy (Canadian Whale Institute 2012).

A similar response of policy and activity changes has been applied to the Northeast Channel. Although cold-water corals are found in a number of locations across the Gulf of Maine, significant concentrations of corals are not. One location where concentrations of corals have been found is the Northeast Channel. These corals show visual evidence of disturbance, such as broken living corals, tilted corals, and skeletal fragments, indicating that the area was being damaged

A number of collaborative U.S./Canada management arrangements exist to protect the Gulf of Maine ecosystem, including mechanisms on acid rain, mercury pollution, climate change, fisheries and shellfish sanitation, and shipping, to name a few (ACZISC 2006). As well, collaborative recovery strategies have been initiated between Canada and the United States for species such as the leatherback turtle, North Atlantic right whale, and Atlantic salmon of the inner Bay of Fundy and Gulf of Maine (Worcester and Parker 2010). Since 1998, the Transboundary Resources Assessment Committee (TRAC) has reviewed fish stock assessments and projections necessary to support management activities for shared resources across the U.S.-Canada boundary in the Gulf of Maine-Georges Bank region. These assessments are necessary to advise decision makers on the status of these resources and likely consequences of policy choices. Recent development of species-specific arrangements for consistent management of individual fish species (cod, haddock and yellowtail flounder) on eastern Georges Bank have also been undertaken as part of international collaborative management (DFO 2012b). A collaborative management and planning body, the Gulf of Maine Council for the Marine Environment (GOMC) is a U.S.-Canadian partnership of government and non-government organizations working to maintain and enhance environmental quality in the Gulf of Maine. The Council has supported numerous initiatives, ranging from bi-national actions to local projects, to improve water quality, conserve land, restore coastal habitats, and enable citizens to be better stewards of the environment around them (see www.gulfofmaine.org).

5.2 MONITORING AND RESEARCH

Monitoring and research are important components of oceans management that allow decision makers to minimize the effects of human activities on the ecosystem. Monitoring involves the systematic collection of data or information over time to track potential changes, while research is focused on finding an answer to a specific predetermined question. As ecological processes and biota function independently of human-established boundaries, such as the Canada-U.S. border, ecosystem management requires transboundary collaborative arrangements and initiatives. These initiatives include sharing collected data sets and ensuring that monitoring and sampling methods within the Gulf of Maine are compatible across the international border. Over 60 monitoring programs have been established within the Gulf of Maine (Chandler 2001). The GOMC maintains a list of many current monitoring programs that are ongoing within the ecosystem, and these are available through their EcoSystem Indicator Partnership (ESIP) website (www.gulfofmaine.org/esip/index.php).

Perhaps the longest running example of transboundary collaboration on monitoring is the consistent sampling methodology within the Gulf of Maine for the collection of plankton data. The United Kingdom's Sir Alister Hardy Foundation for Ocean Science continuous plankton recorder (CPR) program information gaps are specific to a species, and even a portion of that species' life cycle. For example, since the late 1980s and 1990s, Gulf of Maine salmon populations have diminished at an unprecedented magnitude and have drawn attention to the lack of knowledge of salmon life history during the marine phase. Migration routes, distribution, and abundance for specific stocks are completely unknown. Furthermore, the reason(s) behind the current high mortality rates for Atlantic salmon, which are known to be occurring at sea, have no specific known cause(s) (Reddin 2006). It has been suggested that our poor understanding of ecosystem linkages is particularly true in the offshore, where coupling between the far field ocean forcing/migration and inshore coastal areas is not well understood. These knowledge gaps hinder the development of predictive models of the offshore ecosystem (GOMC 2004).

6. References

ACZISC (ACZISC Secretariat and Marine & Environmental Law Institute of Dalhousie University). 2006. Overview of Current Governance in the Bay of Fundy/Gulf of Maine: Transboundary Collaborative Arrangements and Initiatives. Oceans and Coastal Management Report 2006-05. vii + 132 pp.

Aretxabaleta A, McGillicuddy Jr D, Smith K and Lynch D. 2008. Model simulations of the Bay of Fundy Gyre: 1. Climatological results. Journal of Geophysical Research. 113 (C10027), doi:10.1029/2007JC004480.

Auster PJ, Malatesta RJ, Langton RW, Watling L, Valentine PC, Donaldson CLS, Langton EW, Shepard AN and Babb IG. 1996. The impacts of mobile fishing gear on the seafloor habitats of the Gulf of Maine (Northwest Atlantic): Implications for conservation of fish populations. Reviews in Fisheries Science. 4(2): 185-202.

Backus RH and Bourne DW (eds). 1987. Georges Bank. Cambridge, MA: MIT. 593 pp.

Barnhardt WA, Belknap DF, Kelley AR, Kelley JT and Dickson SM. 1996. Surficial Geology of the Maine Inner Continental Shelf. Maine Geological Survey. Geologic Maps 96–6 through 96-12. scale 1:100,000.

Bisagni J. 2000. Estimates of vertical heat flux and stratification from Southern Georges Bank, interannual variability, 1985–1995. Continental Shelf Research. 20: 211-234.

Breeze H, Fenton DG, Rutherford RJ and Silva MA. 2002. The Scotian Shelf: An Ecological Overview for Ocean Planning. Canadian Technical Report of Fisheries and Aquatic Sciences. 2393: 272 pp.

Brown MW, Fenton D, Smedbol K, Merriman C, Robichaud-Leblanc K and Conway JD. 2009. Recovery Strategy for the North Atlantic right whale (*Eubalaena glacialis*) in Atlantic Canadian waters [Final]. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada. 76 pp.

Butman B, Valentine P, Danforth W, Hayes L, Serrett L and Middleton T. 2004. Shaded relief, sea floor topography, and backscatter intensity of Massachusetts Bay and the Stellwagen Bank Region offshore of Boston. U.S. Geological Survey Geological Investigation Map I-2734. scale 1:125,000.

Campana S, Gibson J, Brazner J, Marks L and Joyce W. 2008. Status of Basking Sharks in Atlantic Canada. Canadian Science Advisory Secretariat Research Document 2008/004. 61 pp.

Canadian Whale Institute. 2012. Bay of Fundy Shipping Lanes. http://www.rightwhale.ca/shippinglanes-routesnavigation_e.php (accessed January 2012).

Census of Marine Life. 2007. Gulf of Maine Area Program. http://research.usm.maine.edu/gulfofmaine-census/research/research-projects (accessed February 2007).

Chandler H. 2001. Marine Monitoring Programs in the Gulf of Maine: An Inventory. Maine State Planning Office and the Gulf of Maine Council. 121 pp.

Chang B, Page F and Hill B. 2005. Preliminary analysis of coastal marine resource use and development of open ocean aquaculture in the Bay of Fundy. Canadian Technical Report of Fisheries and Aquatic Sciences 2585. 42 pp.

Clarke TC, Godin M-PF and Diamond AW. 2008. Machias Seal Island 1995-2007. Progress Report. ACWERN, University of New Brunswick. 61 pp.

CLF (Conservation Law Foundation). 2012. Take Action to Prevent Oil Drilling in New England's Ocean. Sept. 10, 2009. http://www.clf.org/blog/tag/georges-bank (accessed February 2012).

Coffen-Smout S, Halliday RG, Herbert G, Potter T and Witherspoon N. 2001. Ocean activities and ecosystem issues on the Eastern Scotian Shelf: An assessment of current capabilities to address ecosystem objectives. Canadian Science Advisory Secretariat Research Document 2001/095: 45 pp.

COOC. 2007. Is our ocean warming? Unusually high temperatures raise climate change concerns. Gulf of Maine Monitor. Coastal Ocean Observing Center, University of New Hampshire.

CSL-WWF. 2006. Marine Ecosystem Conservation for New England and Maritime Canada: a Science-Based Approach to Identifying Priority Areas for Conservation. Conservation Law Foundation and World Wildlife Fund. 193 pp.

Davis D and Browne S (eds). 1996a. Natural History of Nova Scotia: Volume 1 – Topics and Habitats. Halifax, NS: Nimbus. 518 pp.

Davis D and Browne S (eds). 1996b. Natural History of Nova Scotia: Volume 2 – Theme Regions. Halifax, NS: Nimbus. 304 pp.

Desplanque C and Mossman DJ. 2001. Bay of Fundy tides. Geoscience Canada 28(1): 1–11.

DFO (Fisheries and Oceans Canada). 2006. Coral Conservation Plan Maritimes Region (2006–2010). Oceans and Coastal Management Report 2006-01. 71 pp.

DFO. 2007. Recovery potential assessment for right whale (Western North Atlantic population). Canadian Science Advisory Secretariat Science Advisory Report 2007/027. 9 pp.

DFO. 2008. State of the ocean 2007: physical oceanographic conditions on the Scotian Shelf, Bay of Fundy and Gulf of Maine. Canadian Science Advisory Secretariat Science Advisory Report 2008/025. 10 pp.

DFO. 2011. The marine environment and fisheries of Georges Bank, Nova Scotia: consideration of the potential interactions associated with offshore petroleum activities. Canadian Technical Report of Fisheries and Aquatic Sciences 2945: xxxv + 492 pp.

DFO. 2012a. Aquatic Species at Risk: North Atlantic Right Whale. http://www.dfo-mpo.gc.ca/species-especes/species-especes/rightwhaleNA-baleinenoireAN-eng.htm (accessed February 2012).

DFO. 2012b. Transboundary Resources Assessment Committee (TRAC). http://www2.mar.dfo-mpo.gc.ca/science/trac/TRAC.html (accessed February 2012).

Marino II MC and Stokesbury KDE. 2005. Impact of sea star predation in marine protected areas on Georges Bank. ICES CM 2005. Theme Session on the Spatial Dimension of Ecosystem Structure and Dynamics. Poster presentation L:31.

Mavor T and Bisagni J. 2001. Seasonal variability of sea-surface temperature fronts on Georges Bank. Deep-Sea Research II 48: 215-243.

Metaxas A and Davis J. 2005. Megafauna associated with assemblages of deep-water gorgonian corals in Northeast Channel, off Nova Scotia, Canada. Journal of the Marine Biological Association 85: 1381-1390.

Methratta ET and Link JS. 2006. Seasonal variation in groundfish habitat associations in the Gulf of Maine-Georges Bank region. Marine Ecology Progress Series 326: 245-256.

Mortensen P, Buhl-Mortensen L, Gass S, Gordon Jr. D, Kenchington E, Bourbonnais C and MacIsaac K. 2006. Deep-water corals in Atlantic Canada: a summary of ESRF-funded research (2001–2003). Environmental Studies Research Funds Report 143. 83 pp.

Mountain D. 1991. The volume of shelf water in the Middle Atlantic Bight: seasonal and interannual variability, 1977–1987. Continental Shelf Research 2: 251-267.

Mountain DG. 2004. Variability of the water properties in NAFO subareas 5 and 6 during the 1990s. Journal of Northwest Atlantic Fishery Science 34: 103–112.

Mountain D, Strout G and Beardsley R. 1996. Surface heat flux in the Gulf of Maine. Deep Sea Research II 43(7–8): 1533-1546.

Mountain D and Taylor M. 1998. Spatial coherence of interannual variability in water properties on the US northeast shelf. Journal of Geophysical Research 103(C2): 3083-3092.

NMFS (National Marine Fisheries Service). 2011. Fisheries of the United States 2010. Current Fishery Statistics No. 2010. Silver Spring, MD: NMFS Office of Science and Technology.

NOAA (National Oceanic and Atmospheric Administration). 2006. US Atlantic and Gulf of Mexico marine mammal stock assessments – 2005. NOAA Technical Memorandum NMFS-NE-194. 358 pp.

NOAA. 2012a. Ecosystem Monitoring. http://na.nefsc.noaa.gov/ecosystem.html (accessed January 2012).

NOAA. 2012b. Gerry E. Studds Stellwagen Bank National Marine Sanctuary. http://stellwagen.noaa.gov (accessed March 2012).

NSGOV (Government of Nova Scotia). 2010. Georges Bank Moratorium Extended. Press Release, Premiers Office. http://www.gov.ns.ca/news/details.asp?id=20100513005 (accessed January 2012).

Nye J. 2010. Climate change and its effects on ecosystems, habitats, and biota. State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment. 18 pp. http://www.gulfofmaine.org/new-site/resources/state-of-the-gulf-of-maine-report

Oceana. 2012. History of offshore drilling. http://oceana.org/en/our-work/climate-energy/offshore-drilling/learn-act/history-offshore-drilling (accessed February 2012).

OPTF (Oceans Policy Task Force). 2010. Final Recommendations of the Interagency Ocean Policy Task Force. July 19, 2010. http://www.whitehouse.gov/files/documents/OPTF_FinalRecs.pdf (accessed February 2012).

O'Reilly J, Evans-Zetlin C and Busch D. 1987. Primary production. In: RH Backus and DW Bourne (eds), Georges Bank. Cambridge, MA: MIT Press. pp. 220-223.

Ottersen G, Planque B, Belgrano A, Post E, Reid P and Stenseth N. 2001. Ecological effects of the North Atlantic Oscillation. Oecologia 128: 1-14.

Overholtz WJ. 2006. Estimates of consumption of Atlantic herring (*Clupea harengus*) by bluefin tuna (*Thunnus thynnus*) during 1970–2002: an approach incorporating uncertainty. Journal of Northwest Atlantic Fishery Science 36: 55–63.

Overholtz WJ and Link JS. 2006. Consumption impacts by marine mammals, fish, and seabirds on the Gulf of Maine-Georges Bank Atlantic herring (*Clupea harengus*) complex during the years 1977–2002. ICES Journal of Marine Science 64: 1-14.

Page F, Losier R, Drinkwater K, Petrie B, Harrison G and Sameoto D. 2001. Overview of the physical and biological oceanographic conditions on Georges Bank. Canadian Science Advisory Secretariat Research Document 2001/66: 35 pp.

Pappal A. 2010. Marine invasive species. State of the Gulf of Maine Report. Gulf of Maine Council on the Marine Environment. 21 pp. http://www.gulfofmaine.org/new-site/resources/state-of-the-gulf-of-maine-report

Percy JA, Wells PG and Evans AJ (eds).1997. Bay of Fundy issues: a scientific overview. Environment Canada–Atlantic Region Occasional Report no 8. 191 pp.

Pershing A, Deroba J, Golet W, Hare J, Lutcavage M, Richardson D, Runge J, Sherwood G, Stockwell J and Tien R. 2012. Using interdecadal comparisons to understand the trade-offs between abundance and condition in fishery ecosystems. Comparative Analysis of Marine Ecosystem Organization. NOAA. Project in process. http://cameo.noaa.gov/pres_apershing.html (accessed February 2012).

Petrie B and Yeats P. 2000. Annual and interannual variability of nutrients and their estimated fluxes in the Scotian Shelf-Gulf of Maine region. Canadian Journal of Fisheries and Aquatic Sciences 57: 2536–2546.

Pettigrew N, Townsend D, Xue H, Wallinga J, Brickley P and Hetland R. 1998. Observations of the Eastern Maine Coastal Current and its offshore extensions in 1994. Journal of Geophysical Research 103: 623-639.

Reddin D. 2006. Perspectives on the marine ecology of Atlantic salmon (*Salmo salar*) in the Northwest Atlantic. Canadian Science Advisory Secretariat Research Document 2006/018. 39 pp.

RITA (Research and Innovative Technology Administration). 2012. Table 1: Summary of Cruise Ship Waste Streams. Bureau of Transportation Services. http://www.bts.gov/publications/maritime_trade_and_transportation/2002/html/environmental_issues_table_01.html. (accessed March 2012).

WATERSHED STATUS

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

October 2016

1. Issue in Brief

THE GULF OF MAINE WATERSHED EXTENDS FROM CAPE COD EAST TO THE Bay of Fundy and north to the St. Lawrence River valley. The land mass draining into the Gulf encompasses all of Maine and portions of Massachusetts, New Hampshire, New Brunswick, Nova Scotia and Quebec. Its total land area is 179,008 square kilometres (km^2) (69,115 square miles) (Thompson 2010).

The watershed is influenced by a complex mix of climatological and geological forces, tracing back to the last Ice Age when the region was buried beneath glaciers. From that legacy and the dominant bedrock geology of granite and limestone emerged a landscape characterized by abundant lakes, wetlands and river systems.

The Gulf watershed encompasses 27 major riverine watersheds—including those of the Merrimack, Androscoggin, Kennebec, Penobscot, St. Croix, Petitcodiac, Shubenacadie and Saint John rivers. This network of rivers and lakes shaped early transportation routes and settlements, generated hydropower and supported industrial development.

Historically, many of the region's rivers offered fishing and hunting opportunities, and provided habitat for diadromous fish species—like alewife (gaspereau), American shad, Atlantic salmon and eels—that spend part of their lives in fresh water and part of their lives in the ocean.

These waterways have shaped the region's growth. Human activities began transforming watersheds and they continue to affect the Gulf of Maine's ecosystems. This paper focuses on the current status of the region's watersheds, exploring some of the many driving forces, pressures, and impacts affecting their health. It highlights how riverine ecosystems link communities and terrestrial and aquatic habitats inland with the Gulf's estuarine, coastal and off-shore environments.

Some forces shaping watershed dynamics (see Figure 1) are local—such as development and forestry practices. Others are regional—like atmospheric deposition of pollutants such as mercury and acid rain. And some, like climate change, are global forces tied to complex atmospheric and ocean circulatory patterns and the retreat of distant ice sheets and glaciers.

This complex mix of forces generates many pressures on watershed ecosystems, including:

- climate stressors, such as increased temperatures and greater storm intensity;
- changing land uses evident in growing suburbanization and forest fragmentation; and
- pollution from nutrient and contaminant runoff, point discharges and atmospheric deposition.

LINKAGES

This paper links to several other theme papers in the State of the Gulf of Maine Report:

- The Gulf of Maine in Context
- Climate Change and its Effects on Ecosystems, Habitats and Biota
- Climate Change and its Effects on Humans
- Coastal Ecosystems and Habitats
- Coastal Land Use and Development
- Eutrophication
- Microbial Pathogens and Biotoxins
- Toxic Chemical Contaminants
- Species at Risk

2. Driving Forces and Pressures

THE GULF OF MAINE WATERSHED AND ITS MAJOR BASINS (FIGURE 2) HAVE been shaped and affected by geological dynamics, biological systems, the contours and conditions of water bodies, and the weather patterns that characterize the region. Today, these influences are overshadowed by a wide range of anthropogenic factors—including population growth, economic growth, pollution and accelerated climate change.

Figure 2: Map of the Gulf of Maine watershed including the major basins. Watershed boundaries compiled and edited by the U.S. Environmental Protection Agency (EPA) based on the U.S. hydrologic units, the New Brunswick hydrographic network and Nova Scotia watersheds (data sources: U.S. Geological Survey [USGS] and provinces of New Brunswick and Nova Scotia). Prepared by D. Morse, ASRC Federal Vistronix.

Table 1: Land cover in selected Gulf of Maine drainage areas (compiled from the U.S. National Land Cover database [NOAA 2016]; Garroway, Nova Scotia Environment, pers. comm. June 2016; NBELG 2007a, 2007b, 2007c).

NAME	AREA (SQUARE MILES)	AREA (SQUARE KMS)	FOREST/ SHRUBLAND	AGRICULTURAL LAND	DEVELOPED LAND[1]	WATER AND WETLANDS
Cape Cod and South Shore, MA[2]	643	1,666	39%	2%	37%	18%
Charles, MA	1,013	2,624	33%	5%	45%	17%
Merrimack, MA/NH	5,082	13,164	71%	7%	11%	11%
Piscataqua-Salmon Falls, ME/NH	1,416	3,668	66%	9%	9%	15%
Saco, ME & NH	1,700	4,404	83%	5%	3%	9%
Presumpscot, ME	1,086	2,813	65%	9%	9%	16%
Androscoggin, ME	3,634	9,411	83%	5%	2%	10%
Kennebec, ME	5,949	15,408	78%	6%	2%	14%
Penobscot, ME	8,620	22,326	79%	3%	1%	16%
Maine coastal region including St. Croix to Sheepscot	5,153	13,346	73%	6%	2%	17%
Saint John (ME portion)	5,513	14,279	72%	12%	5%	9%
Saint John (NB portion)	10,850	28,101	83%	6%	2%	7%
St. Croix (NB portion)	639	1,655	81%	3%	1%	14%
Petitcodiac, NB	1,093	2,831	80%	10%	4%	4%
Shubenacadie, NS	1,020	2,642	n.d.	8%	4%	n.d.
Annapolis, NS	872	2,259	n.d.	11%	3%	n.d.
Tusket, NS	825	2,136	n.d.	2%	3%	n.d.

n.d. = no data

[1] For Nova Scotia, this is "urban" land. For New Brunswick, this is "occupied" land.

[2] Portions of the Cape Cod and South Shore drainage area are not part of the Gulf of Maine watershed.

Coastal and southern watersheds, such as the Charles River (Boston metropolitan area) and the Merrimack River watershed (parts of Massachusetts and southern New Hampshire) are heavily developed, while some watersheds in the north, like the Penobscot and St. Croix, have less than 2 percent developed land.

Due to glaciation that was relatively recent in geologic terms, the watershed's aquatic communities have relatively low biodiversity and few species unique to the region, and could be susceptible to invasive species (Curry 2007, Moyle and Cech 2004).

The region experiences relatively high rates of snowfall and rainfall, and the resulting abundant freshwater flow has provided cheap power to spur industrial growth. Prevailing winds from the west and southwest often carry airborne pollution into the Gulf of Maine watershed from the Eastern Seaboard and industries in the midwestern U.S.

into local waters—lowering dissolved oxygen (leading to fish kills), stimulating harmful algal blooms, altering ecological communities, and aggravating coastal acidification.

Potential effects of climate change on marine and coastal environments are covered in related papers of the *State of the Gulf of Maine Report* (see *Climate Change and its Effects on Humans* and *Climate Change and its Effects on Ecosystems, Habitats and Biota*).

2.3 POPULATION, ECONOMIC GROWTH AND POWER GENERATION

Population within the Gulf of Maine watershed, particularly in southern portions, is concentrated in coastal regions. More sparsely populated northern and inland areas are losing residents to urban areas and coastal regions that offer more job opportunities (Collins 2004, Index Mundi 2014). Population in the watershed's U.S. states continues to grow (see the *Coastal Land Use and Development* theme paper) while population in the Canadian provinces remains static.

Beyond the few major urban centers, the region's economy relies heavily on natural resources that support forestry, fishing and farming, as well as tourism and recreation that depends on the region's natural beauty and culture of outdoor life.

Historically, rivers powered much of the region's growth. At first, residents built impoundments to store water for household and farm use, and to power water wheels for grinding grain, sawing lumber and carding wool. Later, dams helped facilitate timber transport during log drives, and hydroelectric-generating stations powered paper and pulp processing plants and other industries.

Dams and impoundments can foster recreational uses—such as at the Gulf of Maine watershed's largest dam, which produces 650 megawatts of power, on the Saint John River in New Brunswick. Its headpond, the Mactaquac Dam's reservoir, is a tourist destination with waterfront camping and cottages, beach access, and a robust recreational sport fishery. Similar impoundments along the St. Croix River supply power for a pulp and paper mill while supporting recreational canoeing, camping and a bass sport fishery (ISCRWB 2008).

While fueling economic development, hydropower has reshaped watersheds into a checkerboard of dams, weirs and headponds. The process of creating impoundments and drowning rapids has dramatically altered flow regimes and reduced the diversity and availability of aquatic habitat, particularly for migratory fishes.

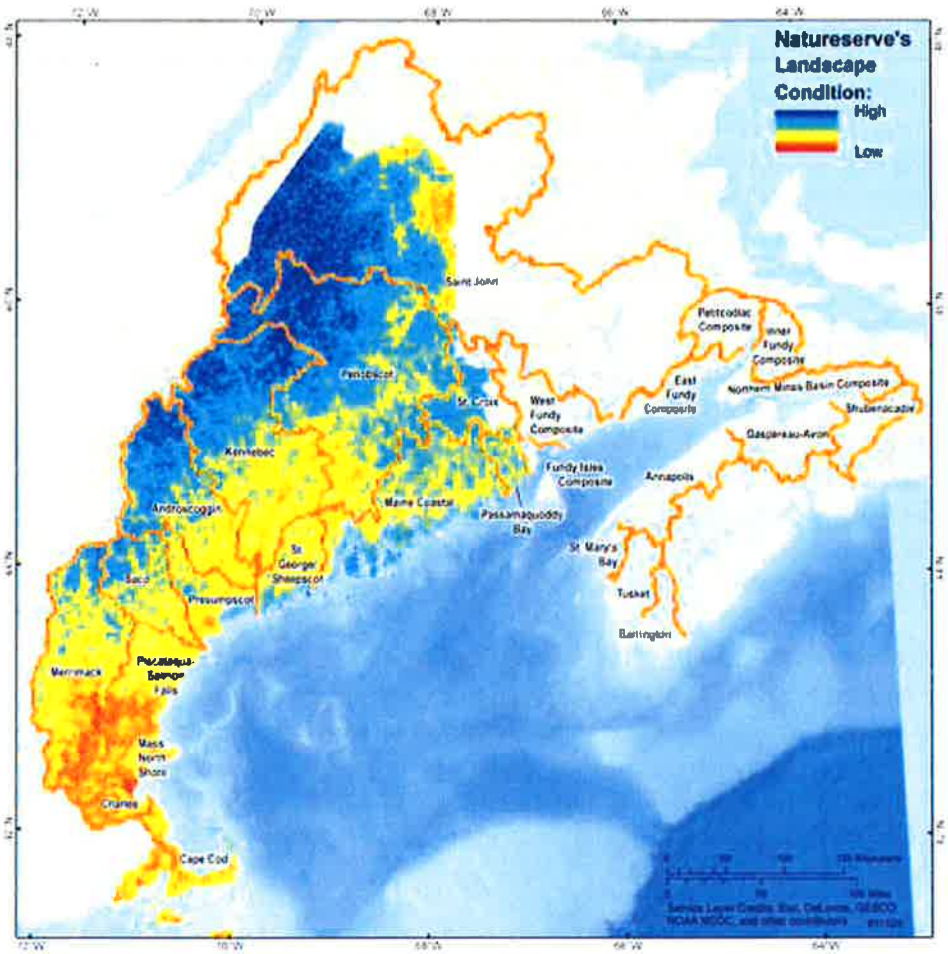

Figure 3: Landscape condition in the U.S. Gulf of Maine watershed, based on the NatureServe Landscape condition modeling tool. This model uses mapped information of human uses that affect ecological condition. Landscape conditions reflect the interaction of physical, chemical, and biological dynamics within natural ecosystems, and incorporate data reflecting human alterations such as vegetation removal or stream alterations. Condition is scaled from 1 to 100; lower numbers represent relatively poor condition while higher numbers represent relatively good condition. Prepared by D. Morse, ASRC Federal Vistronix.

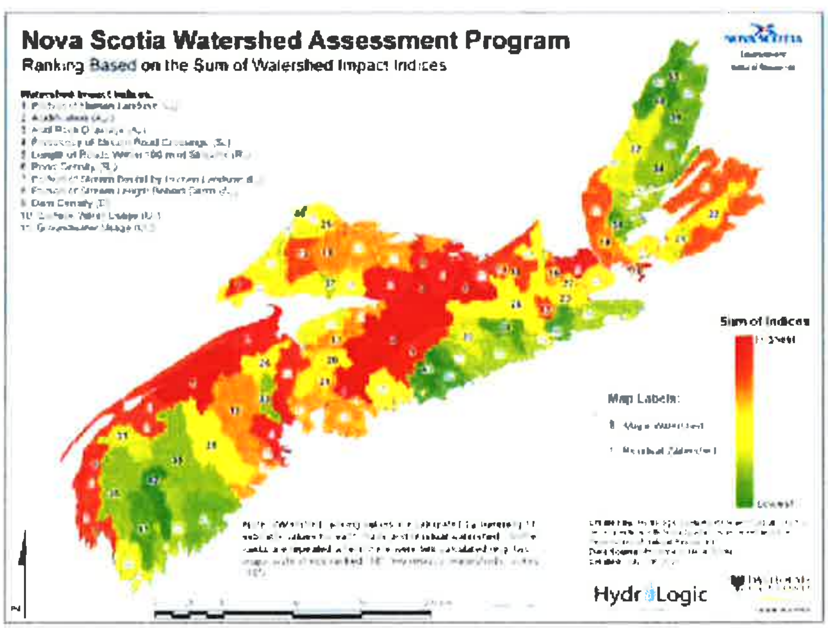

Figure 4: Assessment of watersheds in Nova Scotia based on a sum of rankings of watershed impact indicators. Impact indicators used to calculate rankings are listed on the figure (Hydrologic Systems 2012). Numbers on the map are watershed labels, with bolded numbers indicating major watersheds while non-bolded numbers indicate smaller, "residual" watersheds (see Hydrologic Systems 2012 for more detail of how watersheds were defined). Note that the scale used for this figure is different than Figure 3, with "high" on this figure indicating highly impacted relative to other watersheds.

3. Status and Trends

Centuries of human activity have shaped and reshaped the region's waterways, often changing the flow of water and composition of ecological communities, while introducing pollutants and airborne contaminants and affecting human uses.

3.1 ECOLOGICAL INTEGRITY

Most of the waterways in the Gulf of Maine watershed have been markedly transformed by human activities over generations. According to the USGS, 79 percent of streams assessed in the three U.S. states bordering the Gulf of Maine exhibited modified streamflows (a pattern that mirrors national trends). Changes came from a variety of factors such as impoundments, water diversions, urban runoff/ impervious cover, wastewater discharges and drinking water withdrawals from both groundwater and surface waters (Carlisle et al. 2011, Carlisle et al. 2013). The most urbanized areas within the watershed displayed the most alterations.

Dams, whether small impoundments or large reservoirs, often regulate flow—removing flood peaks and releasing water during lower-flow periods. These kinds of streamflow modifications can transform communities of algae, macroinvertebrates and fish, changing assemblages to those that flourish in slow-moving currents. Before dam construction on the Saint John River, there was 2379 hectares (ha) (5878 acres) of juvenile Atlantic salmon habitat. Available habitat was reduced to 1347 ha (3328 acres) after construction of the Mactaquac, Tobique and Beechwood dams in the mid-twentieth century (Thrive Consulting 2015).

In coming decades, climate change is expected to markedly alter both streamflow and water temperatures. An analysis by the USGS (based on measurements at gauging stations along 22 Maine rivers that drain to the Gulf) found that for the full period of record (70 years), annual average temperature, precipitation and runoff increased in almost all basins. Annual average temperature typically increased by about 1 °C (1.8 °F) per 100 years at many stations (with a range of 0 to 1.9 °C). Estimates of evapotranspiration for each basin indicated moderate increases in most basins but not as high as expected, perhaps due to other climate change factors such as increased cloudiness. These measurements are consistent with climate change impacts and are expected to continue at an increased rate (Huntington 2014).

While regional data have not yet been compiled, NASA and the National Science Foundation have found that lake summer surface temperatures around the world are warming significantly—at an average of 0.34 °C (0.61 °F) per decade across 235 globally distributed lakes between 1985 and 2009 (O'Reilly et al. 2015). Primary drivers of increased lake temperatures include air temperature, solar

Table 2: Recreational use of Gulf of Maine lakes and rivers (based on USDOI et al. 1991; USDOI et al. 2014; U.S. Coast Guard 2011; DFO 1990; DFO 2010b).

STATE/PROVINCE	LAKES	NUMBER OF REGISTERED BOATS (2011)	ECONOMIC VALUE OF BOATING (2011)	RECREATIONAL FISHING IN THE GULF OF MAINE			
				YEAR	NUMBER OF ANGLERS	FISHING DAYS	ECONOMIC VALUE OF RECREATIONAL FISHING*
Massachusetts	2,922	186,140	$488,845,724	1991	652,000	9,183,000	$454,240,000
				2011	532,000	8,367,000	$455,403,000
New Hampshire	944	76,952	$42,710,571	1991	319,000	2,894,000	$86,978,000
				2011	228,000	4,370,000	$208,524,000
Maine	6,000	96,918	$125,133,586	1991	448,000	4,643,000	$147,209,000
				2011	341,000	3,873,000	$371,829,000
New Brunswick	2,500	n/a	n/a	1990	93,307	1,009,934	$60,774,626
				2010	67,509	699,226	$95,798,879
Nova Scotia	6,674	n/a	n/a	1990	71,914	1,236,693	$54,752,350
				2010	64,112	830,761	$85,636,538

* Different methodologies used to calculate economic value in states and provinces.

3.3 SURFACE WATER POLLUTION AND NUTRIENT LOADING

By the mid-twentieth century, industrial discharges, municipal wastewater and agricultural runoff had drastically reduced the quality of surface waters through much of the Gulf of Maine watershed. New England's rivers were among the nation's most polluted waters, and stretches of the Saint John River in New Brunswick became anoxic, causing widespread fish kills (CDNHW 1961; Sprague 1964; Robinson et al. 2004).

Legislation and technology have markedly improved wastewater treatment and reduced municipal effluents (USEPA 2002; Chambers et al. 2012). However, in many urban areas antiquated combined sewer overflow systems still prompt beach closures and swimming advisories associated with heavy precipitation events (when sewage enters waterways without treatment). The high-intensity precipitation events associated with climate change exacerbate this problem, carrying both sewage and nutrients into waterways (see theme papers on *Microbial Pathogens and Biotoxins*, *Eutrophication* and *Toxic Chemical Contaminants*).

Most rivers that discharge into the Bay of Fundy are considered mesotrophic (moderately nutrient-enriched), with a few considered eutrophic (highly nutrient-enriched) (Environment Canada 2011). The nutrient status did not change appreciably in these rivers between 1990 and 2006 (Environment Canada 2011). See *Eutrophication* theme paper for a more in-depth discussion of nutrient loads to estuaries and coastal waters.

3.4 ACID RAIN AND MERCURY DEPOSITION

The 1991 Canada-U.S. Air Quality Agreement has helped reduce sulfur dioxide and nitrogen oxide air emissions by 50 percent from 1980 to 2007 (EPA website). Decreased emissions have gradually changed the chemistry of surface waters, but depletion of calcium in soils (due to acid rain exposure over time) has slowed improvement in waters and in terrestrial and aquatic ecosystems (Lawrence et al. 2015).

Long-term monitoring at the Hubbard Brook Experimental Forest (HBEF) in New Hampshire and other U.S. sites revealed that acid deposition appears to increase river alkalinity by weathering or eroding calcium and magnesium out of soil and into streams and rivers, potentially affecting biological communities in downstream lakes and estuaries (Kaushal et al. 2013).

First established in 1955 as a National Forest Service study site for hydrologic research, HBEF has provided insights into how watershed ecosystems function through studies of nutrient and pollutant cycling (Campbell et al. 2007). Figure 5,

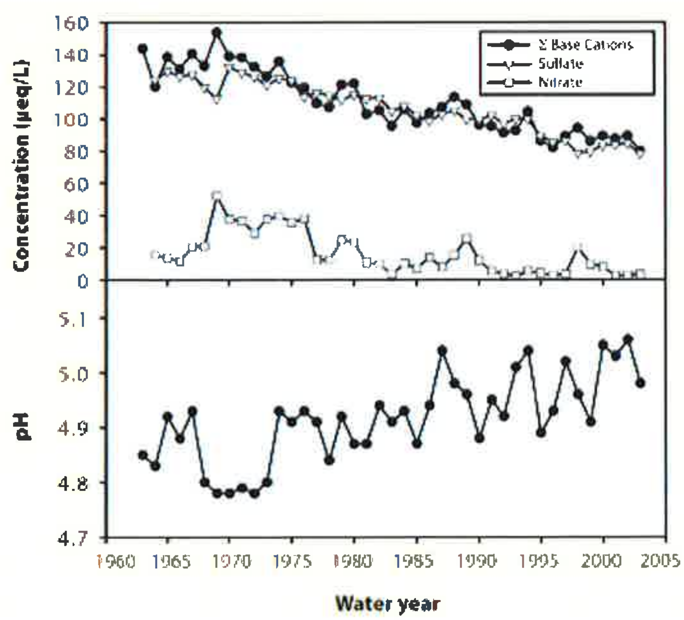

Figure 5: Concentrations of base cations (positively charged ions), sulfate and nitrate, and pH at one location in a stream in the Hubbard Brook Experimental Forest (Campbell et al. 2007).

4. Impacts

4.1 DISRUPTED ECOSYSTEMS

Aquatic ecosystems in the Gulf of Maine watershed are experiencing ecological disruptions, including diminished runs of diadromous fish, due to overfishing, increased temperatures from climate change, multiple impacts of land clearing and urbanization as well as impoundments (the focus of this section).

More than 6,500 river impoundments in the watershed impede migration of diadromous fish, closing off access to freshwater spawning habitats and reducing chances of survival on downstream travels to the ocean. While more than 95 percent of Atlantic salmon smolts moving through reaches of the Penobscot River without dams typically survive, only 52 to 94 percent of smolts survive reaches with dams (Holbrook et al. 2011). Fishways have not worked well for Atlantic salmon, as the fish frequently cannot find their entrances. Less agile swimmers like sturgeon are unable to move past these structures.

Due to impoundments, overharvesting in the twentieth century, and environmental stressors, Atlantic salmon are now listed as endangered in both Canadian and U.S. portions of the Gulf of Maine. Populations are extirpated from New Hampshire and Massachusetts and are critically low in Maine, New Brunswick and Nova Scotia (Saunders et al. 2006; DFO 2010a).

4.2 BIODIVERSITY AND INVASIVE SPECIES

Globally, freshwater habitats occupy less than 1 percent of the Earth's surface yet they support significant biodiversity. Anthropogenic pressures have diminished the range and abundance of many freshwater species, leaving them at greater risk than terrestrial and marine species (Strayer and Dudgeon 2010).

In the Gulf of Maine watershed, as in many other settings, the rate of loss is not easy to quantify because baseline species numbers are not well documented, nor is the potential impact of biodiversity loss on ecosystem function well understood (Higgins 2003). Studies of cyprinid fish populations (minnows) attribute biodiversity losses to urbanization and the introduction of native and non-native predators (Whittier et al. 1997).

In coming decades, freshwater biodiversity loss may be accelerated by climate change, the introduction of invasive species and further landscape fragmentation and nonpoint source pollution. By mid-century, climate change alone could

Ephemeroptera (mayflies), *Trichoptera* (caddisflies) and *Plecoptera* (stoneflies) (Robinson et al. 2004).

Wildlife and human health are jeopardized by blooms of certain species of cyanobacteria (blue green algae), fostered in part by warmer water temperatures and excess nutrients transported into water bodies by more frequent and intense precipitation events. Blue-green algae blooms are becoming more frequent in the region (including lakes in the Charles, Penobscot, Magaguadavic and Saint John River watersheds). Cyanobacteria concentrations vary enormously in space and time as well as in toxicity—making monitoring challenging (Snook 2015).

Harmful Algal Blooms (HABs) such as blue-green algae blooms can last for several weeks, creating potentially dangerous exposure for humans and animals (including livestock, pets and wildlife) due to the toxins, such as microcystins, produced by certain algae. Microcystins cause allergic skin reactions and intestinal problems, and chronic exposure can lead to liver and nervous system damage. Blue-green algae blooms can temporarily shut down municipal water sources as contaminated waters cannot be used for drinking, cooking or washing. While no drinking water advisories have yet occurred in the Gulf of Maine region, HABs have affected back-up water supplies in New Brunswick and been treated in several New England water supplies.

HABs can also prevent recreational use of waters for several weeks, generating significant economic impacts in communities. During the 2015 season, Department of Health officials issued warnings for seven New Brunswick lakes, while the New Hampshire Department of Environmental Services issued warnings for five lakes and ten lake beaches (NBOCMOH 2016, NHDES 2016b)

4.4 TOXICITY TO WILDLIFE AND HUMANS

While there are many potential sources of toxicity to wildlife and humans caused by changes in the Gulf of Maine watershed, this paper focuses on two examples: acid rain and mercury.

Acidic waters have been a long-standing concern in the Gulf of Maine watershed due in part to the region's native ecosystems and geological substrates. Chronic acidification of lakes and rivers weakens freshwater ecosystems, and can cause problems downstream when acidic and nutrient-enriched waters enter estuaries and bays. Large parts of Nova Scotia have naturally low pH due to an abundance of bogs, while Atlantic Canada in general has low innate capacity to buffer or neutralize the acidity because the soils derive from shale and granitic bedrock parent material with lower base cations (i.e., low alkalinity) (Clair et al. 2007).

Low pH (at values below 6) can negatively affect aquatic communities, decreasing growth and survival rates of fish and other organisms. Eggs and young are more

5. Actions and Responses

WATERSHED MANAGEMENT REQUIRES CROSS-BORDER COLLABORATION AT every level from local to international. The Gulf of Maine region has good models of this cooperation and some ongoing mechanisms—such as the Gulf of Maine Council on the Marine Environment—to help facilitate this ongoing work. The following examples, while far from comprehensive, illustrate the breadth of ongoing work to protect and restore Gulf of Maine watersheds.

5.1 LEGISLATION AND POLICY

Clean water initiatives

Clean water legislation in both the U.S. and Canada has benefited Gulf of Maine watersheds. Due to the many different policies and pieces of legislation that impact watersheds, this section cannot provide a comprehensive overview of all policy measures. Instead, it highlights several initiatives seeking to address key pressures on regional watersheds.

Ongoing efforts to implement the U.S. *Clean Water Act* have led to markedly improved water quality in the Gulf of Maine's most densely populated watershed. For more than a century, stormwater from urban development and impervious surfaces has carried pollutants such as phosphorus, nitrogen and polycyclic aromatic hydrocarbons (PAHs) into the Charles River in eastern Massachusetts. Sediments in the lower Charles have accumulated high levels of organic contaminants, such as PCBs and metals such as lead, copper, chromium and cadmium. Efforts to eliminate illicit connections between sewer pipes and storm drains began in 1995, when river water quality was rated a "D." After two decades of work, with more than one million gallons of sewage flow per day eliminated, the Charles River had by 2014 achieved a "B+" rating and was reopened for swimming and recreational contact (EPA website).

Through the *Clean Water Act's* National Pollutant Discharge Elimination System (NPDES), federal regulators issue permits for thermal limits to power plants that exploit river water for cooling operations. At Merrimack Station in New Hampshire, for example, cool water native fish species such as yellow perch have significantly declined over time, and the EPA is now issuing a permit to reduce thermal discharge at this location on the Merrimack River.

New Brunswick and Nova Scotia have put in place watershed management initiatives focused on drinking water supplies. In New Brunswick, where 40 percent of the population depends on public water supplies, the province protects watersheds through legislation, limiting activities that may impact water supply

5.2 MONITORING, PLANNING AND IMPROVING PRACTICES

Citizen science

Throughout the region, dedicated corps of volunteers are monitoring water quality in numerous watersheds, creating baseline data to help track long-term change. Among the earliest to form in eastern Canada was the Clean Annapolis River Project. Across the Bay of Fundy, the Petitcodiac Watershed Alliance has compiled more than 12 years of monitoring data that formed the basis of an Integrated Watershed Management Plan (St-Hilaire et al. 2001; Petitcodiac 2012). Their findings indicate that water quality tends to be worse in areas with the most intense land uses and where riparian zones and wetlands have been damaged.

To improve cyanobacteria monitoring within the region, a New England work group formed in 2013 under the auspices of the EPA's New England Regional Laboratory. It comprises lake and watershed associations, citizen monitoring groups, state and federal environmental water quality and beach monitoring programs, departments of public health, tribes, public water suppliers, non-governmental organizations, university extension agents and academic researchers. The pilot monitoring project employs consistent monitoring kits (with field fluorometers), an image-based "Dirty Dozen" taxonomic key and smartphone apps to report results from more than 100 water bodies. Organizers are finding that this more focused and coordinated effort is yielding better understanding of cyanobacteria's potential impact in the region (Snook 2015).

Standardizing data across watersheds

One consistent challenge for watershed management is the disparity across jurisdictions when it comes to collecting, storing and displaying data. Resource managers in the St. Croix watershed, for example, historically had two different methods of treating geographic information system (GIS) data, hampering efforts to form an integrated view of the river basin. Through the International Joint Commission (IJC), hydrologic data from both Maine and New Brunswick portions of the river basin were harmonized into a unified set of maps and data sets in 2007. This collaboration has served as a model for data integration in other transboundary watersheds (ISCRWB 2008).

Within Canada, two networks help support the growth and integration of community-based water monitoring and management: the Canadian Aquatic Biomonitoring Network (CABIN) and CURA H_2O. CABIN helps partners make formalized scientific observations and assessments using nationally comparable standards, promoting collaborative data-sharing to achieve consistent and comparable reporting on water quality and aquatic ecosystem conditions. CURA H_2O, a community-university research partnership in Nova Scotia that seeks to increase community capacity for integrated water monitoring and management, supports local work on water monitoring and watershed education outreach.

Each municipality participates in the Piscataqua Region Environmental Planning Assessment, an exercise undertaken every five years. Municipal staff members and regional planners complete a detailed assessment of each municipality's regulatory and non-regulatory approaches to challenges such as wetland and shoreland protection, floodplain management, drinking water source protection, stormwater management, erosion control and land protection. PREP's resulting report card indicates how each municipality is doing and how well they're working to address common challenges. Their collective data help inform watershed-scale planning for threats such as nitrogen loading, impervious cover and climate change.

Participating communities are eligible for grants to help implement actions such as completing a natural resources inventory or climate vulnerability assessment, increasing shoreland setbacks and buffers or adopting model regulations for stormwater management or subdivisions that incorporate conserved lands.

5.3 CONSERVATION AND RESTORATION INITIATIVES

Indigenous peoples

For centuries, Indigenous groups in Canada and the United States have depended on the cultural and natural resources of the Gulf of Maine watershed. Today, many are engaged in watershed protection and restoration efforts, including some that span the international border between Maine and New Brunswick.

Passamaquoddy tribal members in the St. Croix River watershed are working with federal agencies in Canada and the U.S. to ensure that alewife and other anadromous fish can successfully access spawning habitat using fish ladders adjoining dams on this boundary river. Both the Maliseet Nation Conservation Council in Canada and the Houlton Band of Maliseet Indians in the U.S. are working to restore Atlantic salmon in the Meduxnekeag River, a tributary of the Saint John River that straddles the border and lies upstream of New Brunswick's Mactaquac Dam.

Land conservation

Throughout the region, local land trusts and other conservation organizations are protecting undeveloped lands that buffer local waterways (with two cross-border examples highlighted here). These efforts can provide relatively cost-effective means of protecting water quality, particularly for drinking water supplies.

Along the border between Maine and New Hampshire, for example, the U.S. Department of Agriculture's Forest Service found that the Piscataqua-Salmon Falls watershed—where 28,000 people rely on public water systems—was particularly vulnerable to forest fragmentation and diminished water quality (Stein et

(Freeman 2013). CARP found that among 777 waterways in its preliminary assessment, 55 percent had barriers. Based on these assessments, CARP targets waterways with full-barrier culverts each year for restoration actions such as debris removal.

Many other groups are doing similar work replacing culverts, and in Queen's County, Nova Scotia, the Mersey Tobeatic Research Institute and partners have created a fish passage culvert demonstration site.

Restoring Fish Passage

At numerous settings around the Gulf of Maine region, projects to restore aquatic connectivity and runs of diadromous fishes are helping repair past hydrologic alterations. Along the Petitcodiac River in southeastern New Brunswick, the provincial and federal governments conducted an environmental impact assessment on the Petitcodiac Causeway. The 1036-metre installation, built in 1968 along a tidal stretch of the river, restricted saltwater flow into upper portions of the river and severely limited fish passage.

The assessment concluded that a bridge would improve tidal flow upstream of the site, reduce loads of sediment, and foster better fish passage for species such as Atlantic salmon, American eel and Atlantic sturgeon. While construction of the bridge has not yet begun, a decision to keep the causeway gates permanently open has realized many environmental benefits already, including an increase in the numbers of striped bass, American eel, rainbow smelt and tomcod using the river (Redfield 2016).

An evaluation of returning fish runs in Maine's Penobscot River following removal of the Great Works and Veazie dams (in 2012 and 2013) confirmed full accessibility to historic freshwater habitat for four diadromous fish species. After removal of a dam on the Sedgeunkedunk Stream (a tributary of the Penobscot), the upstream abundance of spawning-phase sea lampreys increased four-fold, and the number of nesting sites experienced a three- to four-fold increase (Hogg et al. 2013).

7. References

ASMFC (Atlantic States Marine Fisheries Commission). 2016. American Eel. http://www.asmfc.org/species/american-eel (accessed April 2016).

Benke AC and Cushing CE, eds. 2005. Rivers of North America. Amsterdam: Elsevier/Academic Press.

Benoy G, Luiker E and Culp J. 2012. Quantifying watershed-based influences on the Gulf of Maine Ecosystem: the Saint John River basin. American Fisheries Society Symposium 79: 219-234.

Bradford RG. 2012. 2010 status of American eel (*Anguilla rostrata*) in Maritimes Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/083.

Bush EJ, Loder JW, James TS, Mortsch LD and Cohen SJ. 2014. An Overview of Canada's Changing Climate. In: FJ Warren and DS Lemmen (eds), Canada in a Changing Climate: Sector perspectives on impacts and adaptation. Ottawa, ON: Government of Canada. pp. 2364. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf

Campbell JL, Driscoll CT, Eagar C, Likens GE, Siccama TG, Johnson CE, Fahey TJ, Hamburg SP, Holmes RT, Bailey AS and Buso DC. 2007. Long-term trends from ecosystem research at the Hubbard Brook Experimental Forest. Gen. Tech. Rep. NRS-17. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Campo KW, Flanagan SM and Robinson KW. 2003. Water quality of selected rivers in the New England coastal basins in Maine, Massachusetts, New Hampshire, and Rhode Island, 1998-2000. Pembroke, NH: Water-Resources Investigations Report 03-4210. http://pubs.usgs.gov/wri/wri034210/wrir034210report.pdf

Carlisle DM, Meador MR, Short TM, Tate CM, Gurtz ME, Bryant WL, Falcone JA and Woodside MD. 2013. The quality of our nation's waters—ecological health in the nation's streams, 1993–2005 (U.S. Geological Survey Circular 1391). http://pubs.usgs.gov/circ/1391/

Carlisle DM, Wolock DM and Meador MR. 2011. Alteration of streamflow magnitudes and potential ecological consequences: A multiregional assessment. Front Ecol Environ 9(5): 264-270, doi: 10.1890/100053.

Casper AF, Thorp JH, Davies SP and Courtemanche DI. 2006. Ecological responses of zoobenthos on the Kennebec River, Maine, USA. Archiv Fur Hydrobiologie (Large Rivers Supplement 115) 16(4): 541-555.

CDA (Canadian Dam Association). 2016. Regulation of dams in Canada http://www.imis100ca1.ca/cda/Main/Dams_in_Canada/Regulation/CDA/Dams_In_Canada_Pages/Regulation.aspx (accessed April 2016)

CDM. 2004. Merrimack River watershed assessment study: Screening level model. Prepared for U.S. Army Corps of Engineers, New England District. Concord, MA. http://www.nae.usace.army.mil/Portals/74/docs/Topics/MerrimackLower/ScreeningModel.pdf

CDNHW (Canadian Department of National Health and Welfare).1961. Survey report: Effects of pollution, Saint John River, New Brunswick and Maine, 1960 (MS report). Fredericton, NB: Public Health and Engineering Division.

Chambers PA, McGoldrick DJ, Brua RB, Vis C, Culp JM and Benoy GA. 2012. Development of environmental thresholds for nitrogen and phosphorus in streams. Journal of Environmental Quality 41: 7-20.

Chow L, Xing Z, Benoy G, Rees HW, Meng F, Jiang Y and Daigle JL. 2011. Hydrology and water quality across gradients of agricultural intensity in the Little River watershed area, New Brunswick, Canada. J Soil Water Conserv 66: 71-84, doi: 10.2489/jswc.66.1.71.

Clair TA, Dennis IF, Scruton DA and Gilliss M. 2007. Freshwater acidification research in Atlantic Canada: A review of results and predictions for the future. Environ Rev 15: 153-167, doi: 10.1139/A07-004.

Clair TA, Ehrman JM, Ouellet AJ, Brun G, Lockerbie D and Ro C-U. 2002. Changes in freshwater acidification trends in Canada's Atlantic Provinces: 1983–1997. Water Air Soil Pollut. 135: 335–354.

Coles JF, Cuffney TF, McMahon G and Rosiu CJ. 2010. Judging a brook by its cover: The relation between ecological condition of a stream and urban land cover in New England. Northeast Nat 17: 29-48, doi: 10.1656/045.017.0103.

Collins N and Della Valle EA. 2004. Land use. In: GG Pesch and PG Wells (eds), Tides of change across the Gulf: An environmental report on the Gulf of Maine and Bay of Fundy. Portland, ME: Gulf of Maine Council on the Marine Environment and the Global Programme of Action Coalition for the Gulf of Maine. pp. 17–32. http://www.gulfofmaine.org/council/publications/tidesofchangeacrossthegulf.pdf

Conkling PW. 1995. From Cape Cod to the Bay of Fundy: An environmental atlas of the Gulf of Maine. Cambridge, MA: Massachusetts Institute of Technology.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2010. COSEWIC assessment and status report on the Atlantic Salmon *Salmo salar* (Nunavik population, Labrador population, Northeast Newfoundland population, South Newfoundland population, Southwest Newfoundland population, Northwest Newfoundland population, Quebec Eastern North Shore population, Quebec Western North Shore population, Anticosti Island population, Inner St. Lawrence population, Lake Ontario population, Gaspé-Southern Gulf of St. Lawrence population, Eastern Cape Breton population, Nova Scotia Southern Upland population, Inner Bay of Fundy population, Outer Bay of Fundy population) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xlvii + 136 pp. http://www.registrelep-sararegistry.gc.ca/document/default_e.cfm?documentID=2258

ISCRWB (International St. Croix River Watershed Board) and the International Joint Commission. 2008. St Croix River: State of the watershed report. Portland, ME: FB Environmental. http://ijc.org/files/publications/watershed_report.pdf

Kaushal SS, Likens GE, Utz RM, Pace ML, Grese M and Yepsen M. 2013. Increased river alkalinisation in the Eastern U.S. Environ Sci Technol 47: 10302-10311, doi: 10.1021/es401046s.

Lawrence GB, Hazlett PW, Fernandez IJ, Ouimet R, Bailey SW, Shortle WC, Smith KT and Antidormi MR. 2015. Declining acidic deposition begins reversal of forest-soil acidification in the Northeastern U.S. and Eastern Canada. Environ Sci Technol 49: 13103-13111, doi: 10.1021/acs.est.5b02904

Likens GE. 2004. Some perspectives on long-term biogeochemical research from the Hubbard Brook Ecosystem Study. Ecology 85: 2355-2362.

Marshall IB, Schut PH and Ballard M. 1999. A national ecological framework for Canada: Attribute data. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research, and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull.

Mactaquac Generating Station/New Brunswick Power. 2016. What is the Mactaquac project? http://www.mactaquac.ca/ (accessed April 2016)

Massachusetts Department of Public Health. 2015. Marine and freshwater beach testing in Massachusetts annual report: 2014 season. Boston, MA: Bureau of Health/Environmental Toxicology Program. http://www.mass.gov/eohhs/docs/dph/environmental/exposure/beach-reports/beach-annual-report14.pdf

Mitchell SC, LeBlanc JE and Heggelin AJ. n.d. Impact of introduced chain pickerel (*Esox niger*) on lake fish communities in Nova Scotia, Canada. Antigonish, NS: St. Francis Xavier University. https://novascotia.ca/fish/documents/special-management-areas-reports/impact-chain-pickerel.pdf

Moore RB, Johnston CM, Smith RA and Milstead B. 2011. Source and delivery of nutrients to receiving waters in the Northeastern and Mid-Atlantic regions of the United States. J Am Water Resour As 47: 965-990, doi: 10.1111/j.1752-1688.2011.00582.x.

Moyle PB and Cech Jr JJ. 2004. Fishes: An introduction to ichthyology. Upper Saddle River, NJ: Prentice-Hall.

NBELG (New Brunswick Environment and Local Government). 2016. Watershed Protection. http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/land_waste/content/reference_manual/watershed_protection.html (accessed June 2016).

NBELG. 2007a. Petitcodiac River. New Brunswick Watersheds. Environmental Reporting Series 2007. http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/watersheds.html (accessed June 2016).

NBELG. 2007b. Saint John River. New Brunswick Watersheds. Environmental Reporting Series 2007. http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/watersheds.html (accessed June 2016).

NBELG. 2007c. St. Croix River. New Brunswick Watersheds. Environmental Reporting Series 2007. http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/water/content/watersheds.html (accessed June 2016).

NBOCMOH (New Brunswick Office of the Chief Medical Officer of Health). 2016. Public health advisories and alerts. http://www2.gnb.ca/content/gnb/en/departments/ocmoh/health_advisories.html (accessed April 2016)

NELP (New England Lakes and Ponds project). 2010. New England lakes and ponds report. Lowell, MA: New England Interstate Water Pollution Control Commission.

NHDES (New Hampshire Department of Environmental Services). 2016a. Acid Rain Program overview http://des.nh.gov/organization/divisions/air/tsb/tps/acidrain/categories/overview.htm (accessed April 2016)

NHDES. 2016b. Archive of 2015 press releases http://des.nh.gov/media/pr/2015/index.htm (accessed April 2016)

NOAA (National Oceanic and Atmospheric Administration). 2016. Coastal Change Analysis Program regional land cover and change. https://coast.noaa.gov/dataregistry/search/collection/info/ccapregional (accessed May 2016)

NSE (Nova Scotia Environment). 2009. Protected Water Areas of Nova Scotia. https://www.novascotia.ca/nse/water/docs/protected.water.areas.map.pdf

NSE. 2013. Nova Scotia Watershed Assessment Program. Nova Scotia's Water Resources Management Strategy. https://www.novascotia.ca/nse/water.strategy (accessed May 2016)

O'Reilly CM, Sharma S, Gray DK, Hampton SE, Read JS, Rowley RJ, Schneider P, Lenters JD, McIntyre PB, Kraemer BM, et al. 2015. Rapid and highly variable warming of lake surface waters around the globe. Geophys. Res. Lett. 42: 10773–10781, doi:10.1002/2015GL066235.

Pershing AJ, Alexander MA, Hernandez CM, Kerr LA, Le Bris A, Mills KE, Nye JA, Record NR, Scannell HA, Scott JD et al. 2015. Slow adaptation in the face of rapid warming leads to the collapse of the Gulf of Maine cod fishery. Science 350: 809-12, doi 10.1126/science.aac9819.

Petitcodiac Watershed Alliance. 2012. Integrated Water Management Plan for the Petitcodiac River Watershed. Moncton, NB: Petitcodiac Watershed Alliance. http://governamerica.com/documents/Petitcodiac_Integrated_Watershed_Management_Plan.pdf

Pond A. 2014. St. Croix International Management Plan progress update. St. Stephen, NB: St. Croix International Waterway Commission. http://www.stcroix.org/what-we-do/management-plan

Ray GL. 2005. Invasive animal species in marine and estuarine environments: Biology and ecology. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA430308

Redfield, E. 2016. Petitcodiac fish recovery coalition fish trap results, 2015 season. Fort Folly Habitat Recovery Program, Dorchester, NB. 78 pp. http://petitcodiacwatershed.org/wp-content/uploads/2014/03/2015-PFRC-Fish-Trap-Report.pdf

BIODIVERSITY

Diversity of Life

Biological diversity – or biodiversity – is the term given to the variety of life on Earth and the natural patterns it forms. Biodiversity is commonly thought of as the number of species in an area and their relative abundance. It also includes genetic diversity (of a population), and community diversity within a larger area or ecosystem. Habitat diversity, which is the range of habitats in an area, is described in Aquatic Habitats.

The biodiversity we see today is the result of billions of years of evolution, shaped by natural processes and, increasingly, by humans. This diversity is often understood in terms of the wide variety of plants, animals and microorganisms. So far, about 1.75 million species have been identified on Earth, mostly small creatures such as insects. The Census of Marine Life Program in the Gulf of Maine has counted over 3,200 coastal and marine species in area. The current species count identifies at least 652 fishes, 184 species of birds, 733 different species of microscopic plants and algae, and 32 mammals that all call the Gulf of Maine home.

Human activities and natural conditions affect ecosystem functioning through direct and indirect effects on species and communities. Major human impacts include: introduction of non-native species; regional changes in species composition or gene pools; physical and chemical alterations of habitats, and local alterations to biotic communities. Both the United States and Canada are signatories to the Convention on

MARINE INVASIVE SPECIES

STATE OF THE GULF OF MAINE REPORT

Gulf of Maine Council on the Marine Environment

June 2010

1. Issue in Brief

LINKAGES

This theme paper also links to the following theme papers:

- Climate Change and Its Effects on Ecosystems, Habitats, and Biota
- Species at Risk
- Coastal Ecosystems and Habitats
- Emerging Issues

Marine habitats in the Gulf of Maine support an ever-growing suite of marine invasive species, defined as non-native species that cause or are likely to cause harm to ecosystems, economies, and/or public health (ISAC 2006). Invading marine species were first introduced to the northwest Atlantic region by early explorers, either purposely for food sources or accidentally through fouling on the hulls of wooden ships and other means. In modern times, there are a wide variety of transfer mechanisms (vectors) available for hitchhiking marine invaders to travel and spread. At least 64 invasions have occurred in the Gulf of Maine ecosystem, and more are likely to be discovered. Pressures such as habitat modification, aquaculture, shipping, and climate change will continue to have unintended impacts on the system and further influence the survival of non-native species (Figure 1). Impacts from marine invasive species in the Gulf of Maine vary from competitive displacement of native species to aesthetic impacts and fouling of gear, although there is little empirical evidence available, particularly for economics, to assess impacts in depth. Management of invading species in the marine environment is a relatively new endeavour, and there is much to learn regarding successful prevention and control of organisms in open systems. Current regulatory responses are moving toward a more effective management approach that includes a focus on early detection, rapid response, research, and education. These efforts will go a long way in helping to understand the impacts of marine invasive species and protect Gulf of Maine ecosystems and economies.

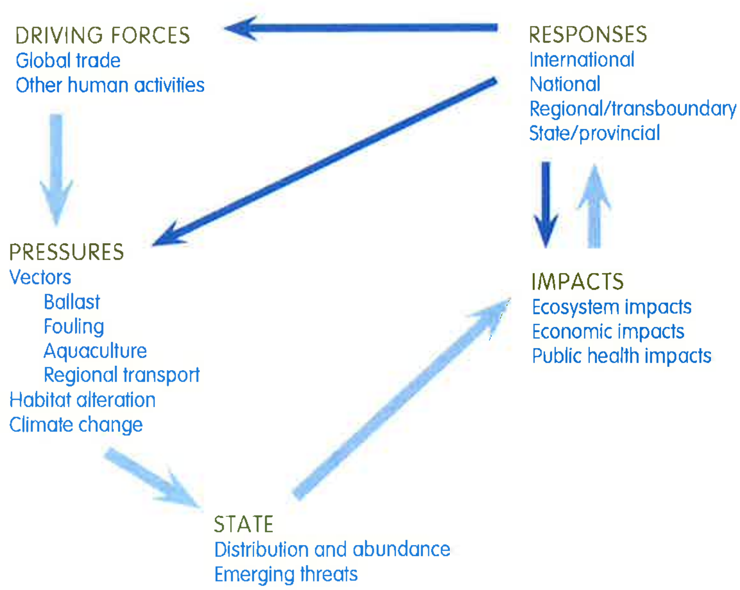

Figure 1: Driving forces, pressures, state, impacts and responses (DPSIR) to marine invasive species in the Gulf of Maine. The DPSIR framework provides an overview of the relation between the environment and humans. According to this reporting framework, social and economic developments and natural conditions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

Table 1: Species introduced by shipping in the Gulf of Maine.

SPECIES	VECTOR	SOURCE
Furcellaria lumbricalis (red alage)	Ballast Water	Mathieson et al. 2008c
Ovatella mysotis (mouse ear snail)	Rock Ballast	Carlton 1992
Fucus serratus (brown algae)	Rock Ballast	Brawley et al. 2009
Littorina littorea (common periwinkle)	Rock Ballast	Brawley et al. 2009
Neosiphonia harveyi (red algae)	Fouling	Mathieson et al. 2008c
Porphyra katadae (nori, red algae)	Fouling	Mathieson et al. 2008c
Botryllus schlosseri (star tunicate)	Fouling	Dijkstra et al. 2007a
Diplosoma listerianum (tunicate)	Fouling	Dijkstra et al. 2007a
Codium fragile ssp *fragile* (green fleece)	Fouling	Carlton and Scanlon 1985
Antithamnion pectinatum (red algae)	Shipping, unspecified	Mathieson et al. 2008c
Bonnemaisonia hamifera (red algae)	Shipping, unspecified	Mathieson et al. 2008b
Lomentaria clavellosa (red algae)	Shipping, unspecified	Mathieson et al. 2008b
Melanosiphon intestinalis (brown algae)	Shipping, unspecified	Mathieson et al. 2008b
Convoluta convoluta (flatworm)	Shipping, unspecified	Rivest et al. 1999

2.1.1 Ballast

The use of solid ballast obtained from intertidal habitats of Europe may have transported entire communities to the Gulf of Maine, and has been implicated in the introduction and subsequent spread of the brown algae *Fucus serratus* and snail *Littorina littorea* to Nova Scotia in the 18th Century (Carlton 1996b; Brawley et al. 2009). In the last half century, an increased number of commercial vessels, reduction of toxins in ballast water, and larger capacity of ballast tanks have improved the survival of marine invaders in transit and thus the number of viable marine introductions (Carlton 1985; Carlton 1996b; Cohen and Carlton 1998). Mysids, amphipods, cladocerans, copepods, numerous microscopic planktonic organisms, algal filaments, and fish have been observed to survive in ballast tanks in journeys lasting nearly two weeks, while polychaete larvae and copepods can survive voyages of 30 days or more (Carlton 1985). In the Gulf of Maine, it is hypothesized that the red alga *Furcellaria lumbricalis* was introduced via ballast water (Mathieson et al. 2008a).


Photo: Jim Frazier

2.1.2 Fouling

Fouling is the accumulation of marine organisms on the hull, sea chest, and other surfaces of ships. Distinguishing between introductions resulting from fouling versus ballast water is extremely difficult (Carlton 1985). However, species that have short-lived larvae, which are not likely to survive long journeys in ballast

2.2.2 Habitat Modification

The role of habitat modification on the introduction and survival of non-native marine species in the Gulf of Maine is not clear. However, increased numbers of non-native species are often seen in areas disturbed by human activities, and successful invaders may possess traits that enable them to perform better in altered habitats relative to native species (Cohen and Carlton 1998; Byers 2002). It is thought that native species compete best on surfaces for which they are evolutionarily adapted, giving non-native species a competitive advantage on newer, artificial substrates (Tyrell and Byers 2007). For example, marine invasive species are often more likely to be present on floating pontoons and pilings than adjacent natural habitat (Glasby et al. 2007; Tyrell and Byers 2007).


Photo: N. Houlihan

Water quality conditions may also play a role in the establishment of marine invasive species. For example, the red alga *Grateloupia turuturu*, a recent invader to the Gulf of Maine, is highly tolerant of polluted waters (Farnham 1980). In eutrophic (nutrient rich) systems, invasive species that are better competitors at high nutrient levels and low oxygen conditions may have an advantage over native species (Byers 2002). However, direct relationships between survival of marine invaders and water quality are not always clear; in southern New England both native and non-native ascidians are most diverse in areas of fair water quality and moderate levels of nitrogen (Carmen et al. 2007). Ironically, recent improvements to water quality, both in local harbors and distant source ports, have been implicated in increased survival of marine invaders both in ballast and at the point of introduction (Carlton 1996a).

2.2.3 Climate Change

Climate change and the resultant modifications in habitat may impact the survival and establishment of species in various ways. Hellmann et al. (2008) propose several consequences of climate change on marine invasive species relevant to the Gulf of Maine: altered patterns of human transport (longer shipping seasons, new routes, etc.), altered climatic restraints favoring non-natives or increasing the possibility of survival for previously unsuccessful invasions, altered distributions (range shifts, etc.), and altered impacts. Long-term studies of rocky shores in California have shown latitudinal shifts in species abundance and geographic range boundaries as a result of temperature increases, and similar changes may occur in the Gulf of Maine if temperatures continue to rise (Barry et al. 1995; see Climate Change). Since organisms are generally most abundant in the center of their range, species with more southerly borders should expand, while those with northern boundaries should decrease (Barry et al. 1995). For example, a warming trend during the last mid century is implicated in the expansion of the green crab, *Carcinus maenas*, from waters south of Cape Cod Massachusetts into the Gulf of Maine (Glude 1955). Changes in climate resulting in warmer winter water temperatures in particular could provide a thermal refuge for invading species

3. Status and Trends

At least 64 marine invasive species have been documented in the Gulf of Maine (Table 2). This count does not include cryptogenic species, organisms that cannot definitively be identified as native or introduced, which are likely to comprise a significant number of species in the region (Carlton 1996b). For example, it is estimated that at least 67 cryptogenic marine species reside in the waters of Long Island Sound to Nova Scotia (Carlton 2003). This count also does not represent results from comprehensive monitoring of all habitats. The bulk of information on marine introductions in the Gulf of Maine and elsewhere is from coastal and estuarine systems, and due to logistical constraints and identification difficulties, only some habitats and taxa are adequately represented. For example, very little information is available on soft substrate benthic infauna, and various microscopic organisms are most certainly underrepresented. Additionally, the identification status for several organisms is not well defined and may fluctuate through genetic work and advanced study. For example, the invasive red algae *Neosiphonia harveyi* was misidentified as the native *Polysiphonia harveyi*

Table 2: Marine invasive species in the Gulf of Maine.

TAXONOMIC GROUP	NUMBER	SOURCE
Crustacea	13	Swan 1956; Beckman and Menzies 1960; Maurer and Wigley 1982; Larsen and Doggett 1991; Wethey 2002; Carlton 2003; Trott 2004; Pederson et al. 2005; Delaney et al. 2008
Rhodophyceae	11	Mathieson et al. 2008 a,b,c
Tunicata	7	Pederson et al. 2005; Harris and Dijkstra 2007
Mollusca	6	Carlton 1992; Carlton 2003; Pederson et al. 2005
Phaeophyceae	5	Hooper and South 1977; Mathieson et al. 2008 a,b,c
Hydrozoa	3	Smith 1964; Blezard 1999; Trott 2004
Bryozoa	3	Scheibling et al. 1999; Pederson et al. 2005
Protista	3	Ford 1996; Cook et al. 1998; Bower 2007
Cnidaria	2	Trott 2004; Pederson et al. 2005
Polychaeta	2	Carlton 2004; Pederson et al. 2005
Platyhelminthes	2	Cone and Marcogliese 1995; Rivest et al. 1999
Diatomacea	2	Carlton 2003; Martine and LeGresley 2008
Kamptozoa	1	Wasson et al. 2000
Nematoda	1	Aieta and Oliveira 2009
Porifera	1	Pederson et al. 2005
Cholorophyceae	1	Pederson et al. 2005; Mathieson et al 2008b
Virus	1	Bouchard et al. 2001
TOTAL	64	

include competition for resources, shading, displacement, and loss of native algal biomass (Scaffelke and Hewitt 2007). Impacts of this species in the Gulf of Maine are as of yet unknown, however, *G. turuturu* has broad environmental tolerances and is likely to continue to spread into the northern Gulf of Maine (Mathieson et al. 2008d).

3.1.2 *Didemnum vexillum*

Photo: Adrienne Pappal

It is thought that the non-native colonial tunicate *Didemnum vexillum* was first introduced to the Damariscotta River area in Maine as a hitchhiker on oysters for aquaculture (Dijkstra et al. 2007a). While there have been anecdotal reports of *D. vexillum* in the Gulf of Maine since the 1970s, it is only relatively recently that this species has begun to aggressively expand its range (Bullard et al. 2007). *Didemnum vexillum* utilizes multiple reproductive strategies to facilitate its spread: it can reproduce both sexually and by fragmentation, and fragments may contain larvae that can be released upon reattachment (Bullard et al. 2007; Valentine et al. 2009). Unlike other invasive tunicates, *D. vexillum* is able to recruit to and utilize open coast and deep water habitats (Osman and Whitlach 2007). It was first recorded on Georges Bank in 2002 and by 2005 had formed large mats that covered more than 50 percent of some transects (Valentine et al. 2007). It has no known predators, and its tunic is highly acidic (Bullard et al. 2007; Valentine et al. 2007). *Didemnum vexillum* is able to overgrow and displace most species and established communities, including pebbles, cobbles, boulders, sea scallops, mussels, shells, sponges, bryozoans, hydrozoans, tube worms, and tunicates (Osman and Whitlatch 2007; Valentine et al. 2007). The formation of large colonies may influence the recruitment of other species and could form a barrier to prey and modify habitat, or lead to the death of bivalves by overgrowing their siphons (Bullard et al. 2007; Dijkstra et al. 2007b; Valentine et al. 2007). Control of aggressive ascidians invaders is difficult, and currently there are no effective means to prevent the spread of this species in the Gulf of Maine. In New Zealand, a focused control effort of *D. vexillum* was attempted, and while some methods were effective during the short term, the overall effort failed resulting in significant losses to nearby mussel farms (Coutts and Forrest 2007). *Didemnum vexillum* has not yet been recorded in Canada at the time of this writing, but has been documented near the US-Canada boundary on Georges Bank (Valentine et al. 2007, 2009).

3.1.3 *Eriocheir sinensis* (Mitten Crab)

Photo: Christian Fischer

Eriocheir sinensis has not been reported in Gulf of Maine waters to date, but has been expanding its range along the Atlantic coast since it was first detected in Maryland in 2006 (Ruiz et al. 2006). Populations of *E. sinensis* are found in bordering watersheds including the Hudson River in New York and the St. Lawrence River in Quebec (Ruiz et al. 2006; Veilleux and de Lafontaine 2007). It is a catadromous species that migrates from freshwater rivers and tributaries to tion dynamic effects (community effects), and effects on ecosystem processes. These impacts can work separately or in combination for any species or suite of species and can range from small localized impacts to larger-scale regional impacts. Table 3 describes examples of impacts of introduced species on native species in the Gulf of Maine.

One of the most well studied impacts in the Gulf of Maine is community shifts resulting from the cumulative effect of two marine invaders—the bryozoan *Membranipora membranacea* and the green alga *Codium fragile* ssp. *fragile*—on native laminarian kelps. Kelp beds in the Gulf of Maine provide critical habitat for a wide range of species, such as native fish and invertebrates (Steneck et al. 2002). Historically, grazing by sea urchins was the major source of disturbance in kelp beds, leading to bare patches and, at times, large-scale removal (urchin barrens) (Johnson and Mann 1998). In the past, kelp would generally re-establish after most disturbances. However, in the late 1980s, a dramatic transformation of kelp beds began in the Gulf of Maine concurrent with the arrival of *M. membranacea*.

Membranipora membranacea, a native of Europe, was first recorded in the Gulf of Maine in 1987, and within three years became the dominant kelp epiphyte in

FLEETING IMPACTS?

Allmon and Sebens (1988) describe the rise and fall of one invader in the Gulf of Maine, the sea slug *Tritonia plebeia*. It was first observed in 1983 on subtidal rock walls in Nahant, Massachusetts, and in just two years its density exceeded that of all other nudibranchs at the site. Predation by *T. plebeia* on the native soft coral *Alcyonium siderium* led to bare patches in the dense coral canopy, which allowed sea urchins to access and prey upon the exposed coral fronds. The combination of predation by *T. plebeia* and sea urchins led to large declines and even complete displacement of *A. siderium* at some locations. While the invasion of *T. plebeia* resulted in significant and cascading impacts on the soft coral community in Nahant, its occurrence was short lived. *Tritonia plebeia* has been rare or absent in Nahant since 1986. It is uncertain whether the slug has returned elsewhere and what influenced its rapid increase and decline.

Table 3: Examples of marine invasive species impacts on native species in the Gulf of Maine.

NATIVE SPECIES	IMPACT	SOURCE
Mytilus edulis (blue mussel)*	• *Hemigrapsus sanguineus* feeds on juveniles, consumes up to 150 mussels per crab per day in the laboratory, comprises 30% of the diet in the field • Flatworm *Convoluta convoluta* feeds on juveniles • Makes up to 45% of the diet of *Carcinus maenas*	Loher and Whitlatch 2002; Byrnes and Witman 2003; Griffen and Delaney 2007
Mya arenaria (soft shell clam)*	• In caging experiments, *C. maenas* removed 80% of small *M. arenaria* and consumed up to 22 clams per crab per day	Floyd and Williams 2004
Homarus americanus (lobster)*	• *C. maenas* arrives to food faster and defends food resources from juvenile lobsters in the laboratory	Williams et al. 2006
Littorina saxatilis (periwinkle)	• Growth rate is reduced when competing with *Littorina littorea* • Susceptible to predation by *C. maenas*	Eastwood et al. 2007
Ilyanassa obsoleta (mud snail)	• *L. littorea* competitively displaces *I. obsoleta* from habitat • *C. maenas* and *L. littorea* feed on egg capsules	Brenchley 1982; Brenchley and Carlton 1983
Fucus spp. (rockweed)	• *L. littorea* can prevent establishment of *Fucus* on smooth surfaces by grazing small germlings	Lubchenco 1983

* Important commercially in the Gulf of Maine

tunicates, and impacts to commercially harvested species is a concern (see Table 3). Fouling by tunicates on gear and harvested product is a major issue for the mussel farming industry in Canada, where approximately 2-3 tonnes of bivalves are harvested each year in New Brunswick and Nova Scotia (Locke et al. 2007). Predation by *Carcinus maenas* on *Mya arenia* (soft shell clam) is implicated in the decline of harvest and value (Glude 1955). Total costs associated with the *C. maenas* invasion in the US are estimated at $44 million, but it is unclear how this figure was derived (Pimentel et al. 2005). In addition, non-native marine species may result in aesthetic impacts that alter recreation and are costly to clean up. For example, *C. fragile* often washes ashore and forms large clumps on beaches that are unsightly and result in noxious odors (Pederson et al. 2005).

4.3 PUBLIC HEALTH IMPACTS

Impacts to public health are included in the suite of potential impacts of marine invaders, although not much is known regarding public health impacts in the Gulf of Maine specifically. Introduced pathogens, such as *Vibrio cholera*, the bacteria responsible for cholera in humans, have been found in ballast water and could potentially be discharged to local waters (Ruiz et al. 2000b). Organisms that result in concentrated toxins in seawater and/or seafood are also a concern. For example, the non-native dinoflagellate *Alexandrium minutum* may contribute to red tide outbreaks south of the Gulf of Maine (Carlton 2003). The majority of pathogenic and/or toxic organisms are microscopic and require specific, and at times, cost-intensive monitoring techniques. There is likely a wide array of potential invasive pathogens that are currently overlooked in the Gulf of Maine due to a lack of targeted monitoring programs (Carlton 2003).

Table 4: Examples of international and national responses to marine introduced species.

INTERNATIONAL	
United Nations	• Environmental Program, Agenda 21, Chapter 17 (1992): addresses the issue of aquatic invasives in the context of ballast water and aquaculture • Food and Agriculture, Code of Conduct for Responsible Fisheries (1995): covers fishing practices and aquaculture • Convention on Biological Diversity, Article 8(h) (1993): commitment to prevent the introduction, and to control and eradicate alien species • International Maritime Organization (2004): International Convention for the Control and Management of Ships' Ballast Water and Sediments (2004)
International Council for Exploration of the Seas (ICES)	• Code and Practice on the Introduction and Transfer of Marine Organisms (2004): aquaculture focused
NATIONAL	
United States	• Lacey Act (1990): limited to controlling intentional introductions of injurious species • Nonindigenous Aquatic Nuisance Species Prevention and Control Act (NANPCA) (1990): regulate ballast water in the Great Lakes and establishment of the Aquatic Nuisance Species (ANS) Task Force • ANS Task Force (1990): coordinates federal activities, provides funding and direction to regional panels, directs states to develop management plans, provides limited funding for plan implementation • National Invasive Species Act (1996): amended NANPCA to broaden ballast water requirements to the entire US • Presidential Executive Order No. 13112 (1999): created the National Invasive Species Council • National Invasive Species Council, National Invasive Species Management Plan (2001): serves as national blueprint for invasive species management
Canada	• Canada Shipping Act, Section 657.1 (2001): provides for the power to pass ballast water regulations • An Invasive Alien Species Strategy for Canada (2004): national strategy for invasive species management • The Invasive Alien Species Partnership Program (2004): provides funding in support of the goals of the Invasive Alien Species Strategy • Canadian Biodiversity Strategy (1995): provides means to anticipate, identify and monitor alien organisms, screening standards, and risk assessment • National Wildlife Policy (1990): nonindigenous species should not be introduced into natural systems • Canadian Environmental Protection Act (1999): applies an ecological risk assessment process before permitting the introduction of any new species • Fisheries Act (1985): develops a standard ecological risk assessment process, specifically in the context of fish stocking, live bait, and aquaculture • National Code on Introductions and Transfers of Aquatic Organisms (2003): assesses proposals for moving aquatic organisms between water bodies

Sources: Doelle 2001; Canada Shipping Act 2001; Government of Canada 2004; IMO 2004; Hewitt et al. 2009.

INDICATOR SUMMARY

INDICATOR	POLICY ISSUE	DPSIR	TREND*	ASSESSMENT
Number of established marine invasive species	Growth in global trade and other human activities	Driving Force, Pressure	–	Fair
Distribution and spread of marine invasives	Increase in regional vectors and habitat pressures (i.e., hull fouling, aquaculture, habitat modification, climate change)	Pressure	–	Poor
Losses incurred by fishery and aquaculture industry	Losses of fishery resources from invasive species impacts	Impacts	/	Fair
Costs incurred or spent on invasive species management	Investment in marine invasive management programs and education	Responses	/	Poor

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

Data Confidence

- Information on number of species in the Gulf of Maine was derived through literature review and confirmed reports of species, and this may not reflect the actual number of marine invasives.
- Native status has not been determined for all taxa, and cryptogenic species were not included in this review, thus species may be underestimated.

Data Gaps

- Caution must be taken with marine invasive species estimates in the Gulf of Maine since large data gaps exist.
- There is a lack of information on impacts, particularly economic impacts, of marine invasive species in the Gulf of Maine. There is a general sense that impacts are occurring in the fisheries and aquaculture industries, but it is unclear whether this results in significant losses.
- The majority of information on marine invasive species is from coastal and estuarine systems.
- Not all habitats or taxa are adequately addressed in monitoring programs.
- There is a lack of empirical studies on the impacts of marine invasive species in the Gulf of Maine and elsewhere.

introduction? Journal of Fish Biology 47(1): 177–178.
Cook T, Folli M, Klinck J, Ford S and Miller J. 1998. The relationship between increasing sea-surface temperature and the northward spread of *Perkinsus marinus* (Dermo) disease epizootics in oysters. Estuarine, Coastal and Shelf Science 46: 587-597.
Coutts ADM and Forrest BM. 2007. Development and application of tools for incursion response: Lessons learned from the management of the fouling pest *Didemnum vexillum*. Journal of Experimental Marine Biology and Ecology 342:154-162.
Delaney DG, Sperling CD, Adams CS and Leung B. 2008. Marine invasive species: Validation of citizen science and implications for national monitoring networks. Biological Invasions 10(1): 117-128.
Dijkstra J, Harris LG and Westerman E. 2007a. Distribution and long-term temporal patterns of four invasive colonial ascidians in the Gulf of Maine. Journal of Experimental Marine Biology and Ecology 342: 61-68.
Dijkstra J, Sherman H and Harris LG. 2007b. The role of colonial ascidians in altering biodiversity in marine fouling communities. Journal of Experimental Marine Biology and Ecology 342: 169-171.
Doelle M. 2001. Legal and policy responses to invasive species, background paper. Prepared for the Commission for Environmental Cooperation. 40 pp.
Drake JM and Lodge DM. 2007. Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems. Aquatic Invasions 2(2): 121-131.
Eastwood MM, Donahue MJ and Fowler AE. 2007. Reconstructing past biological invasions: Niche shifts in response to invasive predators and competitors. Biological Invasions 9(4): 397-407.
Elton CS. 1958. The Ecology of Invasions by Animals and Plants. London: Chapman and Hall. 226 pp.
Farnham WF. 1980. Studies on aliens in the marine flora of southern England. In: Price JH, Irvine DEG, Farnham WF (Editors). The Shore Environment, Volume 2: Ecosystems. London: Academic Press. pp. 875-914.
Floyd T and Williams J. 2004. Impact of green crab (*Carcinus maenas* L.) predation on a population of soft-shell clams (*Mya arenaria* L.) in the southern Gulf of St. Lawrence. Journal of Shellfish Research 23(2): 457-462.
Ford SE. 1996. Range expansion of the oyster parasite *Perkinsus marinus* into the northeastern United States: Response to climate change? Journal of Shellfish Research 15(1): 45-56.
Gavio B and Fredericq S. 2002. *Grateloupia turuturu* (Halymeniaceae, Rhodophyta) is the correct name of the non-native species in the Atlantic known as *Grateloupia doryphora*. European Journal of Phycology 37:349-359.
Glasby TM, Connell SD, Holloway MG and Hewitt CL. 2007. Nonindigenous biota on artificial structures: Could habitat creation facilitate biological invasions? Marine Biology 151(3): 887-895.
Glude JB. 1955. The effect of temperature and predators on the abundance of the soft-shell clam, *Mya arenia*, in New England. Transactions of the American Fisheries Society 84(1): 13-26.
Government of Canada. 2004. An invasive alien species strategy for Canada. http://www.ec.gc.ca/eee-ias (accessed May 2010). 46 p.
Griffen BD and Delaney DG. 2007. Species invasion shifts the importance of predator dependence. Ecology 88(12): 3012-3021.
Hare JA and Whitfield PE. 2003. An integrated assessment of the introduction of lionfish (*Pterois volitans/miles* complex) to the Western Atlantic Ocean. NOAA Technical Memorandum NOS NCCOS 2. 31 pp.
Harlin MM and Villalard-Bohnsack M. 2001. Seasonal dynamics and recruitment strategies of the invasive seaweed *Grateloupia doryphora* (Halymeniaceae, Rhodophyta) in Narragansett Bay and Rhode Island Sound, Rhode Island, USA. Phycologia 40(5): 468-474.
Harris LG and Dijkstra JA. 2007. Seasonal appearance and monitoring of invasive species in the Great Bay estuarine system: A final report to the New Hampshire Estuaries Project. 27 pp.
Harris LG and Tyrell MC. 2001. Changing community states in the Gulf of Maine: Synergism between invaders, overfishing and climate change. Biological Invasions 3: 9-21.
Hayward CJ, Iwashita M, Crane JS and Ogawa K. 2001. First report of the invasive eel pest *Pseudodactylogyrus bini* in North America and in wild American eels. Diseases of Aquatic Organisms 44:53-60.
Hellmann JA, Byers JS, Bierwagen BG and Dukes JS. 2008. Five potential consequences of climate change for invasive species. Conservation Biology 22(3): 534-543.
Hewitt CL, Everett RA and Parker N. 2009. Examples of current international, regional, and national regulatory frameworks for preventing and managing marine bioinvasions. In: Rilov G, Crooks JA (Editors). Biological Invasions in Marine Ecosystems Ecological, Management, and Geographic Perspectives. Berlin, Heidelberg: Springer-Verlag. pp. 335-349.
Hines AH, Miller AW, Ruiz GM and Lion K. 2004. Estimating Domestic and Foreign Ballast Water as a Vector for Invasive Species: Regional Analysis for New England, Northeast North America. In: Pederson, J (Editor). Ballast Water Exchange: Exploring the Feasibility of Alternate Ballast Water Exchange Zones in the North Atlantic. Cambridge: Massachusetts Institute of Technology. pp. 53-63.
Hooper R and South GR. 1977. Additions to the benthic marine algal flora of Newfoundland III, with observations on species new to eastern Canada and North America. Naturaliste canada 104:383-394.
International Maritime Organization (IMO). 2004. International Convention for the Control and Management of Ships' Ballast Water and Sediments. http://www.imo.org/Conventions/Mainframe.asp?topic_id=867 (accessed March 2010).
National Invasive Species Council, Invasive Species Advisory Committee (ISAC). 2006. Invasive Species Definition Clarification

Rudnick D, Veldhuizen T, Tullis R, Culver C, Hieb K and Tsukimura B. 2005. A life history model for the San Francisco Estuary population of the Chinese mitten crab, *Eriochier sinensis* (Decapoda: Grapsoidea). Biological Invasions 7: 333-350.

Ruiz GM, Fofonoff P, Hines AH and Grosholz ED. 1999. Non-indigenous species as stressors in estuarine and marine communities: Assessing invasion impacts and interactions. Limnology and Oceanography 44(3): 950-972.

Ruiz GM, Fofonoff PW, Carlton JT, Wonham MJ and Hines AH. 2000a. Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases. Annual Review of Ecology and Systematics 31: 481-531.

Ruiz GM, Rawlings TK, Dobbs FC, Drake LA, Mullady T, Huq A and Colwell RR. 2000b. Global spread of microorganisms by ships. Nature 408: 49-50.

Ruiz GM, Fegley L, Fofonoff P, Cheng Y and Lemaitre R. 2006. First records of *Eriocheir sinensis* H Milne Edwards, 1853 (Crustacea: Brachyura: Varunidae) for Chesapeake Bay and the mid-Atlantic coast of North America. Aquatic Invasions 1(3): 137-142.

Scaffelke B and Hewitt CL. 2007. Impacts of introduced seaweeds. Botanica Marina 50:397-417.

Scheibling RE, Hennigar AW and Balch T. 1999. Destructive grazing, epiphytism, and disease: The dynamics of sea urchin–kelp interactions in Nova Scotia. Canadian Journal of Fisheries and Aquatic Sciences 56: 2300–2314

Schmidt AL and Scheibling RE. 2007. Effects of native and invasive algal canopies on composition and abundance of mobile benthic macrofauna and turf-forming algae. Journal of Experimental Marine Biology and Ecology 341: 110-130.

Schwaninger HR. 1999. Population structure of the widely dispersing marine bryozoan *Membranipora membranacea* (Cheilostomata): Implications for population history, biogeography, and taxonomy. Marine Biology 135: 411–423.

Smith RT. 1964. Keys to Marine Invertebrates of the Woods Hole Region: A Manual for the Identification of the More Common Marine Invertebrates. Woods Hole (MA): Woods Hole Oceanographic Institution, Marine Biological Laboratory.

Stachowicz JJ, Terwin JR, Whitlatch RB and Osman RW. 2002. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Sciences of the United States of America 99(24): 15497-15500.

Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA and Tegner MJ. 2002. Kelp forest ecosystems: Biodiversity, stability, resilience and future. Environmental Conservation 29(4): 436-459.

Stone SF and Lovell S. 2005. The economic impacts of aquatic invasive species: A review of the literature. United States Environmental Protection Agency, National Center for Environmental Economics. Working Paper #05-02. 66 pp.

Swan EF. 1956. Isopods of the genus *Ligia* on the New England coast. Ecology 37(1): 204-206.

Transport Canada. 2010. A Guide to Canada's Ballast Water Control and Management Regulations TP 13617 E. http://www.tc.gc.ca/eng/marinesafety/tp-tp13617-menu-2138.htm (accessed March 2010).

Trott TJ. 2004. Cobscook Bay Inventory: A historical checklist of marine invertebrates spanning 162 years. Northeastern Naturalist 11(2): 261-324.

Tyrrell MC and Byers JE. 2007. Do artificial substrates favor nonindigenous fouling species over native species? Journal of Experimental Marine Biology and Ecology 342: 54-60.

United States Coast Guard (USCG). 2009. Standards for living organisms in ship's ballast water discharged in U.S. waters. Federal Register 74(166): 44631-44672.

United States Environmental Protection Agency (US EPA). 2009. Vessel general permit for discharges incidental to the normal operation of vessels. 165 p. http://www.epa.gov/npdes/pubs/vessel_vgp_permit.pdf (accessed March 2010).

Valentine PC, Collie JS, Reid RN, Asch RG, Guida VG and Blackwood, D. 2007. The occurrence of the colonial ascidian *Didemnum* sp. on Georges Bank gravel habitat – ecological observations and potential effects on groundfish and scallop fisheries. Journal of Experimental Marine Biology and Ecology 342: 179-181.

Valentine PC, Carman MR, Dijkstra J and Blackwood DS. 2009. Larval recruitment of the invasive colonial ascidian *Didemnum vexillum*, seasonal water temperatures of New England coastal and offshore waters, and implications for spread of the species. Aquatic Invasions 4(1): 153-168.

Veilleux É and de Lafontaine Y. 2007. Biological synopsis of the Chinese mitten crab (*Eriocheir sinensis*). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2812. 53 pp.

Wasson K, Von Holle B, Toft J and Ruiz G. 2000. Detecting invasions of marine organisms: Kamptozoan case histories. Biological Invasions 2(1): 59-74.

Wethey DS. 2002. Biogeography, competition, and microclimate: The barnacle *Chthamalus fragilis* in New England. Integrative and Comparative Biology 42(2): 872-880.

Whitfield PE, Gardner T, Vives SP, Gilligan MR, Courtenay WR, Ray C and Hare J. 2002. Biological invasion of the Indo-Pacific lionfish *Pterois volitans* along the Atlantic coast of North America. Marine Ecology Progress Series 235: 289-297.

Whitfield PE, Hare JA, David AW, Harter SL, Munoz RC and Addison CM. 2007. Abundance estimates of the Indo-Pacific lionfish *Pterois volitans/miles* complex in the Western North Atlantic. Biological Invasions 9(1): 53-64.

Williams PJ, Floyd TA and Rossong MA. 2006. Agonistic interactions between invasive green crabs, *Carcinus maenas* (Linnaeus), and sub-adult American lobsters, *Homarus americanus* (Milne Edwards). 2006. Journal of Experimental Marine Biology and Ecology 329: 66-74.

Wood RD. 1962. *Codium* is carried to Cape Cod. Bulletin of the Torrey Botanical Club 89(3): 178-180.

SPECIES AT RISK

STATE OF THE GULF OF MAINE REPORT

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Gulf of Maine Council on the Marine Environment

Fisheries and Oceans Canada / Pêches et Océans Canada

This publication was made possible through the support of the Gulf of Maine Council on the Marine Environment and funding from Fisheries and Oceans Canada.

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.

Cover photo: Leatherback sea turtle (*Dermochelys coriacea*) by Kara Dodge/The Large Pelagics Research Center (NMFS Permit #1557-03)

Cover map (background): Courtesy of Census of Marine Life/Gulf of Maine Area Program

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especially complex as inherent biological traits render them susceptible to adverse changes in the environment (Table 1). A combination of traits—such as slow growth, long generation times, habitat and food specialization, low reproductive capacity, dependence on the timing of biological cues (e.g., breeding, migration, hibernation), low ability for dispersal, and susceptibility to human exploitation—all raise the risk of extinction (Foden and Cullen 2007).

Monitoring and assessment of endangered species, both nationally in the United States and Canada and internationally by the International Union for the Conservation of Nature (IUCN), is carried out using well-established criteria, procedures, and programs. Both federal governments and each of the provinces and states in the Gulf of Maine have official lists of endangered species based on legislation (Table 2). There is some variation among the lists of the federal governments, provinces and states, a reflection of different jurisdictions, priorities and perspectives within the region. From a coastal and marine perspective, there are four fish species, six cetaceans, five reptiles, and fifteen bird species that can be cited as being endangered or threatened in the Gulf of Maine (Table 3). Of these, four cetaceans and five reptiles are listed as endangered on the international IUCN Red List.

The outcomes of listing endangered species are varied and numerous in that apart from providing an indication of imbalances within the Gulf of Maine environment, there are many social, political, and economic repercussions on society for the way in which natural resources are managed and conserved, as well as the way that investment and development projects are planned and carried out (Linnell et al. 2010). The practice of legally listing species has led to better public understanding and awareness of the importance of species diversity and the need to ensure its protection.

There are numerous ongoing initiatives that are concerned with addressing species at risk within the Gulf of Maine. These range from linkages with international programs such as the United Nations (e.g., Convention on Biodiversity, Convention on the International Trade in Endangered Species, Ramsar Convention, Law of the Sea, etc.) and intergovernmental organization programs such as the IUCN (Red List program and Intergovernmental Platform on Biodiversity and Ecosystem Services) through to federal government (U.S. *Endangered Species Act*, Canadian *Species at Risk Act*), and state and provincial government programs (endangered species legislation). In addition, there are many non-governmental institutions that are involved in aspects of research, monitoring, education, awareness, advocacy, and general recovery-related activities. There is evidence to indicate that "species at risk" issues have become fairly well main-streamed into the management of natural resources throughout the Gulf of Maine.

cumulative impacts that organisms might experience in watershed and marine sea areas (see Figure 2). The factors considered in the analysis include fishing activity, shipping, offshore dump sites, population density, percentage of land in agriculture, and U.S. Environmental Protection Agency (EPA) Toxic Release Inventory. In general, watershed impacts are relatively low for the northerly Gulf of Maine watersheds, with Massachusetts having the highest watershed impacts. By contrast, there are few areas where there are low impacts from anthropogenic activities.

- **Inherent genetic traits** that increase the risk of extinction. Certain species possess biological characteristics that make them particularly susceptible to change, and when they occur in areas where environmental changes are most extreme, the threat of extinction increases (Vié et al.

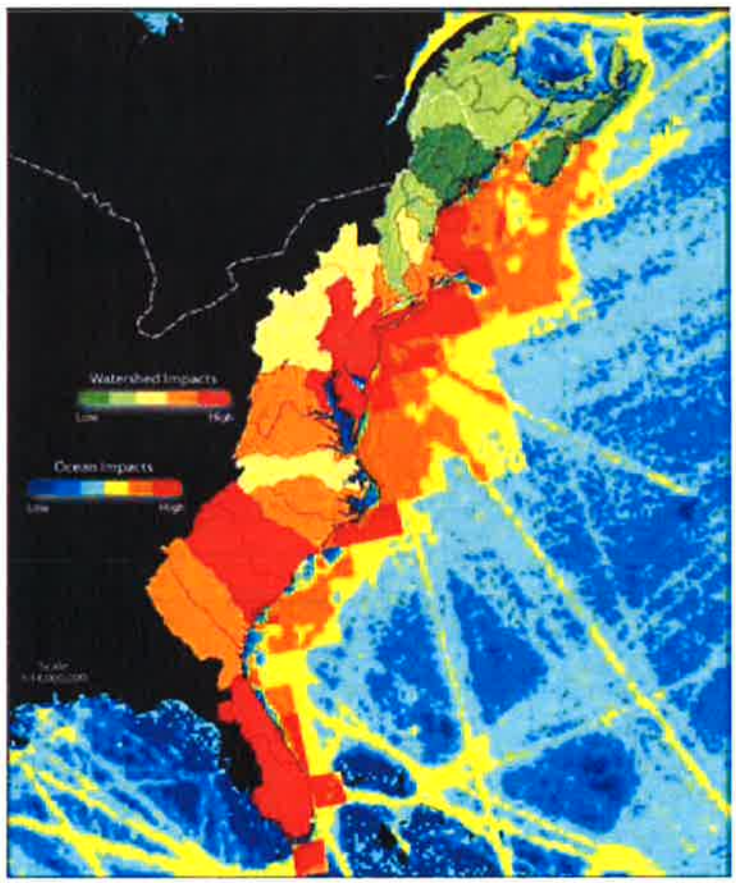


Figure 2: Map showing cumulative impacts of some select pressures for watersheds and adjacent ocean areas along the North American eastern seaboard. Area covers most of the spatial extent for resident and migrant species found in the Gulf of Maine. Pressures include fishing activity, shipping, offshore dump sites, population density, percentage of land in agriculture, and EPA Toxic Release Inventory (from Kraus and Rolland 2007).

3. Status and Trends

UNDERSTANDING OF THE TRENDS AND STATUS OF SPECIES AT RISK IS GREATLY enhanced when monitoring information is available for: 1) trends in abundance and distribution of selected species in a defined area; 2) numbers of endangered, threatened, and species of concern for the area; and 3) changes in the status of threatened species (CBD 2006; IUCN 2012).

The Gulf of Maine contains a diverse marine flora and fauna. The Gulf of Maine in Context (Thompson 2010) reports that there are:

- At least 3317 species of marine flora and fauna in the Gulf of Maine;
- More than 652 species of fish that have been documented living in, or migrating through, the area;
- 271 species of macrophytes;
- 1410 species of invertebrates;
- 3 marine turtles (although this report has identified 5—see Table 3);
- 32 species of marine mammals; and
- 184 species of marine birds.

Assessment of the status of endangered species has received considerable attention from international, federal, and state and provincial organizations, as well as academic and non-governmental institutions (see Thompson 2010; Parker 2012; Census of Marine Life 2012). Both federal governments, the provinces, and the states are continuously monitoring and updating the status of select species (Table 2; see COSEWIC 2012; U.S. Fish and Wildlife Service 2011; NMFS 2012). Assessment and listing in both Canada and the United States is based on criteria related to rarity, distribution, reproductive and population status, threats, specialization (as determined by unique habitat requirements), and vulnerability.

Box 1: Categories of Listed Species

- Extinct: a species that no longer exists.
- Extirpated: a species no longer existing in the wild
- Endangered: a species facing imminent extirpation or extinction throughout all or a significant portion of its range.
- Threatened: a species likely to become endangered within the foreseeable future.
- Special concern: a species that may become a threatened or an endangered species.
- Candidate species: a species where there is evidence to indicate that it requires assessment.

- *Labrador duck* (*Camptorhynchus labradorius*) where the last living individual was seen at Elmira, New York, in 1878 (Fuller 2001; see http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=9).
- *The sea mink* (*Mustela macrodon*) that was last captured at Campobello Island, New Brunswick, about 1894 (see http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=8).
- *Eelgrass limpet* (*Lottia alveus alveus)* that disappeared in the late 1920s (see http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=175).
- *The grey whale (Eschrichtius robustus)* that is extinct in the North Atlantic with no information as to when, or how, this status was reached (COSEWIC 2000).

ENDANGERED AND THREATENED SPECIES

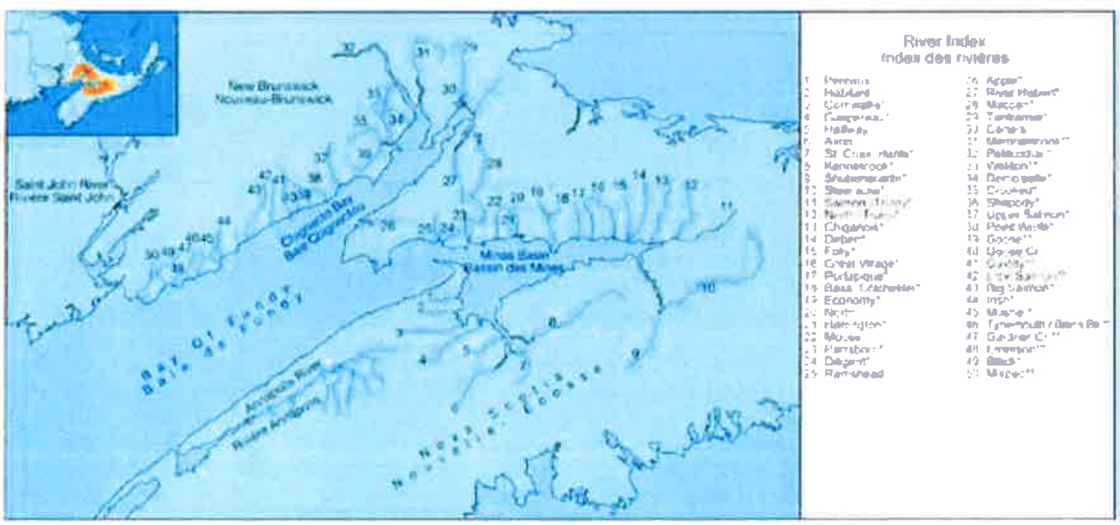
There are currently some 30 coastal and marine species that are relevant in the Gulf of Maine (see list in Table 3). This list does not include species that are considered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) to be in a state of endangerment but are not listed under Canada's *Species at Risk Act*, or species that are still undergoing assessment by the respective jurisdictions. The list indicates that not all of the jurisdictions have the same perspective on what species are at risk, despite most of these species having Gulf of Maine-wide distribution. It is also in part a reflection of the way in which jurisdictional responsibilities (marine and land) are separated between the respective federal, state, and provincial governments.

Fish

There are many species of fish that are considered to be at risk in the Atlantic area (Hutchings and Festa-Bianchet 2009; Walmsley 2011; Royal Society of Canada 2012). Anadramous species are particularly at risk largely because of their migratory requirement to move from an ocean environment into inland freshwater systems to breed. The Gulf of Maine fish species of concern include:

- The **shortnose sturgeon** (*Acipenser brevirostrum*), listed because of previous overharvesting in many estuaries and rivers along the U.S. seaboard from Florida extending north to New Brunswick. Pollution and river system habitat destruction (dams, weirs, bridge construction, etc.) are of major concern (NMFS 1998).
- The **Atlantic sturgeon** (*Acipenser oxyrinchus oxyrinchus*), with a large latitudinal range from the Gulf of Mexico to Labrador. Commercial fishing and pollution have reduced populations, as has river system habitat destruction (COSEWIC 2011).
- The **Atlantic salmon** *(Salmo salar),* not listed for the whole of the Gulf of Maine as populations in the Inner Bay of Fundy and Maine rivers are the focal areas of the endangered listing (see Figure 3). Populations

a)



b)

Figure 3: Rivers where Atlantic salmon populations have been declared endangered by a) the U.S. federal government and the State of Maine (T. Trinkc, NOAA) and b) the Canadian federal government for the inner Bay of Fundy designatable unit range (DFO 2010).

Table 4: Endangered cetacean species, Gulf of Maine, with best estimates of historic and current populations in the western North Atlantic. Estimates from National Oceanic and Atmospheric Administration marine mammal stock assessment reports (NMFS 2013).

SPECIES	HISTORIC POPULATIONS	CURRENT
North Atlantic right whale *(Eubalaena glacialis)*	At least 1000 in the Western North Atlantic during mid-1600s	396 in the western North Atlantic in July 2010
Fin whale *(Balaenoptera physalus)*	No estimate available	Western North Atlantic population of 3985 in 2007
Humpback whale *(Megaptera novaeangliae)*	12 000 in North Atlantic prior to whaling	Gulf of Maine stock estimated at 847 in August 2006
Blue Whale *(Balaenoptera musculus)*	1100–1500 in North Atlantic prior to whaling	At least 440 in the western North Atlantic in 2009
Sei Whale *(Balaenoptera borealis)*	No estimate available	386 for the Nova Scotia stock in 2004
Sperm Whale *(Physeter macrocephalus)*	>1 100 000 worldwide	4804 in the U.S. Atlantic in 2004

listing is breeding habitat disturbance leading to population declines (Birdlife International 2012). All of the listed bird species, with the exception of the piping plover ("near threatened"), are considered of "least concern" internationally by the IUCN.

Candidate Species

Both federal and state/provincial administrations in Canada and the United States have different processes by which species are continuously being monitored and assessed. These are listed as "candidate species" that require formal assessment because there is concern that their populations are decreasing and therefore need official assessment. In Canada, COSEWIC provides an annual prioritized list of candidate species that it uses to decide on the allocation of resources for status report production (see COSEWIC 2013; http://www.cosewic.gc.ca/eng/sct3/index_e.cfm). By contrast the United States responds to petitions from members of the public, or organizations, who wish to have a species assessed (see http://www.nmfs.noaa.gov/pr/listing). Because this listing is continuously changing, and cited candidate species are not always assessed, details and listings of these species are not given in this paper.

4. Impacts

THE IMPLICATIONS OF HAVING LEGALLY LISTED ENDANGERED SPECIES WITHIN any area are numerous in that the achievement of two main objectives has to be taken into account (IUCN 2012). Firstly, the objective of preventing an increase in the number of endangered species within the region, and secondly, ensuring that those which are already designated as being endangered receive the conservation attention (protection and recovery) that legislation demands. Linnell et al. (2010) highlight that there are many costs and conflicts that will arise in pursuing the mission of protecting species at risk. Some key potential areas of impact on society (not in any order of priority) include, amongst others:

POLITICAL

There is a potential for any endangered species to become a political issue at any of international, federal, and state/provincial levels, particularly where the species influences development, investment and trade. Signing of international agreements, promulgation of federal and state/provincial endangered species legislation, and official listing of species carry numerous implications that will affect societal support of policy and decisions on natural resource management and development. The obligation to have congressional and/or parliamentary reporting for budgetary and resource allocation purposes means that species at risk is an ongoing topic on many political agendas.

ADMINISTRATIVE AND LEGAL

Official government listing via legislation is associated with numerous legal and institutional obligations that apply to the protection of species, as well as associated law enforcement systems. An increase in the number of species at risk requires associated increases in professional and administrative personnel and resources to meet these obligations. In addition, an increase in litigation can be expected from parties involved in developing and utilizing natural resources, as well as parties opposed to the use of natural resources.

SOCIAL

There will be increasing concern and a need for dialogue within and between sectors that make use of resources in the Gulf of Maine area. Many of the species have great social value (e.g., cultural, scientific, recreational, sense of wellbeing, etc.). Worm et al. (2006) consider that each species has an ecological existence value that society places a sentimental value on (e.g., salmon and whales). Consequently, there will be an increased need for negotiation processes to achieve consensus on natural resource utilization when species at risk are involved.

5. Actions and Responses

OVER THE LAST 30 YEARS THERE HAS BEEN CONSIDERABLE PROGRESS MADE throughout the world in developing appropriate policies and practices for the preservation of biodiversity and endangered species. This is reflected by a multiplicity of actions by both the United States and Canada at international, federal, and state/provincial levels.

INTERNATIONAL TREATIES AND PROGRAMS

Numerous international agreements aimed at the protection and conservation of biodiversity (ecosystems, habitats and species) have been developed and accepted by most countries throughout the world. Although the United States and Canada are not signatories to all of them, some examples of the relevant treaties that apply to the Gulf of Maine include:

- The 1975 United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) that ensures that international trade in specimens of wild animals and plants does not threaten their survival. CITES provides guidelines and lists of endangered species to which signatory countries are obligated to respond.
- The 1971 Convention on Wetlands of International Importance (Ramsar) that provides a framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.
- The 1992 United Nations Convention on Biological Diversity (CBD) that deals with international conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of benefits arising from genetic resources.
- The 1982 United Nations Law of the Sea (UNCLOS) defines the rights and responsibilities of nations in their use of the world's oceans and provides guidelines for businesses, the environment, and the management of marine natural resources.
- The 1946 International Convention for the Regulation of Whaling (ICRW) that provides for the conservation of whale stocks and the orderly development of the whaling industry.
- The 1974 International Convention for the Safety of Life at Sea that protects the safety of marine ships in international waters, particularly spills of chemicals and oil.

Both the United States and Canada are members of the IUCN and participate in activities that relate to the Red List (IUCN 2012) and have indicated that they

Table 5: Legislation and institutions mandated to regulate and manage species at risk in the Gulf of Maine.

ORGANIZATION	RELEVANT LEGISLATION	COMMENT AND KEY LINKS
CANADA		
Environment Canada Fisheries and Oceans Canada (DFO) Parks Canada	The *Species at Risk Act* (2002) is coordinated by Environment Canada in collaboration with DFO and Parks Canada. DFO is responsible for aquatic species. *Fisheries Act* (1985) managed by Fisheries and Oceans Canada The *Oceans Act* (1997) managed by Fisheries and Oceans Canada	A species at risk public registry keeps a record of the status of all Canadian species at risk (http://www.registrelep-sararegistry.gc.ca). COSEWIC assesses and designates which wildlife species are in danger of disappearing from Canada (http://www.cosewic.gc.ca/eng/sct6/index_e.cfm). The Government of Canada has a Habitat Stewardship Program (HSP) for species at risk (http://www.ec.gc.ca/hsp-pih/default.asp?lang=En&n=59BF488F-1). Parks Canada has a species at risk program (http://www.pc.gc.ca/eng/nature/eep-sar/index.aspx). DFO has a regionally-based species at risk program for aquatic species (http://www.dfo-mpo.gc.ca/species-especes/search-location-recherche-endroit-eng.htm). DFO also administers the *Fisheries Act* and the *Oceans Act*, both of which have provisions for protection of species.
Nova Scotia Department of Natural Resources	Nova Scotia *Endangered Species Act* (1999)	Details of status reports and recovery action teams and plans for Nova Scotia are shown at. http://www.gov.ns.ca/natr/wildlife/biodiversity/species-recovery.asp
New Brunswick Department of Natural Resources	*Endangered Species Act*/proposed *Species at Risk Act*	http://www2.gnb.ca/content/gnb/en/departments/natural_resources/wildlife/content/SpeciesAtRisk.html The New Brunswick government has revised its legislation with the intention of promulgating a new act and listings in 2013. A species database is maintained for over 2300 species.
UNITED STATES		
U.S. Fish and Wildlife Service (FWS) National Marine Fisheries Service (NMFS)	*Endangered Species Act* (1973)	The FWS has primary responsibility for terrestrial and freshwater organisms (http://www.fws.gov/endangered/species/us-species.html). The NMFS is concerned mainly about marine wildlife (http://www.nmfs.noaa.gov/pr/).
Massachusetts Division of Fisheries and Wildlife	Massachusetts *Endangered Species Act* (2005)	The Natural Heritage and Endangered Species Program is involved with endangered species and maintains GIS shapefiles as well as a variety of site-specific information for use at town and area level. (http://www.mass.gov/dfwele/dfw/nhesp/species_info/species_home.htm).
New Hampshire Fish and Game Department	New Hampshire *Endangered Species Conservation Act* (1979)	The Nongame and Endangered Wildlife Program is involved in the protection of some 400 species including those that are listed (http://www.wildlife.state.nh.us/Wildlife/Nongame/endangered_list.htm).
Maine Department of Inland Fisheries and Wildlife Department of Agriculture, Conservation and Forestry	Maine *Endangered Species Act* (1975)	Species listed as endangered or threatened are protected under the Maine Endangered Species Act (http://www.maine.gov/ifw/wildlife/species/endangered_species/state_federal_list.htm). Maine Natural Areas Program maintains a list of protected and endangered plants (http://www.maine.gov/doc/nrimc/mnap/index.html).

6. Indicator Summary

INDICATOR	DPSIR ELEMENT	STATUS	TREND
Change in seawater temperatures due to climate change.	Pressure	Fair – General increases recorded to date have not resulted in status changes for species at risk.	Worsening – Monitoring shows a general increase over the region which is likely to lead to population declines in species with narrow temperature tolerances.
Cumulative impacts from human activities in the Gulf of Maine ocean areas.	Pressure	Poor – Much of the Gulf of Maine has been assessed as having high or near high impacts.	Unknown – No overall trend data: some human activities are increasing while the footprint of others is decreasing.
Cumulative impacts from human activities in the Gulf of Maine watershed.	Pressure	Fair – Most of the Gulf of Maine watershed has moderate to low watershed impacts.	Unknown – In general human activities appear to be increasing, but no trend data.
Inventory of species in the Gulf of Maine area	State	Fair – Good information on large organisms and waters above 200 metres.	Improving – Recent research has identified a number of species not previously known in the area.
Number of endangered and threatened species	State	Fair – 30 coastal or marine species are listed as threatened or endangered by one or more jurisdictions in the Gulf of Maine.	Worsening – Numbers will increase as more species are assessed and listed.
Number of delisted species	State	Poor – No species have achieved delisted status.	No trend – Delisting is dependent on the attainment of recovery plan population levels that require decades to achieve.
Ecosystem changes	Impacts	Unknown – most recovery plans have included mitigation measures to improve critical habitats of listed species. The overall impact of those mitigation measures on critical habitats is not yet known.	Unknown – While resource management changes have been implemented it is not clear what this means for the overall health of multiple habitats in Gulf of Maine.
Development of recovery plans	Response	Good – Most listed species have recovery plans as per legislation.	Improving – Gulf of Maine jurisdictions are publishing and implementing recovery and action plans for listed species.
Identification of critical habitat	Response	Poor – There are many species at risk where critical habitat has not yet been identified.	Improving – Gulf of Maine jurisdictions are achieving success in identifying and declaring critical habitats.

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

Data Confidence

- Monitoring of marine water temperature is carried out by numerous organizations.
- Gulf of Maine jurisdictions maintain a good record of species status, management measures related to each species, and recovery plans.

Data Gaps

- The number of factors influencing each species is enormous and the interactions between them make it difficult to understand those most responsible for influencing population numbers of particular species.
- Cumulative impacts may present a good general picture of pressures in the area but do not work well for species for which there is a specific threat.
- Information on population size is generally poor because of migratory nature of species, the different jurisdictions involved, and lack of resources to monitor populations.
- Deep waters of the Gulf of Maine have not been fully explored and may identify species new to the region. Throughout the region, there are many microorganisms not yet discovered or identified.

NOAA (National Oceanic and Atmospheric Administration). 2013. North Atlantic Right Whales. http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale_northatlantic.htm

Nye J. 2010. Climate change and its effects on ecosystems, habitats and biota. State of the Gulf of Maine Report. 20 pp. http://www.gulfofmaine.org/2/resources/state-of-the-gulf-of-maine-report/climate-change.

Parker M, Wells P and Walmsley D. 2007. Developing a Gulf of Maine ecosystem overview report: A scoping exercise to identify key review literature and considerations for report production. A report to Oceans and Coastal Management Division, Fisheries and Oceans Canada. 43 pp.

Parker M. 2012. Offshore ecosystems and habitats. State of the Gulf of Maine Report. 41 pp. http://www.gulfofmaine.org/2/resources/state-of-the-gulf-of-maine-report/aquatic-habitats

Royal Society of Canada. 2012. Sustaining Canada's marine biodiversity: Responding to the challenges posed by climate change, fisheries, and aquaculture. An expert panel report. Royal Society of Canada. 316 pp. http://rsc-src.ca/documents/RSCMarineBiodiversity2012_ENFINAL.pdf

SCBD (Secretariat of the Convention on Biological Diversity). 2006. Global biodiversity outlook 2. Montreal: Secretariat of the Convention on Biological Diversity. vii + 81 pp.

Seebacher F and Franklin CE. 2012. Determining environmental causes of biological effects: The need for a mechanistic physiological dimension in conservation biology. Philosophical Transactions of the Royal Society B 367: 1607-1614.

Scott WB and Scott MG. 1988. Atlantic fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 219. 731 pp.

Suckling K. 2006. Measuring the success of the Endangered Species Act: Recovery trends in the Northeastern United States. A report by the Center for Biological Diversity, Tucson, Arizona. 125 pp.

Thompson C. 2010. The Gulf of Maine in context. State of the Gulf of Maine Report. 58 pp. http://www.gulfofmaine.org/2/resources/state-of-the-gulf-of-maine-report

Troy A. 2012. Valuing Maine's natural capital. Manomet, MA: Manomet Center for Conservation Sciences. 74 pp. http://www.manomet.org/sites/manomet.org/files/reports/Troy_2012_Value_of_Maine.pdf

U.S. Fish and Wildlife Service. 2011. Listing a species as threatened or endangered: Section 4 of the Endangered Species Act. Fact Sheet. 2 pp. http://www.fws.gov/endangered/esa-library/index.html#listing.

Vié JC, Hilton-Taylor C, Pollock CM, Ragle J, Smart J, Stuart SN and Tong R. 2009. The IUCN Red List: A key conservation tool. In: J-C Vié, C Hilton-Taylor and SN Stuart (eds), Wildlife in a changing world. An analysis of the 2008 IUCN Red List of threatened species. Gland, Switzerland: IUCN. pp 1–13.

Walmsley D. 2010. Climate change and its effects on humans. State of the Gulf of Maine Report. 16 pp. http://www.gulfofmaine.org/2/resources/state-of-the-gulf-of-maine-report/climate-change

Walmsley D. 2011. Species at Risk. State of the Scotian Shelf Report. http://coinatlantic.ca/index.php/state-of-coast-and-ocean/state-of-the-scotian-shelf. 24 pp.

Wells P. 2010. Emerging issues – circa 2010. State of the Gulf of Maine Report. 22 pp. http://www.gulfofmaine.org/2/resources/state-of-the-gulf-of-maine-report/emerging-issues

Wilkinson T, Wiken E, Bezaury-Creel J, Hourigan T, Agardy T, Herrmann H, Janishevski L, Madden C, Morgan L and Padilla M. 2009. Marine Ecoregions of North America. Montreal: Commission for Environmental Cooperation. 200 pp.

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, et al. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314 (5800): 787–790.

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EMERGING ISSUES – *CIRCA* 2010

STATE OF THE GULF OF MAINE REPORT

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Gulf of Maine Council on the Marine Environment

Fisheries and Oceans Canada | Pêches et Océans Canada

This publication was made possible through the support of the Gulf of Maine Council on the Marine Environment and a grant from Fisheries and Oceans Canada.

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.

Cover photo by Steven Erat

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Table 1: Recognised marine and coastal environmental issues in the Gulf of Maine and related emerging issues.

	KNOWN IMPACTS	EMERGING ISSUES
Aquaculture (see also Aquaculture in the Gulf of Maine)	• Pesticide and pharmaceutical use • Organic discharge • Parasitic infections and introductions • Impact of escapees on native stocks • Loss of marine space to other users	• Long-term, sub-lethal effects of the chemicals combinations (e.g., endocrine disrupting chemicals) (see also Section 3.4) • Offshore finfish aquaculture
Commercial Fisheries (see also Commercial Fisheries and Fish Stock Status)	• Overfishing of target species • Destruction of habitat by fishing gear • Entanglement of marine mammals • Bycatch • Change in pelagic trophic structure • New pathogens, with unknown human health and ecological health consequences	• Fishing "down" the food chain – impact of increased invertebrate fisheries • Emerging fisheries • Sustainable fisheries • Ecosystem–based fisheries management (see also Section 4.4)
Petroleum Exploration and Development (including transportation and LNG terminals)	• Habitat degradation and loss • Contamination of living resources • Vessel collisions with right whales	• Large increase in marine traffic • Impact of a large spill in the Gulf of Maine (particularly on shallow banks) • Exploration of Georges Bank (see also Section 3.3)
Mining (minerals and aggregates)	• Habitat destruction and degradation • Contamination of rivers, lakes, wetlands and estuaries • Degradation of beaches • Decreased water and sediment quality	• Offshore exploration and mining (see also Section 2.3)
Coastal Development and Land Use (see also Coastal Development and Land Use)	• Degradation and destruction of coastal habitats • Loss of species diversity • Decreased water quality • Decreased air quality • Loss of public access to resources	• The effect of coastal development combined with climate change and sea level rise • Changes in demographic patterns
Habitat Change (see Coastal Ecosystems and Habitats; Marine Ecosystems and Habitats)	• Degradation and loss of habitats including: eelgrass beds, salt marshes, riparian habitat, beaches, mud flats, etc. • Loss of biodiversity	• The effect of coastal development combined with climate change and sea level rise • Preservation of man-made habitats of cultural and economic significance (e.g., Acadian dyke-lands) • Increased network of protected areas • Increased protection of species at risk (see also Section 3.2)
Invasive Species (see Invasive Species)	• Loss of biodiversity • Widespread degradation of habitats • Economic and aesthetic impacts	• Introduction of new species, with unknown ecological and economic consequences
Industrial Chemicals and Effluents (see also Toxic Contaminants)	• Decreased water and sediment quality • Acute toxicity leading to mortality of organisms • Chronic sub-lethal effects on organisms • Bioaccumulation of toxic chemicals	• New synthetic chemicals • Cumulative sub-lethal effects (see also Section 3.4)
Eutrophication (see Eutrophication)	• Oxygen depletion in fresh and marine waters • Aesthetic impacts • Decreased recreational value • Health risks due to toxic algal blooms	• Interaction of increased nutrients and increased algal blooms with warming waters due to climate change
Microbial Pathogens (see Microbial Pathogens and Toxins)	• Human health impacts • Closure of bathing beaches • Shellfish closures • Uptake in the food chain	• New pathogens, with unknown human health and ecological health consequences

various locations around the Gulf of Maine, from near Cape Cod shorelines to the Cobequid Hills of Nova Scotia. Wind turbines located on land, and on artificial islands, such as those for the southern Gulf (e.g., the Cape Cod Bay wind field) may affect migratory land and shore birds, pelagic seabirds, bats, shipping movements and people (aesthetics, real estate prices and tourism). Large wind turbine farms are being planned for high elevations in several locations in coastal Nova Scotia. Potential impacts on both ecosystem and human health from wind installations, on land or at sea, are still being hypothesized or are under investigation.

2.3 Marine Mining

The Gulf of Maine has considerable mineral resources (besides oil and gas) including for example: mineral aggregates on the seafloor of the mid to upper Bay of Fundy; trace rare elements in sediment deposits in the Shubenacadie Estuary, Minas Basin, NS; and vast quantities of gypsum and basalt in the coastal lands in south-western Nova Scotia. For the time being, the only new land mining operation to be permitted is the new surface gypsum deposit at Hantsport, NS.

The ecological consequences of mineral extraction, especially from the bottom sediments in mid Bay of Fundy and specific river estuaries, are a potential concern. If new minerals were to be mined from the ocean floor, the concern would be the magnitude of the ecological impacts of surface aggregate removal on the benthic habitats and benthic species. Unique horse mussel reefs might be disturbed or destroyed, and removal of surface consolidated rocks and stones may lead to winnowing of the exposed softer sediments. A similar threat exists for the Shubenacadie Estuary, NS, where disturbance of the sediments by mining and resulting degraded water quality could be detrimental to the migration and survival of local fish such as shad, gaspereau, smelt and salmon, with salmon being a listed species at risk under the Canadian Species at Risk Act.

2.4 Climate Change

Implications of climate change in the Gulf region have been considered for some years (G Lines, Environment Canada, pers. comm., 2009). It has also been reviewed by other local groups (e.g., Frumhoff et al. 2007; Pederson 2009). It is now one of the priority issues for the region, with two theme papers being prepared on it as part of the State of the Gulf of Maine Report (see Climate Change). Concerns exist about sea level rise, coastal erosion, more frequent strong storms, impacts on species distributions, including exotic or invasive species, potential effects on coastal infrastructure, etc., for coastal areas, and for the Gulf's watersheds, changes in hydrodynamics of the watersheds, effects on migratory species such as anadromous and catadromous fish, and movement of pollutants into and through watersheds. As well, there could be changes in the pattern of incoming ocean currents, freshwater runoff, acidification and nutrient distributions, all potentially affecting one or more of the fisheries, coastal develop-species and its pelagic ecosystem is the east coast cod (*Gadus morhua*) and the north-west Atlantic; fish stocks on the Grand Banks, once considered inexhaustible, have not recovered from collapse caused primarily from over-fishing.

An example of incremental or cumulative change due to human activity in the Gulf ecosystem over the past 100-150 years is change caused by the construction of dams on rivers, and causeways and other barriers on estuaries, throughout the Gulf of Maine watersheds (Wells 1999, 2000; Percy and Harvey 2000). Dams and causeways, collectively called barriers, have had direct and indirect effects on the movement of fish upstream and downstream in waterways, with effects of their populations (e.g., middle Bay of Fundy salmon, and eels), as well as many other effects (e.g., changed sedimentation patterns, hydrologies and water quality). Dam and causeway impacts remain throughout the Gulf as a system-wide threat to the health of estuaries and rivers, and need to be continually addressed and mitigated, as at Cheverie Creek, NS, and several restored rivers in Maine and Massachusetts.

Another example is the incremental effect of clear-cutting forests over the past 200+ years. The effects on watersheds include changed water quality, with detrimental effects on salmonids and other migratory fish. Although now more controlled in the New England states, this method of forest harvesting still occurs in New Brunswick and Nova Scotia, with bare recognition or control of the side effects on aquatic ecosystems and the whole landscape. A need exists to inventory and document such region-wide changes, consider their interactions and impacts, and implement strategies to combat them. In the past, economies have taken precedence over ecologies, often with large-scale effects on the Gulf's ecosystems as a whole; the challenge is to find a better balance.

The Gulf of Maine offshore ecosystem is not stationary; it changes naturally over time (J Hare, RARGOM 2009). Changes in the Gulf may be of three kinds: incremental and slow; disruptive and faster; and transformative, involving changes in the structure of relationships across scales (Gunderson and Holling 2001; Holling 2001; Holling, as cited in Ross 2010). Some of these changes are related to basin-scale, upstream forcing events involving Labrador Current and Gulf Stream systems, which will affect lower trophic levels in particular (J Hare, RARGOM 2009). In the Gulf of Maine intertidal biota, the spring blooms of phytoplankton, the nepheloid layer (bottom water with high levels of sediment), the nutrient regime, and biodiversity in general, have changing patterns, and are all currently under study to detect and interpret unusual variation if and when it occurs (RARGOM 2009). A key recent observation is that the nepheloid layer moves algal cysts around the Gulf, influencing locations of toxic algal bloom breakouts (C Pilskain and B Keafer, RARGOM 2009), a clear linkage of current science to a major health and economic concern. The Gulf of Maine Research Institute protect biodiversity that is incompletely known, and how this incomplete knowledge affects our ability to apply ecosystem approaches to environmental and fisheries management; i.e., how do agencies apply EBM for an incompletely known and continually changing ecosystem? Mechanisms are also needed to ensure that research, description, and inventory of biodiversity are continued with maximum support and expertise.

Impacts of Gulf of Maine fishing practices on ocean habitats and biodiversity, including non-target species, need to be understood and ameliorated. Together with climate change, fishing is recognized as a major driver of ecosystem change on the oceans (Cohen and Langton 1992; GMRI 2009; Worm et al. 2009). Society needs to reduce this 400 year-long pressure on the biodiversity of the Gulf. The region is well situated with its marine institutes to study this stressor and make recommendations for reducing impacts (e.g., GMRI in Portland, ME).

Another emerging area of biodiversity research addresses the social and institutional dynamics of endangered species protection and recovery. In Canada, it is too early to note the social and ecological impacts of new legislation (i.e., the Species at Risk Act). One can anticipate substantial links with existing work on the following: survival of coastal communities; the sustainability of fisheries systems including human as well as marine populations; the inter-generational tradeoffs involved in protecting species or regions on which existing communities depend for their livelihoods; and the growing body of work applying the precautionary principle to coastal issues (OMRN 2003). Two other biodiversity research areas are priorities:

- Related to fisheries, a need exists to better understand intra-specific biodiversity, a formerly ignored characteristic of exploited populations (Stephenson and Kenchington 2000).
- Related to the deeper parts of the Gulf of Maine, the deep sea biodiversity of the Gulf is not well understood, especially species associated with hard corals in the deep canyons and abyssal areas.

3.3 Hydrocarbons (Transport and New Sources)

General shipping and the bulk carriage of hydrocarbons in tankers, including crude oil, refined products and liquefied natural gas (LNG), occurs in the Gulf (see The Gulf of Maine in Context). This presents ecological risks due to operational or accidental discharges and spills (e.g., loss of the Irving barge *Shovel Master* in November 2008 off south-western Nova Scotia), accidental explosions, and ship strikes on marine mammals. The shipping lanes into the Bay of Fundy have been changed recently by the International Maritime Organization (IMO) in response to concerns about ship strikes on right whales during the summer and early fall. An emerging issue is the capacity of the outer Bay of Fundy to withstand the impacts of LNG tanker traffic, should ships be allowed to transit Head Harbor Passage en route to coastal Maine. The impact of increased shipping traffic overall

(DDT), DDT residues, and organotins, decades after banning their use. Mercury, from automobiles and industrial sources such as coal-fired electrical generating power plants, has accumulated in pelagic food chains and its risk (levels of exposure, potential toxic effects) to biota is being investigated (GCH Harding, Bedford Institute of Oceanography, pers. comm., 2010). Many persistent and bioaccumulative industrial chemicals in the Gulf's ecosystem are likely not yet characterized for risks to biota and human health (Shaw et al. 2006, 2007, 2008; Gulfwatch Committee, pers. comm., 2010), as they are being found elsewhere. These would include nanomaterials, plasticizers (phthalates), toxaphenes, alkylated phenols, polybrominated diphenyl ethers (PBDEs), silicon-based compounds, and other POPs. Concerns about endocrine disrupting chemicals (EDCs), such as pharmaceuticals, estrogens and personal care products, are recent and evidence of their discharge exists from analyses of raw and treated sewage. There is a need to ensure that sufficient monitoring across key species and food chains occurs for these substances, and that additional marine environmental quality guidelines are established in both countries to interpret the risks of detected levels, for both ecosystem and human health.

A long-term issue for the Gulf, and a theme running throughout the GOMC action plans, has been reducing the impact of land-based activities on coastal organisms and ecosystems. In this context, there are concerns of the ecological risks associated with new chemicals primarily originating from point sources (industrial, home, municipal) and non-point sources on land (agricultural lands, managed forests). Emerging chemicals would include those listed above, as well as atrazine (a common herbicide), bisphenyl a (a widely used component of plastics), dioxin like compounds, non-ionic organics, triclosam (an antimicrobial agent), and the myriad of trace chemicals found in municipal sewage effluents.

Estuarine and near-shore waters are a dynamic chemical soup of very low (ng/l or µg/l) levels of hundreds of synthetic chemicals, from households, industries, and municipal sources. There is generally little knowledge about their fate, bioavailability and toxic effects, direct (lethal and sublethal), indirect (sublethal), and interactive. There is a special need to characterize the risks to biota in the heavily populated coastal areas of Boston, Portland and Saint John, and around the prolific salmon aquaculture sites of southwestern New Brunswick and northern Maine (Haya et al. 2001; Hargrave 2005; Halwell 2008).

Environmental problems associated with industrial chemical and effluent discharges have been studied and acted upon from a regulatory perspective for almost 50 years, involving government and industry in both the US (under the National Pollutant Discharge Elimination System) and Canada (under the Fisheries Act and the Canadian Environmental Protection Act, amongst others). However, chemicals still enter watersheds from many upstream industrial operations (e.g., pulp mills, forestry operations with pesticides, and municipalities). Along the coast, sewage effluents enter the Gulf from several hundred sewage together, or sequentially, in the same location. Stressors often function at low levels, acting with different modes of action, at different spatial and temporal scales, on different structural and functional components of the exposed ecosystems. Cumulative change or effects in coastal watersheds and waters are difficult to observe or measure, either spatially or temporally, without large, long-term, multiple variable/stressor databases. Exceptions are the cumulative impacts of coastal development (measured by photography or mapping surveys over decades), shellfish bed closures (monitored annually for decades), and reductions in certain species (e.g., mid-bay population of Atlantic salmon in the Bay of Fundy). Generally cumulative change/impacts are subtle, not visible (in the Gulf of Maine itself) and require sensitive, continuous measurement.

Two examples illustrate the complexity but urgency of addressing this issue:

- Continued massive coastal development (building suburbs, paving, infilling, restructuring water courses, etc) - According to the Massachusetts Ocean Management Task Force (2004), some of the future developments that may contribute to cumulative impacts in Massachusetts waters in the future are: "energy facility development; desalination plants; sound pollution; increasing shellfish aquaculture and fish farm development; and continued construction of docks, piers and floating hotels".
- Effects of single sector fisheries - In Canadian waters, one of the key challenges of integrated ocean management is assessing the cumulative impacts of fisheries on the Gulf's ecosystems (F. Scattalon, RARGOM 2009), the limitations being the scale of effects and availability of related data.

Both examples illustrate the daunting task of being able to detect, control and reduce cumulative effects in Gulf's waters. There is a need to instruct managers and policy makers on the dimensions and complexity of measuring the effects of multiple stressors and a need for improved methodologies and data for conducting cumulative impact assessments (GOMC 2004).

The importance of this issue is reflected in how effective the institutional and operational arrangements are in the Gulf of Maine for responding to environmental crises. The US and Canada are well organized federally to counter oil spills, and cooperate across the border on monitoring certain threats (e.g., harmful algal blooms), but the situation is uncertain for other threats. This is important in the context of some of the emerging issues discussed in this paper (e.g., new LNG terminals and tankers, chemical tankers, bulk carriers, fish diseases, and aquaculture impacts).

4.3 Practicing Integrated Coastal and Ocean Management

Although coastal and ocean management is clearly a priority for Gulf of Maine managers (GOMC 2004), there is, as yet, no comprehensive ICOM framework for environmental and resource management in the Gulf of Maine. A framework could ensure that: ecosystem-based management moves forward in a coordinated fashion, with clear goals, objectives and measurable outcomes; that Gulf science be effectively linked to its policy and management, and that addressing issues such as land use and other land-based activities are operationally linked to maintaining the health of estuaries and coastal waters.

Interaction between the GOMC and the Regional Association for Research on the Gulf of Maine (RARGOM) has led to several key science-policy workshops (e.g., RARGOM 1997, 2009; Wallace and Braasch 1997). Such workshops assist in opening up "a more effective process for communicating information needs from policy makers to scientists, and for translating research results into a form that can be used to create effective coastal policy" (NRC 1995). For the Gulf, this mechanism could be institutionalized as a way of tracking progress on ICOM and charting future courses of action.

Marine access and marine spatial planning are also frontline emerging issues. Conflicts regarding marine space have already occurred. For example, there is open water fish aquaculture development along the New Brunswick (Grand Manan Island) and Maine coastlines, with concerns of impacts on local fisheries and ship movements. The mapping of coastal areas needs to be continued for formal allocation of uses. Various jurisdictions are currently investigating marine spatial planning as a tool for managing ocean space (e.g., Fisheries and Oceans Canada, DFO, National Oceanic and Atmospheric Administration, NOAA, and the State of Massachusetts). Under the Massachusetts Oceans Act, the Massachusetts Ocean Management Plan has been developed and was promulgated on December 31, 2009 (see http://www.mass.gov).

geographic and seasonal information on predator-prey relationships". In support of EBFM, seabed mapping is a useful tool for "a greater understanding of spatially and temporally explicit ecosystem components, processes and services. A habitat classification scheme, covering water column and bottom, would aid the process of developing a functional equivalency of habitats for fished and non-fished areas" (Noji et al. 2006). A guiding EBFM framework could help set priorities and integrate research, habitat classification and mapping activities.

A revitalized approach to EBFM in the Gulf is needed (S McGee, RARGOM 2009), including "adequate monitoring across fisheries, flexible management plans, improved inter-jurisdictional coordination, and resource sharing". Given the historic impact of fisheries on the Gulf's marine ecosystems (biomass removal, ecosystem change, effects of gear, ship-related pollution), communication and operational collaboration between practitioners of EBFM with those of EBM, ICOM and marine protected areas (MPAs) should occur. Only in this way will there be assurance of sustained abundance, resilience and diversity of the Gulf's fisheries and non-fisheries species in intact ecosystems (M Fogarty, RARGOM 2009), albeit greatly changed ones.

4.5 Promoting Protected Areas in the Gulf

There are many protected coastal areas around the Gulf, from the Cape Cod National Seashore and Stellwagen Bank National Marine Sanctuary off Massachusetts, to the coastal reserves and parks of coastal Maine, to the Fundy National Park and the provincial parks of both Canadian provinces (e.g., Five Islands Provincial Park, NS; New River Beach Provincial Park, NB). There are also national and international wildlife reserves in the upper Bay of Fundy. Some of the protected areas are official MPAs under the Oceans Act (Canada), such as Musquash Marsh, near Saint John, NB. Some are simply designations, without legal protection, such as the Fundy Biosphere Reserve centred on Chignecto and Shepody Bays, and the Right Whale Sanctuary at the mouth of the Bay of Fundy. Coastal protected areas have been shown to work in many locations, protecting fish populations and specific ecosystems such as coral reefs. Protected areas should include representative and critical benthic habitats, supported by GIS and ocean mapping tools and services (Lubchenco et al. 2003; Noji et al. 2006), as well as fish closure areas, covering critical habitat for growth and reproduction (Noji et al. 2006).
In the Gulf, there is currently an uncoordinated patchwork of the various areas, established with specific objectives (e.g., protection of mudflats and salt marshes, and protection of migratory shorebirds, whales, and islands, etc.). The emerging issue is the need to officially create a network of protected areas. A network would make it possible to determine if the areas collectively are offering sufficient protection of critical habitats, species at risk, and resource species across the Gulf, and if and where other areas are needed. An outstanding question to address is whether migration corridors of various species are being adequately protected by such a network, as many species move in and out of the Gulf seasonally (e.g., fish, turtles, birds, mammals). As well, critical habitats for reproduction, nursing, feeding and

5. References

Anonymous. 2007. Six years in the mud. Restoring maritime salt marshes: lessons learned and moving forward. Feb. 1-2, 2007. Bedford Institute of Oceanography, NS. 5 pp.

Backus RH and Bourne DW. (Eds.). 1987. Georges Bank. The MIT Press, Cambridge, MA. 593p.

Burridge LE, Haya K, Waddy SL and Wade J. 2000a. The lethality of anti-sea lice formulations Salmosan (Azamethiphos) and Excis (Cypermethrin) to sate IV and adult lobsters (*Homarus americanus*) during repeated short-term exposures. Aquaculture 182: 27-35.

Bur ridge LE, Haya K, Page FH, Waddy SL, Zitko V and Wade J. 2000b. The lethality of the cypermethrin formulation Excis to larval and post-larval stages of the American lobster (*Homarus americanus*). Aquaculture 182: 37-47.

Canfield C. 2010. Fish cannery packs it in. The Nova Scotian, Halifax, NS, Sunday, April 25th, 2010. pp. 8-9.

Chase ME, Jones SH, Hennigar P, Sowles J, Harding GCH, Freeman K, Wells PG, Krahforst C, Coombs K, Crawford R, Pederson J and Taylor D. 2001. Gulfwatch: Monitoring spatial and temporal patterns of trace metal and organic contaminants in the Gulf of Maine (1991-1997) with the blue mussel, *Mytilus edulis*. Mar. Pollut. Bull. 42(6): 491-505.

Cohen EB and Langton RW. 1992. The ecological consequences of fishing in the Gulf of Maine. In: DW Townsend and PF Larsen, The Gulf of Maine. Proceedings of a Seminar held May 22, 1989, Washington, DC. NOAA Coastal Ocean Program, Regional Synthesis Series Number 1: 45-69.

Communication Partnership for Science and the Sea (COMPASS). 2007. A Policy Relevant Science Vision for EBM in the Gulf of Maine. Internal Document, GOMC. AA Rosenberg, Ed. May 2007. 39 pp.

Conservation Council of New Brunswick (CCNB). 2002. Two Hundred Years of Ecosystem and Food Web Changes in the Quoddy Region, Outer Bay of Fundy. Tech. Rept., CCNB. H Lotze and I Milewski, authors.

Cordes RE, MacDonald BH and Wells PG. 2006. Publications of the Gulf of Maine Council on the Marine Environment and Their Use. Report to GOMC, June 2006. http://www.gulfofmaine.org (accessed March 2010).

Courtney Fand Wiggin J. 2003. Ocean Zoning for the Gulf of Maine: A Background Paper. GOMC and NOAA (MPA Center). Jan. 2003. 32+ pp.

Di Giulio RT and Monosson E (Eds). 1996. Interconnections Between Human and Ecosystem Health. Ecotoxicology Series 3. Chapman and Hall, London. 275 pp.

Epstein PR, Sherman B, Spanger-Siegfried E, Langston A, Prasad S, et al. 1998. Marine Ecosystems : Emerging Diseases as Indicators of Change. Harvard Medical School, Cambridge, MA. 85 pp.

Foley, J. 2010. Boundaries for a healthy planet. Sci. Amer. 302(4): 54-57.

Francis, G. 2010. The hardcore guide to resilience. Alternatives Journal 36(2): 13-15.

Frumhoff PC, McCarthy JJ, Melillo JM, Moser SC and Wuebbles DJ. 2007. Confronting climate change in the US Northeast : science, impacts and solutions. Union of Concerned Scientists, Cambridge, MA.

Garrett, C. 1992. Oceanographic and modeling considerations in marine environmental protection. Mar. Pollut. Bull. 25(1-4): 41-44.

Gulf of Maine Area (GOMA). 2008. GOMA Census of Marine Life. Synthesis Plan, May 2008. http://www.coml.org/projects/gulf-maine-program-goma (accessed April 2010). 12 pp.

Gulf of Maine Council on the Marine Environment (GOMC). 1991. The Gulf of Maine Action Plan. 1991-2000. GOMC, 34 pp.

Gulf of Maine Council on the Marine Environment (GOMC). 2001. The Gulf of Maine Action Plan. 2001-2006. GOMC, 2001.

Gulf of Maine Council on the Marine Environment (GOMC). 2004. A Survey of Coastal Managers Science and Technology Needs Prompts a Retrospective Look at Science-based Management in the Gulf of Maine. GOMC, August 2004. Internal document prepared by M Ernst, NOAA, NOS. 12 pp.

Gulf of Maine Council on the Marine Environment (GOMC). 2007. Action Plan. 2007-2012. http://www.gulfofmaine.org (accessed December 2009).

Gulf of Maine Research Institute. (GMRI). 2009. Two marine research institutes named to regional marine partnership. http://www.gmri.org/ (accessed March 2010).

Gunderson L and Holling CS. 2001. Panarchy; Understanding Transformations in Systems of Humans and Nature. Island Press, Washington, DC, USA.

Halwell B. 2008. Farming Fish for the Future. Worldwatch Report 176. The Worldwatch Institute, Washington, DC. 48 pp.

Hargrave BT (Ed.). 2005. Environmental Effects of Marine Finfish Aquaculture. Springer-Verlag, Berlin, Heildelberg. 494 pp.

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofmann EE, Lipp EK, Osterhaus ADME, Overstreet RM, Porter JW, Smith GW and Vasta GR. 1999. Emerging marine diseases – climate links and anthropogenic factors. Science 285 (No. 5433): 1505-1510.

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS and Samuel MD. 2002. Review: Ecology. Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158-2162.

Haya K, Burridge LE and Chang BD. 2001. Environmental impact of chemical wastes produced by the salmon aquaculture industry. ICES Journal of Marine Science 58 (2): 492.

and Management in Decisions Affecting the Environmental Quality of the Gulf of Maine. Workshop, Migis Lodge, Sebago Lake, ME. June 2-3, 1997. 5 pp.

Regional Association for Research on the Gulf of Maine (RARGOM). 2009. Proceedings of the Gulf of Maine Ecosystem Science Conference, October 4-9th, 2009, St Andrews, NB. In prep.

Ross N. 2010. Calling Buzz Holling. Alternatives Journal 36(2): 8-11.

Shaw SD, Berger ML, Brenner D, Fang F, Hong C-S, Storm R and O'Keefe P. (2006). Polybrominated diphenyl ethers (PBDEs) in harbor seals (*Phoca vitulina concolor*) from the northwestern Atlantic. Organohalogen Compounds 68: 600-603.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Addink R and Hilker D. (2008). Bioaccumulation of polybrominated diphenyl ethers in harbor seals from the northwest Atlantic. Chemosphere 73: 1773-1780.

Shaw SD, Brenner D, Berger ML, Fang F, Hong C-S, Storm R, Hilker D and O'Keefe P. (2007). Polybrominated diphenyl ethers (PBDEs) in harbor seals from the northwestern Atlantic. Are seals debrominating DecaBDE? Organohalogen Compounds 69: 829-832.

Stephenson R and Kenchington E. 2000. Conserving fish stock structure is a critical aspect of preserving biodiversity. Defining the role of ICES in supporting biodiversity conservation. ICES, CM 2000/Mini: 07. 7 pp.

Toms EG. 2007. Description of the Fundy Information Collaboratory. In: G Pohle et al. (Eds), Challenges in Environmental Management in the Bay of Fundy-Gulf of Maine, October 25- 27, 2006. Fairmont Algonquin Hotel, St Andrews, NB, 7th BoFEP Bay of Fundy Science Workshop Proceedings, BoFEP Technical Report No. 3, Wolfville, NS.

Wallace G and Braasch E (Eds). 1997. Proceedings of the Gulf of Maine Ecosystem Dynamics: A Scientific Workshop and Symposium, St Andrews, NB. RARGOM Rept: 97-1.

Wells PG. 1999. Environmental Impacts of Barriers on Rivers Entering the Bay of Fundy: Report of an ad-hoc Environment Canada Working Group. Environment Canada, Canadian Wildlife Service, Technical Report Series 334, Environment Canada, Sackville, NB. 46 pp.

Wells PG. 2000. Environmental Impacts of Barriers on Rivers Entering the Bay of Fundy. In: J Percy and J Harvey (Eds), Tidal Barriers in the Inner bay of Fundy: Ecosystem Impacts and Restoration Opportunities. Proceedings of a Workshop, April 14-15, 1999, Moncton, NB. Conservation Council of New Brunswick, Marine Conservation Program, Fredericton, NB. pp. 15-22.

Wells PG. 2005. Chapter 17. Assessing marine ecosystem health – concepts and indicators, with reference to the Bay of Fundy and Gulf of Maine, Northwest Atlantic. In: SE Jorgensen, F-L Xu and R Costanza (Eds), Handbook of Ecological Indicators for Assessment of Ecosystem Health. Francis and Taylor/CRC Press, Boca Raton, Fl. pp. 395-430.

Wells PG. 2009. Chapter 84. Aquatic toxicology: concepts, practice, new directions. In: B Ballantyne, TC Marrs and T Syversen (Eds), General and Applied Toxicology, Third Edition, John Wiley and Sons. Ltd., London. pp. 2123-2155.

Wells PG. 2010. A history of research in environmental science and ecotoxicology at SABS (St Andrews Biological Station). SABS paper, submitted July 2009. (In press)

Wells PG, Keizer PD, Martin JL, Yeats PA, Ellis KM and Johnston DW. 1997. Chapter 3. The Chemical Environment of the Bay of Fundy. In: JA Percy, PG Wells and AJ Evans (Eds), Bay of Fundy Issues: A Scientific Overview. Proceedings ofa Workshop, Wolfville, NS, January 29 – February 1, 1996. http://docs.informatics.management.dal.ca/gsdl/collect/bofep1/pdf/WA/BOFEP1-1996-037.pdf (accessed May 2010).

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ and Watson R. 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314: 787-790.

Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, Fogarty MJ, Fulton EA, Hutchings JA, Jennings S, Jensen OP, Lotze HK, Mace PA, McClanahan TR, Minto C, Palumbi SR, Parma AM, Ricard D, Rosenberg A, Watson R and Zeller D. 2009. Rebuilding global fisheries. Science: 325: 578-585.

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